TAPHONOMIC SIGNATURES OF ANIMAL SCAVENGING IN NORTHERN CALIFORNIA: A FORENSIC ANTHROPOLOGICAL ANALYSIS

A Thesis

Presented

to the Faculty of

California State University, Chico

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

in

Anthropology

by

Lisa N. Bright

Spring 2011

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ACKNOWLEDGMENTS

This thesis could not have happened without the support and assistance from many people. If I were to thank every individual that gave me emotional, physical, or mental support during this process it would take quite a while, and since this thesis is long enough already, this is a thank you to my greatest supporters.

First and foremost a big round of thanks is given to my thesis committee: Drs. Eric Bartelink, Frank Bayham, and Turhon Murad. As a thesis committee, professors, and friends they went above and beyond what many people would do. As my chair, Dr. Bartelink has been a continuous source of support and resources over the course of my time at Chico. I would not be the anthropologist I am today without his guidance. I will always be thankful for the generosity of Frank Bayham. His classes taught me a great deal, his advice was almost always calming, and without him I would not have had the pigs for my experiment. Turhon Murad was always there to lend an ear and offer direction and advice. I must thank all of them for serving on my thesis committee.

I would like to acknowledge the support of the Big Chico Creek Ecological Reserve, both monetarily and physically. Without the generous student grant my research would not have been possible. Their willingness to allow my project to occur and their continuous support was amazing. And to Jeff Mott, the reserve's director, thank you for putting up with three years of emails and calls regarding this project.

I also must thank all of the individuals that helped me trek through the woods looking for pig parts and with their processing at the lab: Susan D'Alanzo, Maija Glasier, Kate Davis, Crystal Spessard, Brendon Armstrong and the CSUC-HIL interns. Kevin Dalton also deserves a special thank you for making my maps.

I am grateful for the continued support and patience of my close friends and family. Kristina Crawford helped me in so many ways, from cheering me up with things hit a roadblock, tromping through the woods to find my mysteriously vanishing pig, teaching me how to make maps and read a compass, and knowing just when to hand me a glass of wine. Thank you for just nodding your head every time I muttered pigs under my breath. A special thanks to Ben Rangel for always being there when I needed you, I couldn't have done it without your help.

On a more personal note, I have to thank my family, especially my mother Diane Bright. They have always been supportive of the decisions I have made and I know they will always be there for me.

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ABSTRACT

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Taphonomy is an important component of forensic anthropology, archaeology, bioarchaeology and paleoanthropology. The ability to understand the factors that result in the breakdown of organic remains in multiple contexts is a necessary component of anthropological research. Forensic taphonomic research is invaluable for understanding postmortem events that affect human remains in medicolegal contexts.

This thesis analyzes scavenging damage on forensic cases curated by the California State University, Chico Human Identification Laboratory (CSUC-HIL) and involves actualistic experiments, using five pigs (*Sus scrofa*) to better understand scavenger behavior and modification of human remains in northern California. The human remains cases (*n* = 22) were inventoried and scavenger modification and tooth impact mark diameter was documented. The pig remains were collected and examined in the same manner as the CSUC-HIL forensic sample.

Results indicate that there is significant variation in the distribution of scavenging damage in the CSUC-HIL forensic sample. Distal appendicular elements were less intensively scavenged than more proximal segments and areas with the greatest damage coincide with large fat deposits. The tooth impact mark data indicated that it is not possible to assign the damage to a specific species but rather to a size class of large or small carnivore. Actualistic experiments indicated that there is a specific order in which scavengers access carrion, with damage concentrated in areas with the largest amount of fat. Future scavenging research is necessary to gain an understanding of scavenger modification of human remains and should include natural environmental settings.

CHAPTER I

INTRODUCTION

Taphonomy is traditionally situated within the field of paleontology, and has only recently been incorporated into forensic science. Taphonomic processes can drastically alter the appearance and preservation of human remains. An understanding of taphonomic processes can lead to a better estimate of the postmortem interval, and in distinguishing trauma from pseudo-trauma. To understand the potential value of the incorporation of taphonomy in forensic anthropological assessments, it is first necessary to discuss the traditional role of taphonomy.

The term taphonomy was coined by Russian paleontologist I.A. Efremov in 1940. He defined taphonomy as the "…study of the transition, in all its details, of organic remains from the biosphere to the lithosphere" (cited in Lyman 2002:xix). Taphonomy has been traditionally used within a paleontological context and restricted to interpretations of the fossil record. In simple terms, taphonomy is anything that happens to an organism from the time of death until the time of discovery.

The same processes that modify remains also influence the formation of the archaeological record. These processes include weather conditions, the freeze-thaw cycle, sun bleaching, plant growth, rodent gnawing, carnivore scavenging, trampling by animals, fluvial transport and fossilization to name a few (Behrensmeyer 1975; Behrensmeyer and Hills 1980; Brain 1981; Gifford 1981; Haglund and Sorg 1997;

Haglund and Sorg 2002; Lyman 1994; Nielsen 1991; Olson and Shipman 1988; Ubelaker 1997; Wood and Johnson 1978). Taphonomy not only addresses the role of the remains themselves, but as components of their ecosystems (Gifford 1981).

Forensic taphonomy is a relatively new field that can be defined as the application of taphonomic models within the medicolegal context, and is concerned with the short-term processes that occur after death (Adlam and Simmons 2007). Forensic taphonomy can be viewed as an extension of forensic anthropology and forensic archaeology. Understanding the processes a set of remains is exposed to from the time of death until the time of discovery allows for a more accurate interpretation of the postmortem interval and aids in the assessment of trauma. Many processes, such as weathering, the freeze-thaw cycle, and plant growth can alter the appearance of bone, and affect the analysis of the remains.

One such taphonomic process is animal scavenging. The damage to remains created by scavenging is a little studied area of forensic taphonomy as many of the previous studies have focused on reconstructions of hominid behavior (Blumenschine 1987; Shipman 1986). Scavenging results in high rates of damage to carcasses, such as consumption of soft tissues, modification to bone, as well as disarticulation and scattering of remains (Haglund 1989, 1992, 1997a, 1997b, 1997c, 2002). Animal scavenging represents one of the greatest contributors to the destruction of human remains in forensic contexts, and is commonly found on human remains from outdoor context in northern California (Murad 1997).

Research Design

The purpose of this thesis is to evaluate the model proposed by Haglund (1989, 1992) regarding scavenging and disarticulation sequences, specifically in northern California. Haglund's model is widely cited in both archaeological (Degusta 1999; Milner et al. 1991; Pickering et al. 2004b) and forensic papers (Bachmann and Simmons 2010; Byart et al. 2002; Megyesi et al. 2005, Prieto et al. 2004; Rainio et al. 2001), yet it has never been robustly evaluated. The level of reliability this model produces has rarely even been critiqued (Murad and Bayham 1990). Without testing the validity and reliability of this model, it is impossible to state if it provides an accurate model regarding the scavenging of human remains. This thesis aims to investigate the reliability of Haglund's scavenging model and evaluate its applicability in forensic contexts.

The first phase of the research will analyze and describe the inter-element and intra-element variation in scavenging damage within a California State University Chico Human Identification Lab (CSUC-HIL) forensic sample and document and analyze the carnivore tooth impact marks on the forensic cases. The second phase will conduct actualistic experiments using pigs (*Sus scrofa*) to document local scavenger activity and to attempt to replicate the scavenging damage patterns documented in the CSUC-HIL forensic collection. This study evaluates the following hypothesis and derives a series of test implications.

Research Hypothesis

The main hypothesis relates to the specific sequence in which different skeletal elements are scavenged. The current prevailing scavenging sequence proposed by Haglund (1989, 1992) states that scavengers first target the thorax, followed by the upper limb, lower limb, vertebral column, and finally the skull. The skeletal elemental damage sequence will be tested using five pig carcasses.

Although the anatomy of a pig differs from that of a human, the morphology is similar enough that the sequencing for humans is expected to be reproduced in the pig carcasses. The use of pigs in taphonomic experiments has been standard practice in forensic taphonomy (Adair and Kolz 1998; Anderson and VanLaerhoven 1996; Hewadikaram and Goff 1991; Kjorlien et al. 2009; Komar and Beattie 1998a, 1998b). Several studies suggest that the sequence of disarticulation of the forelimbs and hindlimbs of quadruped mammals will be slightly different from humans (Behrensmeyer and Hill 1980; Haynes 1981, 1982; Toots 1965). This portion of the thesis seeks to test the validity of Haglund's scavenging sequence.

Test Implication One

Carnivore accessibility to carrion differs among scavenger species, thus it can be expected that larger carnivores, such as bears, will scavenge a carcass before smaller carnivores, such as canids. If there is a relationship between carnivore scavenger access and carcass consumption patterns, then there is a greater possibility that patterns of damage can be understood and predicted in greater detail.

Test Implication Two

Data collected from the CSUC-HIL forensic sample is not expected to follow the exact sequence proposed by Haglund for the Pacific Northwest (1989, 1992) but instead is expected to coincide with the data collected from the actualistic experiments conducted in northern California. Elements that are scavenged first, according to Haglund, are expected to show a greater amount of damage than those scavenged later.

The elements in the forensic sample will be compared to Haglund's model. However, Haglund's sequence does not deal with inter-element and intra-element sequences in detail, thus this study will expand on this knowledge.

Test Implication Three

It has been suggested that there is a relationship between tooth impact marks and carnivore body size. The diameter of pits and punctures has been correlated with scavenger body size, and in some instances a specific species. It can be expected that the tooth impact mark size can be used to estimate the size class of a species based upon tooth size of the animal. This study will evaluate the validity of this approach in regards to identifying scavenger species in scavenged human and nonhuman animal remains from northern California.

Outline of Thesis

Chapter II provides an in-depth review of scavenging literature. This chapter is divided by the forensic or archaeological emphasis of the studies. A general introduction to taphonomy, and specifically forensic taphonomy is provided and current tooth impact mark and scavenging sequence studies are discussed. An overview of the role of carrion within an ecosystem is also provided. Chapter III contains a detailed discussion of the materials and methods used to address the research questions proposed in the Chapter II.

In Chapter IV the scavenging pattern and tooth impact mark results based on the CSUC-HIL forensic sample are discussed. Chapter V examines the results of the actualistic experiment. Chapter VI provides a discussion of the results from Chapters IV and V, which are evaluated in light of Haglund's model. The specific limitations of this study are also discussed. Finally, Chapter VII summarizes the previous chapters and offers conclusions and suggestions for additional future research.

CHAPTER II

LITERATURE REVIEW

When any assemblage of skeletal material is evaluated, taphonomic factors that may have affected the remains must be taken into consideration. Taphonomic analysis is an important component of any archaeological or physical anthropological analysis. Scavenger damage to skeletal assemblages is well documented, but has rarely been studied. Understanding scavenger damage to human skeletal remains is an important part of physical and forensic anthropology because it helps contribute to the understanding of assemblage formation, element bias, damage patterns, and distinguishing trauma from postmortem damage in forensic contexts

Though studies have been conducted concerning scavenger contribution to fossil assemblages, these mainly focus on extinct African mammals and hominid activity. A majority of studies that have been conducted use captive animals and processed and de-fleshed portions of carcasses. To date only two studies have been conducted with regards to North American carnivores (Kjorlien et al. 2009; Morton and Lord 2006) that used complete carcasses, natural environmental settings with free ranging animals, and motion sensitive recording equipment to document scavenger activity. There remains a lack of research concerning scavenger behavior and their interaction with complete carcasses.

Carrion as a Food Source

Vertebrates extensively use carrion as a food source; it is a phenomenon that is frequently noted but infrequently described. Difficulties associated with quantifying the amount of scavenged material in an animal's diet have also contributed to the perceived inconsequential role of scavengers within ecosystems. The most common ways to identify food in an animal's diet is the analysis of scat and stomach contents. However, these methods cannot determine if the meat that was ingested was killed by the animal or scavenged after death. Thus, carrion is often omitted from lists of commonly consumed items (DeVault et al. 2003).

The phenomenon of scavenging is often viewed as a behavioral curiosity rather than an important process within an ecosystem. It is often assumed that decomposers, mainly arthropod and microbial, are the primary consumers of carrion, but vertebrate scavengers usually digest carcasses first, thus keeping energy flows higher in the food webs (DeVault et al. 2003). A certain level of competition is to be expected between vertebrate scavengers and decomposers.

Carrion Availability

To understand the role of scavengers in terrestrial ecosystems the issue of carrion availability must first be discussed. Carrion availability is dependent on cause and location of animal mortality. The availability of carrion to vertebrate scavengers is directly dependent on the accessibility of the carcass, as well as the structure of the vertebrate and invertebrate community. Thus, not all carcasses produced will become accessible to vertebrate scavengers. It seems plausible that many larger animals die in accessible locations and become directly available to scavengers. Conversely, smaller animals such as rodents and birds die in locations that many vertebrate scavengers cannot immediately access (DeVault et al. 2003). However, a sufficient number of carcasses are produced in most ecosystems to “influence the behavior, ecology, and evolution of vertebrate scavengers” (DeVault et al. 2003:228).

Given the large number of carcasses that are likely available to facultative, or optional, scavengers it seems plausible that many food items in diets of carnivores were scavenged rather then preyed upon (Cowles and Phelan 1958; DeVault et al. 2003; Errington 1935; Mullen and Pitelka 1972). Although it is difficult to determine the amount of carrion consumed by scavengers, available research suggests vertebrates scavenge most available carcasses with efficiency averaging 75 percent (Akopyan 1953; Balcomb 1986; Crawford 1971; DeVault and Rodes 2002; DeVault et al. 2003; Houston 1986, Houston 1988; Kostecke et al. 2001; Linz et al. 1991; Linz et al. 1997; Mullen and Pitelka 1972; Pain 1991; Rosene and Lay 1963; Simonetti et al. 1984; Stoddart 1970; Tobin and Dolbeer 1990).

Carrion is ephemeral in nature; though plentiful, there is no guarantee of its availability. This patchiness has inhibited evolution towards strict specialization for scavenging behavior in most vertebrates (Braack 1987; DeVault et al. 2003; Heinrich 1988; Houston 1979). Due to the rapid decomposition of carcasses, there is typically more live prey than carrion available at any one time. As a result, obligate scavengers are very rare. Thus, nearly all carnivores should be considered facultative scavengers (DeVault et al. 2003). Although facultative scavenging is common, the degree of carrion use varies widely among species. Some species use carrion frequently, whereas others scavenge only rarely. Even species that are not typically associated with scavenging occasionally will eat carrion.

Forensic Literature Review

A problem in forensic taphonomy research is the limited awareness of taphonomic applications among the greater medicolegal community (Haglund and Sorg 1997; Ubelaker 1997). Previous publications, such as Stewart (1979), briefly mention the role of taphonomy but provide little detail on the subject.

Taphonomic research within the forensic sciences has been steadily increasing over the past twenty years. Two major volumes, *Forensic Taphonomy: The Postmortem Fate of Human Remains* (Haglund and Sorg 1997) and *Advances in Forensic Taphonomy: Method, Theory, and Archaeological Perspectives* (Haglund and Sorg 2002), have been published in an effort to bridge gaps in research and to better educate the scientific community on the applications of forensic taphonomy.

Forensic taphonomy is relatively new, thus few studies have been conducted toward a better understanding of animal scavenging behavior of human remains in forensic contexts. The first major publication that dealt with scavenging in a taphonomic context is William Buckland's 1823 publication, which investigated how hyenas gnawed and subsequently destroyed animal bones in Kirkdale cave, a site in northern England. He used analogies with modern hyenas and the bones they had eaten to support his conclusion. Many of the modern forensic taphonomic studies use this same analytical approach to draw conclusions from actualistic natural experiments. This scientific approach works because the main paradigm of taphonomy is uniformitarianism. If modern analogies can be used to understand fossil assemblages, then they may also be used to interpret modern assemblages. Uniformitarianism can be divided into two main principles: 1) all processes are uniform through time; and 2) all natural laws are uniform in space and time (Haglund 1992).

Research involving scavenging focuses on questions such as: “How can scattered remains be located in order to maximize their recovery?,” “Is it possible to distinguish scavenger related damage to bone from other death or injury-related trauma?,” and “Can scavenging assist in the estimation of the postmortem interval?” (Haglund 1997a:367). Current research trends focus on understanding the decay process in general (Adlam and Simmons 2007), analyzing the modern scavenging of remains (Carson et al. 2000; Dominguez-Solera and Dominguez-Rodrigo 2008; Freeman and Leman 2008; Haglund 1989, 1992, 1997a,b; Klippel and Synstelien 2007; Morton and Lord 2006; Murmann et al. 2006; Symes et al. 2002), understanding how taphonomic processes alter bone, how taphonomic processes mimic trauma, and how taphonomic processes can disguise trauma (Symes et al. 2002).

Taphonomists research the “agents and casual mechanisms responsible for the accumulation, spatial distribution, frequency dimensions, and modifications” to bone (Bonnichsen 1989:1). A taphonomic agent is the cause of the force that modifies bones. A taphonomic process is the dynamic action of the agent on the organism; it is the direct cause of the modification. A taphonomic pattern is the resulting change on the bone caused by the process (Bonnichsen 1989; Lyman 1994). In terms of scavenging, the agent is the scavenger, the process is the chewing, gnawing and fracturing of the bone, and the pattern is the resulting pits, punctures, scores, furrows, and bone consumption.

To apply taphonomic models in the forensic context, the traditional role of taphonomy within the realm of paleontology should be understood. If forensic taphonomy is to build its own theoretical platform (see Sorg and Haglund 2002; Nordby 2002), it is critical to take a multidisciplinary approach.

Forensic Research

Haglund (1989, 1992, 1997a) focused on disarticulation sequences in the Pacific Northwestern U.S. and attempted to assign degrees of disarticulation to specific postmortem intervals. The postmortem intervals are very specific, and often only have a small sample size within each postmortem interval range. The involvement of canids in scavenging and disarticulation is incredibly important, but assigning postmortem intervals based on the condition of the remains continues to be tenuous. His sample is mainly based on the victims of the Green River serial killer, therefore a majority of the individuals were of similar height, weight, and age, and were disposed of in similar type of environment (e.g. woodland settings) providing similarity among the sample population.

Haglund (1992, 1997a) states that first the ventral thorax and upper extremities will be disarticulated, followed by the lower extremities, all other elements except the vertebral column, and finally by the cranium. Anatomically, the appendicular skeleton can be removed as a series of connected elements, making transport of multiple bones easier. The upper appendicular skeleton is also more easily disarticulated than the lower appendicular skeleton because the head of the humerus articulates into a shallower socket than the femur. The amount of muscle, tendon and ligamentous attachments also contribute to the resistance of scavenger related disarticulation (Haglund 1997a:372).

In forensic taphonomy, and in forensic anthropology in general, the skeleton or skeletal element, is the unit of analysis. The ability to properly interpret the postmortem events the unit (body) has undergone is important to case analysis, and generally requires a multidisciplinary approach. Applying this idea to taphonomic scavenging, biologists would aid in understanding the “motivation” of scavengers, anatomists and zoologists would aid in identifying specific species that have scavenged remains, and forensic anthropologists should be able to not only provide a biological profile, but also identification of taphonomic events remains have undergone.

Species-Specific Scavenging

The assessment of species-specific carnivore damage is an issue that relates to paleontology, archaeology, and forensic anthropology. Paleontologists use tooth mark frequencies and dimensions to infer the extent of carnivore involvement in site formation and modification, the size classes of carnivores involved, and potential hominid influences (Blumenschine 1987; Blumenschine 1988; Blumenschine and Pobiner 2007; Delaney-Rivera et al. 2009; Dominguez-Rodrigo et al. 2007; Dominguez-Rodrigo and Piqueras 2003; Marean et al. 1992; Pobiner 2007; Selvaggio and Wilder 2001; Selvaggio 1994; Shipman 1986).

Scavenging is pertinent to forensic taphonomy because the activity of the scavenging animals can scatter, damage, and destroy major portions of skeletal elements. The ability to determine a specific species as the agent causing the damage is important for time since death estimations, of damage analysis, and to achieve higher recovery rates. Carnivores of different species and sizes can leave different patterns of damage on the remains, which influence recovery rates, the extent of damage, and the distance elements can be transported. If a specific scavenger can be identified, an understanding of their specific morphology and scavenging behavior can drastically influence forensic analysis and recovery.

Carnivore Scavenging

Two major types of bone modification include fractures and tooth marks. A fracture results from different types of loading, while all non-fractures are considered marks. With regards to scavenging, spiral fractures are especially important. A spiral fracture is “curved in a helical, partially helical, or completely helical pattern around the circumferences of the shaft”(Gifford-Gonzalez 1989:188). Spiral fractures can be produced by the force of a scavengers levering, pulling and gnawing (Haynes 1983:105).

Tooth marks produced by scavenging include pits, punctures, scores, and furrows. A pit is a circular depression that does not breach the compact bone. A puncture is a circular depression, deeper than a pit, that breaches the compact bone. Scores are striae in which the length is three or more times its width. Furrows are broad linear gouges through cortical bone, that have exposed cancellous bone (Delaney-Rivera et al. 2009). Unique patterns are only produced by a specific process or agent. In order to assign scavenging damage to a specific agent, it is assumed that different scavengers produced unique patterns.

Several factors that influence the degree of scavenging include accessibility, number of available carcasses or bones, meat volume, number of scavengers, type of scavenger, availability of alternate food sources, age, scavenger strength, season, and method of prey death (Haynes 1982; Lyman 1989). Accessibility refers to conditions such as the carcasses being covered or uncovered, climate, and topography. The number of available carcasses or bones affects the degree to which the carcass is utilized. If there is a surplus of prey animals available, the carcass will be less intensely scavenged, while in times of resource stress the carcass will be more intensely scavenged.

For instance, Haynes (1982) demonstrated that North American wolves (*Canis lupus*) tend to more fully scavenge prey they have killed themselves than animals that have died from other causes during the winter. Scavenger age should also be taken into consideration, as fully matured adult members of a species will have larger permanent dentition and greater body strength than a juvenile member of the species.

Carnivores can damage bone as an incidental result of tissue consumption or they may deliberately ingest the bone (Gifford 1977:279). Both actions may result in the disarticulation and scatter of the remains, and permanently eliminate portions of the body in the process of consumption. To interpret the modification to bone, an understanding of how carnivores produce the damage is necessary.

Morphological characteristics of the scavenger dentition and bite force are important components to take into consideration. The bite force and anatomical characteristics of the jaws place limitations on the scavenging ability of an animal (Klippel and Synstelien 2007; Murmann et al. 2006; Freeman and Leman 2008). The unique bite mark patterns of mammals left by their canines can often result in identification to the species level based on the inter-canine distance measured between adjacent tooth marks on bone (Murmann et al. 2006). However, the ability to distinguish marks that represent the inter-canine distance on bone is difficult, and the Murmann et al. (2006) study focuses on the marks left only on soft tissue. Carnivores often target the proximal and distal ends of long bones and elements of the axial skeleton, consuming the nutrient rich cancellous portions and the marrow.

Carnivores crush and destroy bone using a “quasi-static loading technique in bone reduction” (Johnson 1989:473). The primary technique used by carnivores involves chewing the epiphyseal ends of long bones. The removal of the epiphysis alters the bone’s response to force and the subsequent collapse and splintering of the diaphysis results from the static pressure applied by the carnivore’s jaw. A secondary strategy used by carnivores involves the direct focus on the diaphysis in order to access bone marrow (Johnson 1989; Haynes 1981, 1982).

Punctures caused by carnivore tooth morphology form an inverted v-shaped conical depression associated with localized compressive failure, due to the constant pressure that is exerted (Johnson 1989). The triangular cross-section of the canines produces the circular tooth pit or puncture (Haglund 1997a). Carnivores can also create dynamic loading points, defined as a “circular depressed area caused by localized compressive failure due to the sudden impact of the loading device” (Johnson 1989:437). The crushing caused by this action can be extensive, often causing bone flakes, crushed bone, and ring fractures. Carnivores gnawing on the edges of fractures may result in a scalloped appearance.

The dental formula of the canid family provides an example of the jaw morphology of many scavengers. Their dental formula is I 3/3: C 1/1: P 4/4: M 2/3. In addition to the canines, the carnassial upper fourth premolar and lower first molar also produce damage to bone. These teeth are blade-like and are built to shear against one another during mastication. A carnivore's powerful jaw, in combination with their body size, aids in the destruction of muscle and bone (Haglund 1997a).

Rodent Scavenging

The unique anatomy of the rodent jaw produces distinct marks on bone. Rodents gnaw in order to regulate the length of their continuously growing incisors (Haglund 1997b). The morphology of their incisors also leaves uniquely identifiable marks, especially parallel channels or striae (Haglund 1997b). It is important in to be able to distinguish between the marks left by carnivore scavenging, rodent gnawing, and human induced trauma in forensic cases (Haglund 1997b; Symes et al. 2002; Ubelaker 1997).

The incisive movement of rodent teeth is a characteristic specialization of rodents. The rodent mandible is loosely joined at the symphyseal region, allowing a large range of motion that is uncommon in other mammals. The maxillary incisors are pressed on bone, while the mandibular incisors move up and down, gouging out bone in a chisel-like action (Haglund 1997b). This is what causes the distinctive parallel striae.

Investigators should be cautious, as scoring by the incisors of canids can cause grooves that may mimic the gnaw marks typically left by rodents. Kippel and Synstelien

(2007) also indicate that not all marks left by rodent species will conform to the typical parallel striations generally attributed to rodents.

Species-Specific Determinations

There are three main models with regards to species-specific scavenging determination: patterns of damage, element representation, and pit and puncture measurements. Species-specific determination based solely on patterns of damage to the remains has been studied intensely by Haynes (1980, 1981, 1982, 1983) and to a lesser degree Binford (1981). Determination of species-specific scavenging based solely upon element representation is emphasized by Carson et al. (2000). Pit and puncture measurement is the most widely used methodology, having been applied by multiple anthropologists (Andrews 1997; Delaney-Rivera et al. 2009; Dominguez-Rodrigo and Piqueras 2003; Haglund 1997b; Njau and Blumenschine 2006; Pobiner 2007; Selvaggio 1994; Selvaggio and Wilder 2001).

Haynes (1980, 1981, 1982, 1983) used the types of gnawing damage inflicted on bone by carnivores to differentiate taxa. He carried out long-term studies, beginning with projects involving captive zoo animals. Fresh domestic cattle (*Bos taurus*) limbs and appendicular elements were fed to bears, wolves, large cats, and hyenas. The sequence of damage, length of time required for specific types of damage, and amount of time bones were utilized was recorded. Haynes also documented the feeding behavior of wild wolves, bears in northern North America, as well as lions and hyenas in Africa. Fresh carcasses and skeletons that were modified by the animals were located and monitored (Haynes 1980, 1981, 1982, 1983).

Haynes (1980, 1981, 1983) concludes that carcasses are utilized by large carnivores in patterned, predictable sequences. The patterns are broken down into single element stages (light, medium, and heavy), and by scavenger type. For example, the hyena (*Crocuta crocuta*) in early stages of scavenging a femur will score the compact bone surfaces with impact depressions averaging 1x2 cm in length. In the medium stage, the proximal epiphysis is consumed and the diaphysis fragmented. In the heavy stage, the bone may be entirely consumed or abandoned when only small segments of the diaphysis remain (Haynes 1983:166). Haynes (1983) also discusses this type of patterning for wolves (*Canis lupus*), bears (*Ursus arcto, U. americanus, Helarctos malayanus, Tremarctos ornatus, U. maritimus*), lions (*Panthera leo*), tigers (*P. tigris*), and jaguars (*P. onca*).

Haynes (1983) determined that hyenas, wolves, bears, lions, tigers, and jaguars all produced different damage patterns on bovid femora. Wolves, in the early stages of scavenging large bovid femora, penetrate the outer bone surfaces of the epiphyses with their cheek teeth, exposing trabecular bone. The damage may consist of isolated tooth punctures or sets of individual tooth punctures that run together. In the medium stage, individual tooth furrows may still be visible, and the thin compact bone is further damaged, exposing larger amounts of cancellous bone. In the heavy stage, only the diaphysis remains, with most scores and furrows appearing at right angles or diagonal to the long axis of the shaft. The tooth scores and furrows may be up to 3 cm in length, 1 mm in depth, and up to 2-3 mm in width. Tooth impact marks are most abundant at the edges of the remaining diaphysis. The edges of the shaft may appear polished, possibly due to repeated licking, checking, or abrasion on the ground surface. In some instances, the femoral head and one or both distal condyles may also remain. The major difference between hyena and wolf scavenging is the degree of damage, with hyenas producing more damage and impact marks.

Most bears do not gnaw heavily on bones after the soft tissue has become desiccated or removed, although behavioral differences between individuals and species have been documented. Damage from bear gnawing can be distinguished from damage caused by canids and hyenas because the broader cheek teeth of bears grind and crush cancellous bone, and plane or shear off portions. Bears, much like hyenas or wolves, can leave distinct furrows and scores on cancellous bone. In the early stages of scavenging a large bovid femur, a bear’s cheek teeth often shear off most of the greater trochanter, with the teeth aligned parallel to the trochlear rim. In the later stages the exposed cancellous bone may be gouged with five or fewer pits that are 6 mm in depth and 10-20 mm in length. Each of these pits may correspond to an individual cheek tooth of large bear. There may be no tooth marks on the surface of the shaft. Tooth pits on compact bone are not deeper than 0.5 mm and scores are seldom wider than 1.5 mm or longer than 9 mm (Haynes 1983:168-169).

Lion, tiger, and jaguar scavenging leave very similar patterns on bone. Large cat gnawing damage is often minimal, as they often do not gnaw on bones for sustained periods of time. Damage from large cats to a bovid femur consists of removal of the greater trochanter, damage to the inferior surface of the femoral head, and scraping of the trochlear rims, leaving few, relatively deep, furrows running perpendicular to the larger trochlear rim. These furrows are larger than those produced by hyenas or wolves. The basic identifying characteristic of large cat damage is the rough, irregular marks left on the cancellous bone of the epiphyses. These tooth marks are wide, deep, and often distinct from one another (Haynes 1983:169).

Haynes (1983:164) acknowledges that the presence and exact degree of damage due to carnivores can never be predicted at the taxon level without understanding the local conditions related to the hunting and feeding of the scavengers. Another limitation Haynes' noted is that minimal damage by all taxa of carnivores can look similar. The sequences may be affected if an entire carcass had been present, rather than just a limb bone. Scavengers modify portions of a carcass in a different manner or sequence than an isolated limb bone.

Carson et al. (2000) propose that bear scavenging can be distinguished from canid using the representation of certain elements because specific patterns of damage, such as Haynes (1980, 1981, 1983), are not accurate indicators of scavenger identity. Carson et al. (2000) base these inferences on three bear-scavenged forensic cases representing seven individuals. Carson et al. (2000) compare the recovery rate and amount of damage of these three cases with Haglund's (1997b) several stages of canid scavenging. Haglund (1997b) describes the two most severe stages (stages 3 and 4) as follows: in stage 3 major sections of the axial skeleton may still be articulated, but are usually scattered, and long bones have been disarticulated and the epiphyses damaged. In stage 4, all recovered bones are disarticulated, extensively gnawed, and scattered. Carson et al. (2000) compare the survivorship and recovery frequencies of the skeletal elements in their three cases with the frequencies from the cases Haglund (1997b) categorizes as stage 3 and 4.

Carson et al. (2000) conclude that with the exception of the os coxa, femur, and ulna, remains scavenged by canids show a higher or near equal rate of element recovery compared to individuals that were scavenged by black bears. The only times the bears were more likely to remove or consume elements at a higher rate than canids was in relation to the vertebrae, sacra, and sterna. Carson et al. (2000) contend that bears more intensively exploit the vertebral column, so a lack of recovered vertebrae is evidence of bear scavenging. The lack of vertebrae is also attributed to the bear's ability to drag the carcass a further distance than a canid.

Element representation is not an unbiased means of determining species-specific scavenging patterns. There are many intrinsic and extrinsic factors that can affect element survivorship and recovery frequency. Bones of low density, such as ribs and vertebrae, are easily destroyed by processes such as weathering, fluvial transport and trampling, in addition to carnivore scavenging (Schick et al. 1989). Recovery rates can also be affected by the training and skill of the individual performing the recovery, as well as the terrain, weather conditions, and postmortem interval. Items such as skulls and femora are easily identified as human by untrained law enforcement officials, while the smaller bones of the hands, feet and the patella are often overlooked.

Pit and puncture measurements provide the most objective method for determining species-specific scavenging. The presence of tooth marks on bone has long been used as evidence of carnivore involvement in the modification of archaeofaunal assemblages (Binford 1981). The basic premise of this method is that tooth pit and puncture size is related to scavengers tooth size. Thus, one must be able to measure the pit or puncture diameter and compare it to range of possible species. Pit and puncture size may also be related to the density of the impacted bone. Though many individuals have noted the diagnostic potential of tooth pit morphology and anatomical placement of the pits (Andrews and Fernandez 1997; Blumenschine 1989; Blumenschine and Selvaggio 1988; Blumenschine et al. 1996; Binford 1981; Delaney-Rivera et al. 2009; Dominguez-Rodrigo and Piqueras 2003; Njau and Blumenschine 2006; Pobiner 2007; Selvaggio 1994, Selvaggio and Wilder 2001), the diagnostic potential is generally overlooked.

Selvaggio (1994) studied tooth pits and punctures from a wide sample of extinct (*Dinofelis, Homotherium, Megantereon,* and *Percrocuta)* and extant (hyenas, leopards, lions, jackals, and cheetahs) carnivores. Selvaggio observed that tooth mark dimensions are related not only to carnivore size, but also to bone density. The sample was separated into three levels: cancellous bone, thin cortical bone, and dense cortical bone. Pit length and breadth were analyzed, along with circularity and area. Selvaggio concluded that there was a significant overlap between the length and breadth produced in tooth pits among different carnivores (Selvaggio 1994). However, Selvaggio's main goal was not to attempt to identity species-specific scavenging, but rather to study hominid access to carcasses for scavenging or hunting.

Selvaggio and Wilder (2001) expanded upon this research in their assessment of specific carnivore involvement in the modification of bone assemblages. This study differs from previous research (Haynes 1983; Selvaggio 1994) in that the sample is derived from a greater number of carnivore species (hyena, leopard, cheetah, lion, jackal, and the FLK *Zinjanthropus* assemblage), comparisons are limited to specific marks that resemble tooth crown or cusp shape, and the sample is stratified to evaluate the impact of bone density on tooth mark area (Selvaggio and Wilder 2001:466). All measurements were taken from molded impressions using Xanthropren™, a material that provides a negative impression of tooth marks (Selvaggio and Wilder 2001:466).

Similar to Selvaggio (1994), the mean area of pits were stratified by bone type: cortical bone, thin cortical bone, and cancellous bone (Selvaggio and Wilder 2001). The authors conclude that the area of tooth pits on cancellous bone is greater than those on cortical bone. Cancellous bone has less resistance to the static-loading pressure caused by the carnivore jaw compared to cortical bone. Thus, tooth pit size is directly related to bone density. A lion tooth pit on cortical bone is similar in area to leopard tooth pits on cancellous bone (Selvaggio and Wilder 2001). Therefore, when attempting to match pits and punctures to a specific species, the location of the tooth mark must be taken into consideration. Selvaggio and Wilder (2001) do not provide a definitive means of determining species-specific scavenging, but rather provide basic guidelines.

Dominguez-Rodrigo and Piqueras (2003) also attempt to discern carnivore taxa according to tooth mark location and size. Dominguez-Rodrigo and Piqueras used the methods developed by Selvaggio (1994), including the stratification by bone density. The authors also use negative impression molds to measure the pits and punctures. A correlation between length and width was determined among all carnivore taxa, including data from Selvaggio (1994). Therefore, tooth size is the main factor that accounts for the correlation of the length, width, and area of tooth pits. This study also corroborates Selvaggio (1994) and Selvaggio and Wilder's (2001) findings that the size of pits is larger on cancellous bone than on cortical bone.

Dominguez-Rodrigo and Piqueras (2003:1386) conclude that tooth pit size cannot be used to differentiate among specific taxa unless the tooth pit distribution and range of variation, bone segment, element, and other variables are taken into consideration. Even then, attribution of bone damage to specific carnivores can only be confidently made when comparing carnivores by size class. The authors determine three size class criteria, based on tooth pit length:

1. Marks less than 4 mm are most likely caused by small canids (jackals) and medium sized felids (leopards and cheetahs).

2. Marks between 4-6 mm are most likely caused by medium-sized and large-sized carnivores (baboons, dogs, and bears), except felids other than lions.

3. Marks greater than 6 mm are most likely caused by large carnivores, such as lions and hyenas.

The authors conclude that carnivores can produce a wider degree of variation in tooth mark by taxa than previous experiments have documented. Tooth pit size can, however, provide significant information regarding the type of carnivores that have modified an assemblage. These three size classes most likely do not directly apply to northern California fauna. The largest carnivores in this area are the mountain lion and black bear, with many more carnivores that are much smaller than the leopards and cheetahs comprising the smallest tooth impact category.

Delaney-Rivera et al. (2009) depart from previous studies (e.g., Dominguez-Rodrigo and Piqueras 2003; Selvaggio 1994; Selvaggio and Wilder 2001) in their methodology. The authors suggest that previous studies suffer from several limitations such as a small number of taxa investigated, a bias towards large carnivores, and lack of data for taxa aside from mammalian carnivores. Due to these limitations the determination of carnivore taxon and size remains problematic. Delaney-Rivera et al.

(2009) expand the range of taxa studied by combining previous studies that have recorded their data in a similar manner, with an additional 14 species (including two omnivores). The authors' primary goal was to examine the relationship between tooth mark dimensions and body size, as well as the dimensional variability of marks in relation to the density and thickness of the impacted bone (Delaney-Rivera et al. 2009: 2598).

Other researchers have recorded pit and puncture dimensions through the use of digital calipers and negative image molds of the bone surfaces (e.g., Dominguez-Rodrigo and Piqueras 2003; Pickering et al. 2004a; Selvaggio and Wilder 2001). Delaney-Rivera et al. (2009) found that the measurement of the pits with digital calipers was difficult to reproduce with accuracy. They consequently developed a method using digital photography and computer-based feature measurement to document pit and puncture size and shape. The authors do not include flaked or torn edges adjacent to a tooth mark in the measurement calculations of that mark as they occur at the outer limit of a pit or puncture, and therefore do not accurately reflect tooth size.

The authors conclude that the strongest correlation between body mass and tooth pit dimensions occur on the epiphysis, while the diaphysis showed the weakest correlation (Delaney-Rivera et al. 2009:2600). They note that individual pits cannot be attributed to carnivore class size as there is within-taxon tooth pit size variability, and that non-felid species can produce pits larger than would be anticipated for their body size. The Delaney-Rivera et al. (2009) data set largely conforms to the size classes proposed by Dominguez-Rodrigo and Piqueras (2003). The overlap in pit dimensions between size groups argues against the reliance on pit dimension alone to identify a specific taxon's involvement. However, the authors contend that although there is considerable overlap in the dimensions of tooth marks created by multiple taxa, there is a positive correlation between taxon size and the size of tooth marks on epiphyses (Delaney-Rivera et al. 2009:2603).

Summary

Animal scavenging is one of the greatest contributors to the destruction of human remains from forensic contexts. It is a little studied area within biology and anthropology. The few anthropological studies that have been done focus on disarticulated limb bones rather than on intact carcasses. Research conducted on species-specific scavenging is mostly focused on prehistoric scavengers and hominids. This thesis uses models to generate hypotheses about modern scavengers and their impact on forensic cases using curated forensic material and actualistic scavenging experiments.

CHAPTER III

MATERIALS AND METHODS

Forensic Research

Haglund's (1989, 1991) model regarding scavenging and disarticulation sequences of human remains is the only of its type currently employed in forensic anthropological analysis. As a result, this study was designed to critically evaluate the model's level of reliability, specifically in northern California. For this thesis, 22 curated forensic cases submitted to the CSUC-HIL for analysis were examined. Sixteen of these cases are currently curated, while the remaining six were documented from previous case reports by E.J. Bartelink. The cases derive from 13 counties in northern California, and were originally submitted to the CSUC-HIL between 1986 and 2009. With one exception, all cases derive from outdoor contexts.

Inventory of Skeletal Remains

For each case, a detailed inventory was conducted. Due to the nature of this thesis, only elements with unambiguous scavenging-related damage were examined in detail. Diagrams were used to record the completeness of each element. Appendicular elements (humerus, ulna, radius, femur, tibia, fibula and all metacarpals, metatarsals, and phalanges) were divided into thirds, representing the proximal, shaft, and distal portion of the element. All other elements were divided into medial, lateral, and middle portions.

Missing portions of an element were attributed to scavenging if the borders of the intact portion showed evidence of scalloping (Binford 1981) or showed evidence of pits or punctures. The percentage of bone missing due to scavenging was also recorded for all appendicular elements using an ordinal scale as a measure of scavenging intensity.

Classification Definitions

The same diagrams were used to record the distribution of pits and punctures. For the purposes of this research, pits are defined as an impact mark less then 1 mm in depth with a circular shape. A puncture was defined as an impact mark greater than 1 mm in depth. Scalloped edges were defined as fractured margins with a rough edge, often including semi-circular impressions. Spiral fractures were also included as signs of scavenging activity.

Scavenger Identification

The second phase of this research attempted to identify the involvement of specific species associated with the scavenging damage. Digital calipers were used to measure the maximum diameter of all pits and punctures present within the sample to the nearest millimeter. These measurements were recorded in association with their placement along the element.

In addition, dental measurements were recorded for the canine teeth of the following species from the CSU, Chico zooarchaeology comparative collection: grey fox (*Urocyon cinereoargenteus, N* = 3), raccoon (*Proycon lotor, N* = 3), bobcat *(Lynx rufus N* = 3), mountain lion (*Puma concolor, N* = 3), coyote (*Canis latrans, N* = 3), and black bear (*Ursus americanus, N* = 3). These species were chosen due to their presence in northern California (Zielinski 2005). The specific specimens were chosen based on completeness of maxillary and mandibular canines, and a collection location within northern California. The maximum diameter of the canine tip, maximum labio-lingual crown diameter, and maximum mesio-distal crown diameter was recorded with digital dental calipers for each specimen. Bivariate plots were used to compare canine tip diameters with shallow pits and maximum crown measurements with puncture marks.

Big Chico Creek Ecological Reserve

To conduct the experimental taphonomic research, a site that supports the parameters of this study was selected. The Big Chico Creek Ecological Reserve (BCCER) was chosen for its diverse natural habitat of native flora and fauna, and its proximity to CSU, Chico.

The BCCER is owned by the CSU, Chico Research Foundation and managed by the Institute for Sustainable Development. Part of the land purchase agreement that formed the BCCER included a conservation easement held by the Wildlife Conservation Board. This agreement also included a memorandum of understanding with the California Department of Fish and Game (Big Chico Creek Ecological Reserve 2009a).

The memorandum of understanding mandates that the management of the BCCER will protect biological resources, and provide management and protection of the five miles of Big Chico Creek that flows through the reserve. This area of the creek is a transition zone between oak woodland and pine-fir forest. These lands are part of the migration, holding, and spawning corridor of threatened species such as the spring run Chinook salmon *(Oncorhynchus tshawytscha)* and steelhead trout *(Oncorhynchus* *mykiss*). The BCCER also provides critical habitat for multiple native populations of plants and animals that have been impacted by urban development (Big Chico Creek Ecological Reserve 2009a).

The BCCER currently encompasses 3,950 acres of diverse habitat. The CSU, Chico, Research Foundation has owned and maintained this land since the initial purchase of the Simmons Ranch in 1999 and the Henning Ranch in 2001. The reserve is composed of creek riffles and pools, riparian areas, oak woodland, chaparral, pine forests, rock cliffs, springs, and 4.5 miles of Big Chico Creek. The habitat supports more than 140 different documented species (Big Chico Creek Ecological Reserve 2009b).

The BCCER is located in the foothill area of the Big Chico Creek watershed. It is irregular in shape, and at its widest is 4.5 miles north to south and 2.0 miles east to west, with the narrowest portion extending only 0.5 miles east to west. Elevation ranges from 700 feet to 2,160 feet. The eastern half of the property is within Big Chico Creek Canyon, and constitutes a narrow floodplain and a series of terraces. The western half of the property contains a gently tilted plane with small headwater streams (Big Chico Creek Ecological Reserve 2009c).

Actualistic Experiment

To conduct the experimental taphonomic research at the Big Chico Creek Ecological Reserve (BCCER), a total of five pig (*Sus scrofa*) carcasses were used. Each pig weighed approximately 100 pounds at the time of slaughter. The pigs were purchased from Tom Millar Show Swine, Glenn, California. The pigs were dispatched prior to staging at the reserve.

Carcass Placement and Monitoring

A total of five locales were chosen for carcass placement. These locations were determined by Jeff Mott, BCCER director, and the author. The sites were equally spaced (terrain dependent) at intervals of approximately three-quarters of a mile. The sites were chosen for their accessibility from the road, with a clearing of at least 15 meters and with protective vegetation. One motion sensitive trail camera was positioned at each location to identify animal species and to monitor scavenger behavior. Moultrie brand (model I40) digital game cameras with a 4.0 mega pixel resolution, an optical field of view of 52 degrees and an infrared light were used. The cameras were set to take still pictures with an image resolution of 640 x 480. One picture was taken each time the motion sensitive laser was triggered, with a delay of one minute between pictures. Each camera was equipped with a 4 gigabyte SD card that was changed daily. The motion sensitive trail cameras were placed in a protective wooden box to minimize damage by animals. The box was then strapped to a tree using wire. The camera was aimed directly at the carcass. Figure 1 illustrates the setup of the camera and carcass used at each site.

To prevent the immediate removal from the site location, each carcass was tied down to rebar stakes with lengths of wire wrapped around the forelimbs and hindlimbs. Each site was monitored daily (weather permitting) until the remaining elements were collected. Monitoring lengths varied from four to thirty four days, due to differential scavenging of the carcass at each site. Monitoring began at 9 am and typically lasted until 3 pm. The general state of the carcass was documented, especially an examination of tooth impact marks and fragmentation of skeletal elements. Upon arrival at the site, the first step was to replace the active memory card with a blank memory card.

Figure 1. *Carcass monitoring setup (site #4).*

The active memory card was examined onsite to note when the most recent scavenger was on site, to ensure safety and to see if the camera needed to be adjusted.

Daily Site Recording

Each day the overall condition of the site was recorded. Overview pictures of the location and detailed photographs of the carcass were taken. Once disarticulation of the carcasses occurred, all located scattered elements were photographed and recorded with a Trimble® GeoHX™ handheld GIS data collection unit. This handheld device delivers decimeter (10 cm / 4 inch) to subfoot (<30 cm) accuracy, and used a 520 MHz processor, 128 MB of RAM, and 1 GB of onboard storage. At each site, the tree with the camera attached to it was used as the primary datum. Locating the disarticulated remains was achieved using traditional archaeological survey methods and by following game and blood trails. The areas surrounding the sites were searched until all skeletal elements were located, or until the author determined that further searching was unlikely to produce additional elements. Sites with extreme dispersal of elements were surveyed in 10 meter transects over an approximate 400 meter radius surrounding the last known location of the carcass.

Collection Methods

Elements were collected once they had been disarticulated, and had over 90 percent of the tissue removed. After collection the elements were returned to the CSUC-HIL for processing and analysis. All elements were macerated to remove the remaining tissue. Carcasses were separated and large amounts of adhering tissue was removed using scalpels, tweezers and medical scissors and the remains were placed on towels to dry. Once the remains were fully processed they were examined at the CSUC-HIL. An inventory was also taken, noting element completeness and degree of scavenging. All pits and punctures were measured with a digital caliper for maximum diameter.

Statistical Analysis

Statistical analyses were performed using PASW Statistics 18.0. Descriptive statistics for the human skeletal inventory included recording presence and absence of each element, and the portion of the element represented. A scavenging intensity value was also assigned to each element. A Spearman’s rank correlation coefficient was completed to evaluate the relationship between element representation and the intensity of scavenging damage. Descriptive statistics of the tooth impact marks included minimum and maximum measurements, range, and standard deviations.

Summary

The methods outlined in this chapter were followed to evaluate evidence of scavenging damage. A detailed inventory and application of the scavenging intensity measurement provide understanding of how scavengers in northern California have impacted forensic cases submitted to the CSUC-HIL. The actualistic experiment at the BCCER will provide firsthand scavenging data to compare with the forensic sample. The tooth impact mark portion of the study seeks to better understand the relationship between pit and puncture size, as well as scavenger body size.

CHAPTER IV

RESULTS I: FORENSIC SAMPLE

The background discussed in the previous chapters has outlined the need for an evaluation of Haglund's scavenging model. As stated in the research design, this thesis is critiquing this model in two main phases. The first phase inventories and analyzes the inter-element and intra-element scavenging damage, as well as tooth impact marks seen in the CSUC-HIL forensic sample. This chapter discusses the results obtained from the 21 forensic cases curated at the CSUC-HIL. The element representation, inter-element and intra-element scavenging patterns, and tooth impact mark measurements are discussed in detail. The tooth impact marks are compared with the tooth measurements from carnivores represented in the CSUC zooarchaeological comparative collection.

Element Representation

The complete skeletal inventory and documentation of presence or absence of scavenging damage is provided in Appendix A. Figure 2 shows the percent of representation of each element or body region, and Table 1 presents the percent of available elements with evidence of carnivore and rodent scavenging. Recovery of remains was primarily conducted by law enforcement, thus the representation of elements may be more informative of the recognizability and size of skeletal elements than element survivorship. For example, 95.2 percent of crania, 88.1 percent of femora, and

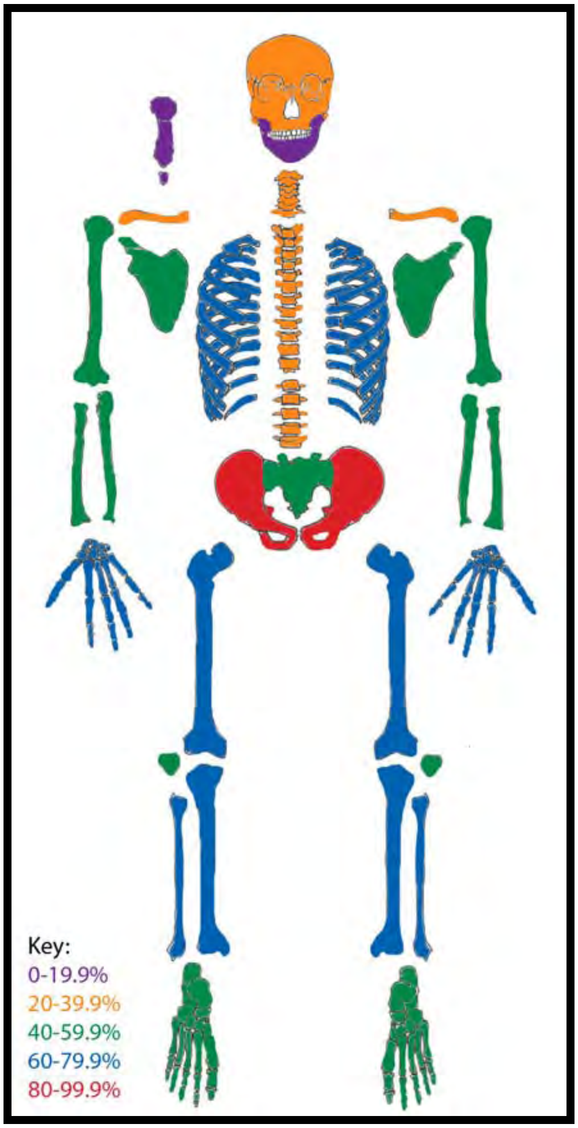

Figure 2. *CSUC-HIL forensic cases element representation.*

Source: Adapted from Inforce Foundation. Printed with permission.

83.3 percent of innominates were recovered, all which represent large, recognizable elements. In contrast, small elements of the hands and the patella are the least represented (33.3 percent, and 27.3 percent, respectively). All recognized criteria, including pits, punctures, scoring, and furrows were examined on each case.

Table 1. *Element Representation and Carnivore and Rodent Scavenging Damage*

Element/Portion	*N*	% Represented	% Carnivore	% Rodent	% Total
Femora	37	88.1	64.9	13.5	78.4
Tibiae	28	66.7	53.6	10.7	64.3
Fibulae	24	57.1	58.3	0.0	58.3
Humeri	25	59.5	52.0	4.0	56.0
Innominates	35	83.3	40.0	11.4	51.4
Foot	22	52.3	59.1	9.0	68.1
Radii	25	59.5	36.0	4.0	40.0
Hand	14	33.3	21.4	7.1	28.5
Ulnae	26	61.9	30.8	7.7	38.5
Ribs	17	81.0	35.3	0.0	35.3
Scapulae	31	73.8	29.0	0.0	29.0
Sacrum	16	76.1	18.8	0.0	18.8
Clavicles	30	71.4	2.0	0.0	2.0
Patellae	12	28.6	25.0	0.0	25.0
Crania	20	95.2	5.0	15.0	20.0
Vertebrae	270	53.6	14.4	0.0	14.4
Mandibles	14	66.7	0.0	14.3	14.3
Sterna	12	57.1	8.4	0.0	8.4

Scavenging Distribution

Approximately 50 percent of all elements examined showed evidence of animal scavenging, 98 percent of which are affected by carnivores and 7.5 percent by rodents. Carnivore tooth impact marks were most common on the hand, ribs, and lower limb elements, and were rarely observed in vertebrae, sterna, and in the skull. Figure 3 shows the scavenging distribution by element for all cases.

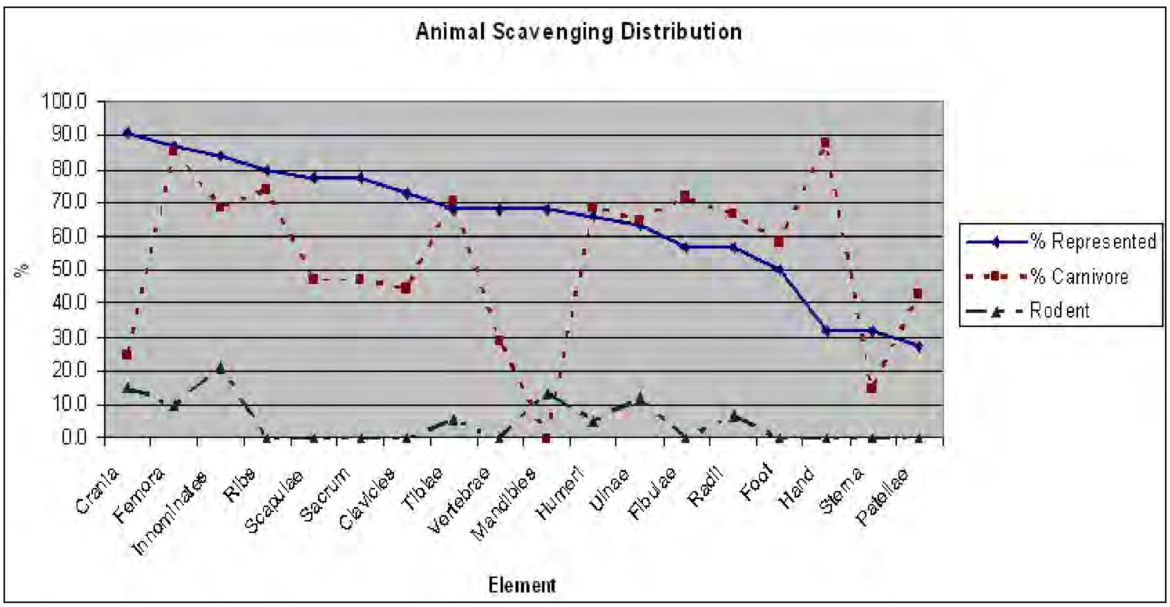

Figure 3. *Scavenging distribution by element showing percent represented, percent modified by carnivores, and percent modified by rodents.*

Rank ordered comparisons of the percent representation of an element and its frequency of scavenging are not statistically significant (total = rho = 0.332, p = 0.179; carnivore = rho = 0.389, p = 0.111; rodent = rho = 0.167, p = 0.509). This suggests that differential recovery of remains largely accounts for variation in the representation of elements.

Element Scavenging Intensity

The scavenging intensity for each portion of an element was totaled. The averages are that total divided by the total possible ranking score for all present portions of that element. Table 2 shows the top ten most intensively scavenged elements by rank

Table 2. *Scavenging Intensity of the Top Ten Most Intensively Scavenged Elements and Element Portions*

Element	% Scavenged	Rank
Pubis	54.4	1
Ischium	43.3	2
Proximal Ulna	43.2	3
Proximal Tibia	42.5	4
Proximal Humerus	42.1	5
Proximal Radius	37.5	6
Distal Ulna	36.4	7
Distal Radius	36.3	8
Proximal Fibula	35.7	9
Distal Fibula	32.1	10

and includes the pubis, ischium and proximal and distal segments of long bones. Figure 4 is a visual representation of the scavenging intensity rank order. The pelvis aside, it is evident that proximal segments of long bones tend to be more intensively scavenged than distal segments. This pattern may be a product of the articulation of the long bones

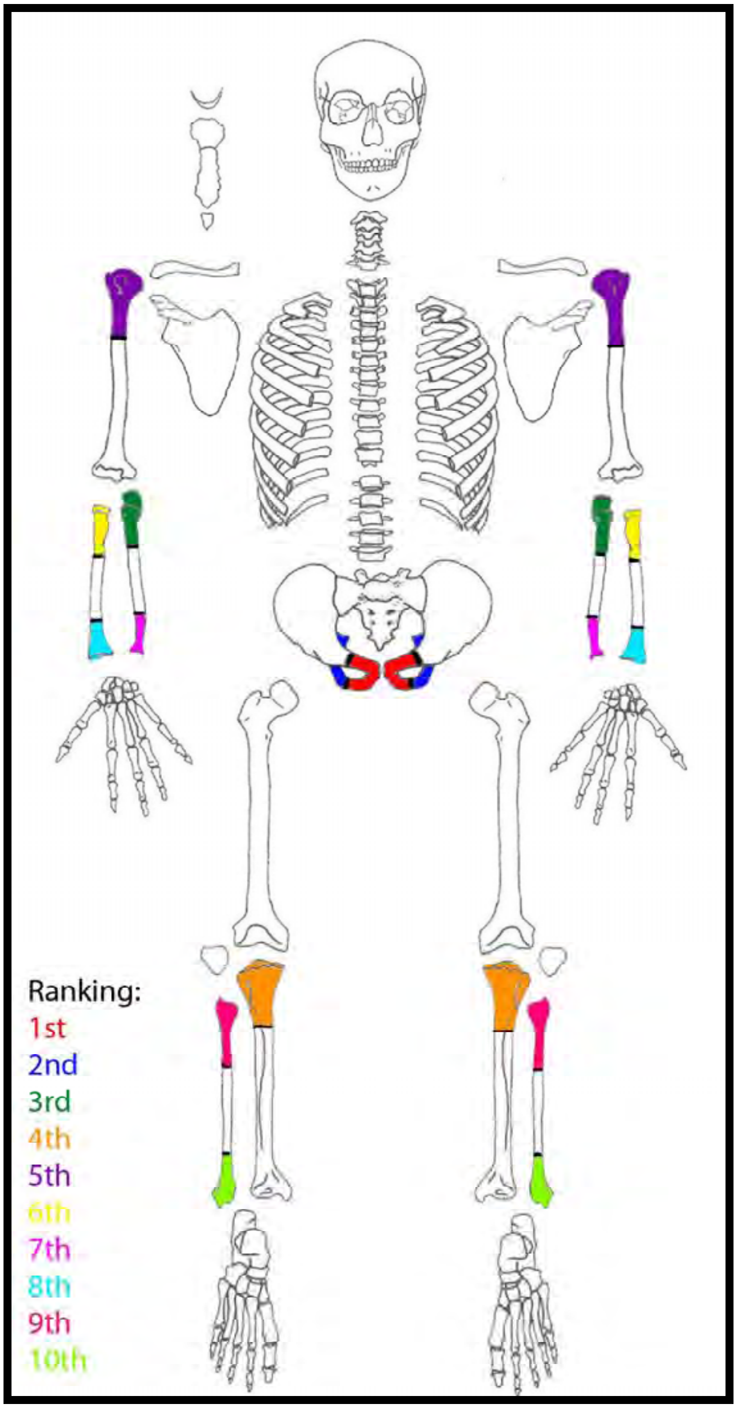

Figure 4. *Visual representation of scavenging intensity of the top ten most intensively scavenged element portions*.

Source: Adapted from Inforce Foundation. Printed with permission.

themselves, the ease of which they are disarticulated, or the amount of overlying soft tissue.

Table 3 and Figure 5 show the total average scores for all element portions ranked on scavenging intensity. There is a high degree of variation between the proximal

Table 3 *Total Average Scores for All Element Portions Ranked by Scavenging Intensity*

Element/Portion	Proximal %	Mid %	Distal %
Femora	16.7	0.0	26.4
Tibiae	42.5	0.36	28.5
Fibulae	35.7	5.7	31.1
Humeri	42.1	2.1	20.4
Innominates	Ilium 29.4	Ischium 43.3	Pubis 54.4
Radii	37.5	6.3	36.3
Ulnae	43.2	8.2	36.4
Scapulae	18.3	16.7	16.3
Clavicles	12.0	0.0	16.0

and distal portions of several elements, such as the humerus, femur, and tibia. All elements have a midshaft rank of less than 10 percent. These results indicate that elements must be viewed as part of the musculoskeletal system as a whole, rather than as a isolated element portions. For example, the difference in scavenging intensity of the proximal and distal humerus may only be explained in the context of the shoulder and

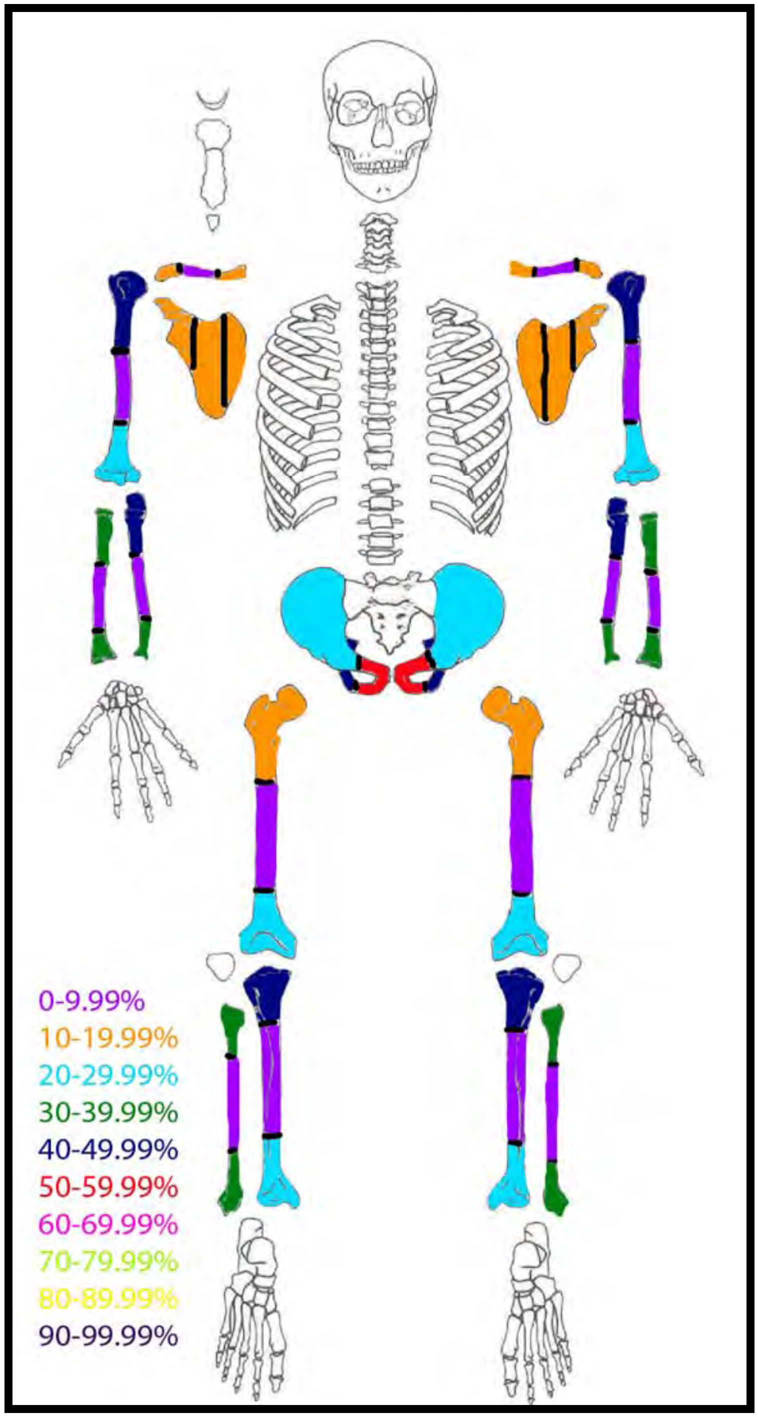

Figure 5. *Intra-element scavenging intensity.*

Source: Adapted from Inforce Foundation. Printed with permission.

elbow joint, and the overlaying soft tissues. When articulated, the proximal portions of the ulna and radius overlay the distal portion of the humerus, protecting it from scavenging damage. The proximal portions of the ulna and radius have scavenging intensity rankings of 43.2 percent and 37.5 percent respectively, while the distal humerus has a scavenging intensity ranking of 20.4 percent (see Table 3). When scavenging is directed at the elbow joint, the ulna and radius incur a most of the damage. Similarly, the anatomy of the shoulder joint may explain the scavenging damage patterns seen on the proximal humerus and scapula. The head of the humerus is easily separated from the glenoid fossa of the scapula. The proximal portion of the humerus has a scavenging intensity of 42.1 percent while the lateral portion of the scapula has an intensity of only 18.3 percent.

Tooth Impact Marks

A complete inventory of the tooth impact mark pit and puncture diameters is provided in Appendix B, and the maximum, minimum, and average dimensions of the impact marks in Appendix C. The carnivore specimen tooth measurements are provided in Appendix D. Figure 6 is a box-and-whisker plot showing the distribution of the maximum tip and mesio-distal canine diameters for the various carnivore species. There is minimal overlap between the two. For this study, it is assumed that pits will be more strongly correlated with the canine tip diameter, whereas the larger punctures will be more strongly correlated with maximum mesio-distal diameter.

Figure 7 shows the distribution of the pit and puncture diameters recorded on the CSUC-HIL collection. Comparison of pits versus punctures indicates a high degree of

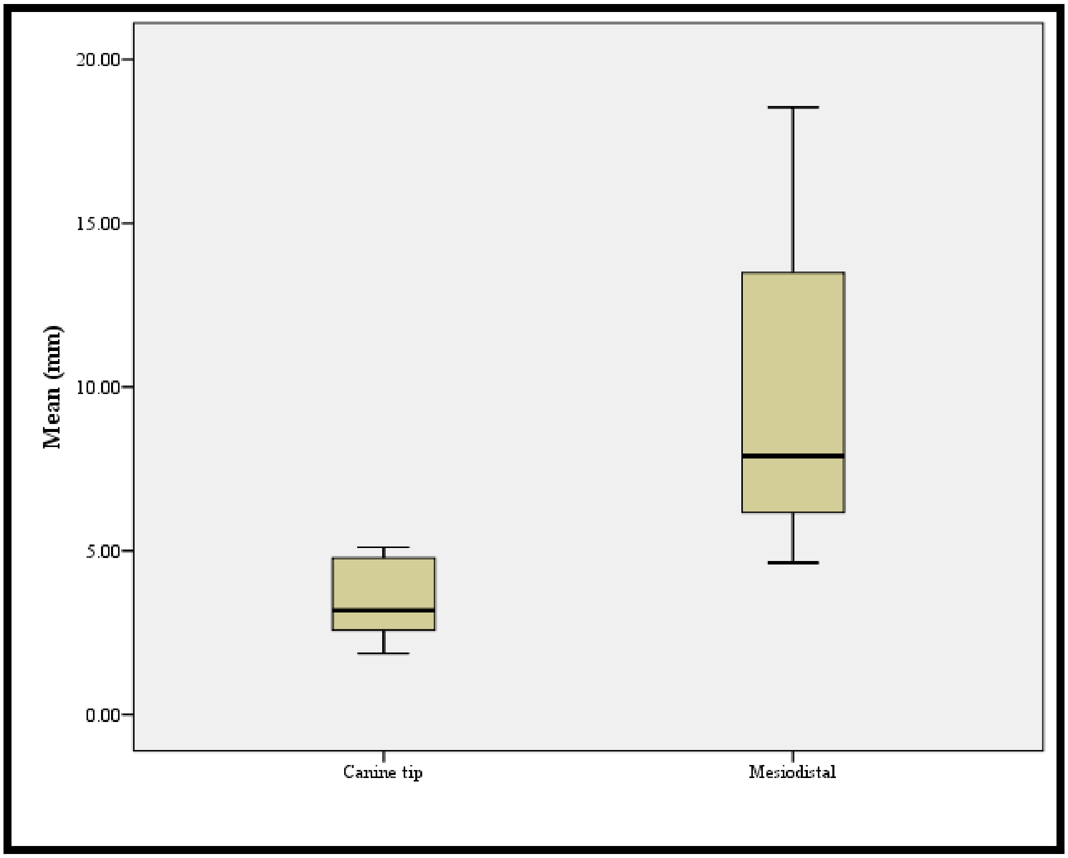

Figure 6. *Distribution of the maximum tip and mesiodistal canine diameters for the various carnivore species.*

overlap. Note the outliers in both the pits and punctures are all above the category ranges. Larger carnivores are expected to produce larger pit and puncture diameters, which may account for some of this variation. Alternately, because many of the outliers are on the innominates, density may also be a factor in pit and puncture dimensions. For example, a carnivore can produce larger tooth impact marks on less dense element portions composed primarily of cancellous bone than in the denser, thick cortical areas of long bone diaphyses.

Pits have a mean diameter of 2.22 mm and punctures a mean diameter of 3.8 mm, a statistically significant difference (t-value = -11.3, *df* = 256.7, $p <. 001$, equal

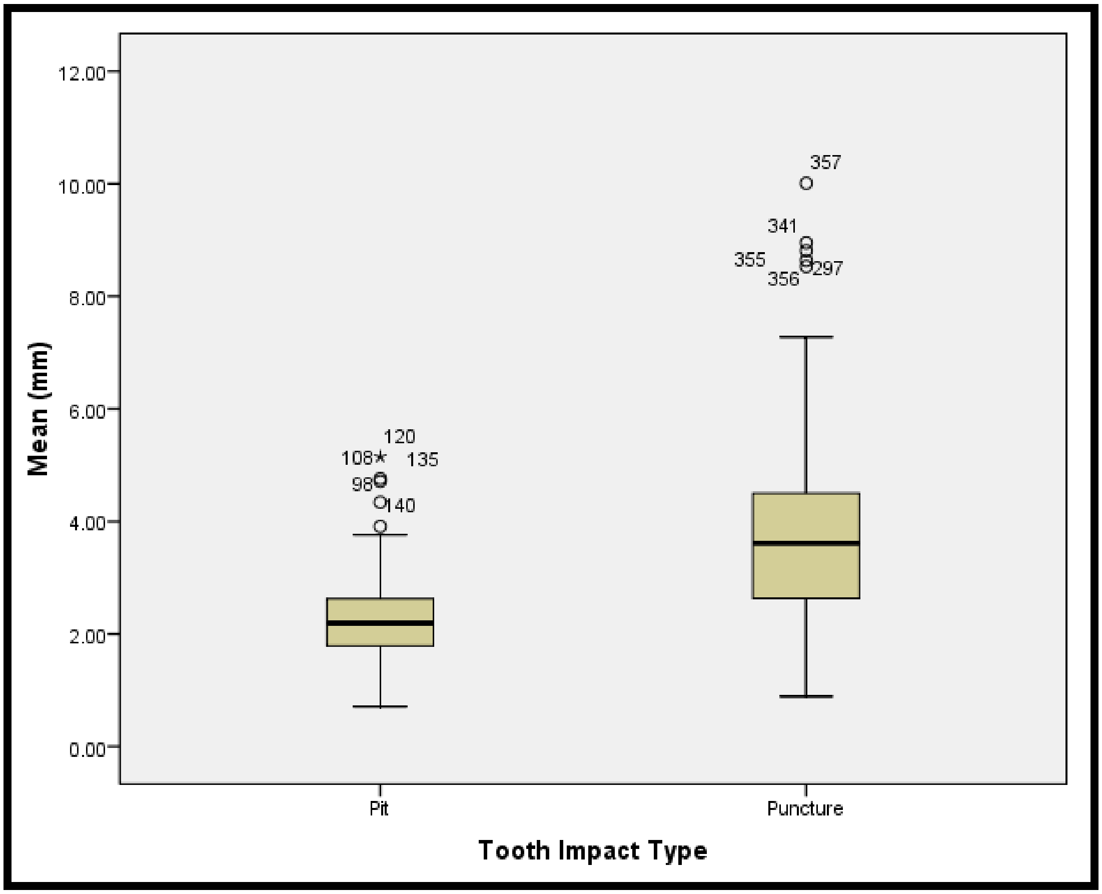

Figure 7. *Distribution of the pit and puncture diameters recorded on the CSUC-HIL collection.*

variances not assumed). This suggests that for this data set, pits can to a degree, be distinguished from puncture tooth marks, regardless of the carnivore species involved. A sectioning point was created to examine metric classification of pits versus punctures. The sectioning point is 3.1 mm, with cases below the value classified as pits and those above the value classified as punctures. Correct classification was only achieved in 63.3 percent of cases for pits but was 85.5 percent for punctures. Thus, punctures were much more likely to be classified as pits based on diameter than vice versa. The low classification rate is likely the result of scavenging activity of both medium and large-sized carnivores; smaller scavengers will have punctures that are smaller in diameter than the pits created by larger-sized carnivores, such as bears and mountain lions. Table 4 shows the mean pit and puncture diameters, total number of pits and punctures, as well as the standard deviations. Table 5 shows the pits and punctures after the sectioning point of 3.1 mm was applied.

Table 4. *Pit and Puncture Diameter from the CSUC-HIL Forensic Sample*

Impact Type	**Mean (mm)**	***SD***	***N***
Pits	2.22	0.82	152
Punctures	3.80	1.59	169

Table 5. *Pit and Puncture Sectioning Point Classification Accuracy*

Sectioning Point (3.1 mm)	**Classification Accuracy**
Pits	63.3% correct
Punctures	85.5% correct

The mean pit versus puncture diameter by element for the innominate, femur, sacrum, humerus, and tibia were compared. Table 6 shows the pit and puncture diameters

Table 6. *Pit and Puncture Diameter by Elements with Sufficient Impact Marks*

Element	Mean Different (mm)	P-value
Overall	1.57	<0.001
Innominate	1.88	<0.001
Femur	1.62	<0.001
Sacrum	1.55	0.032
Humerus	0.98	0.084
Tibia	0.87	0.032

listed by element. These elements had sufficient sample sizes for comparison, and are ranked from the greatest to smallest difference between pit and puncture diameters. With the exception of the humerus, significant differences between pit and puncture diameters are found for each element. Although bone density differences cannot be robustly evaluated with the present data set, the greatest mean differences occur for the innominate, followed by the femur, sacrum, and tibia. Puncture diameters showed higher standard deviations than pit diameters, with the greatest variation found for the innominate, followed by the sacrum, femur, and tibia. This suggests that less dense, more cancellous rich elements such as the innominate and sacrum, are more likely to show greater variability in puncture dimensions associated with animal scavenging behavior.

The maximum canine tip measurements for both the maxilla and mandible of each scavenger species and the pits from the CSUC-HIL forensic sample are shown in Figure 8. The bottom row represents the pit marks on the CSUC-HIL forensic sample. A

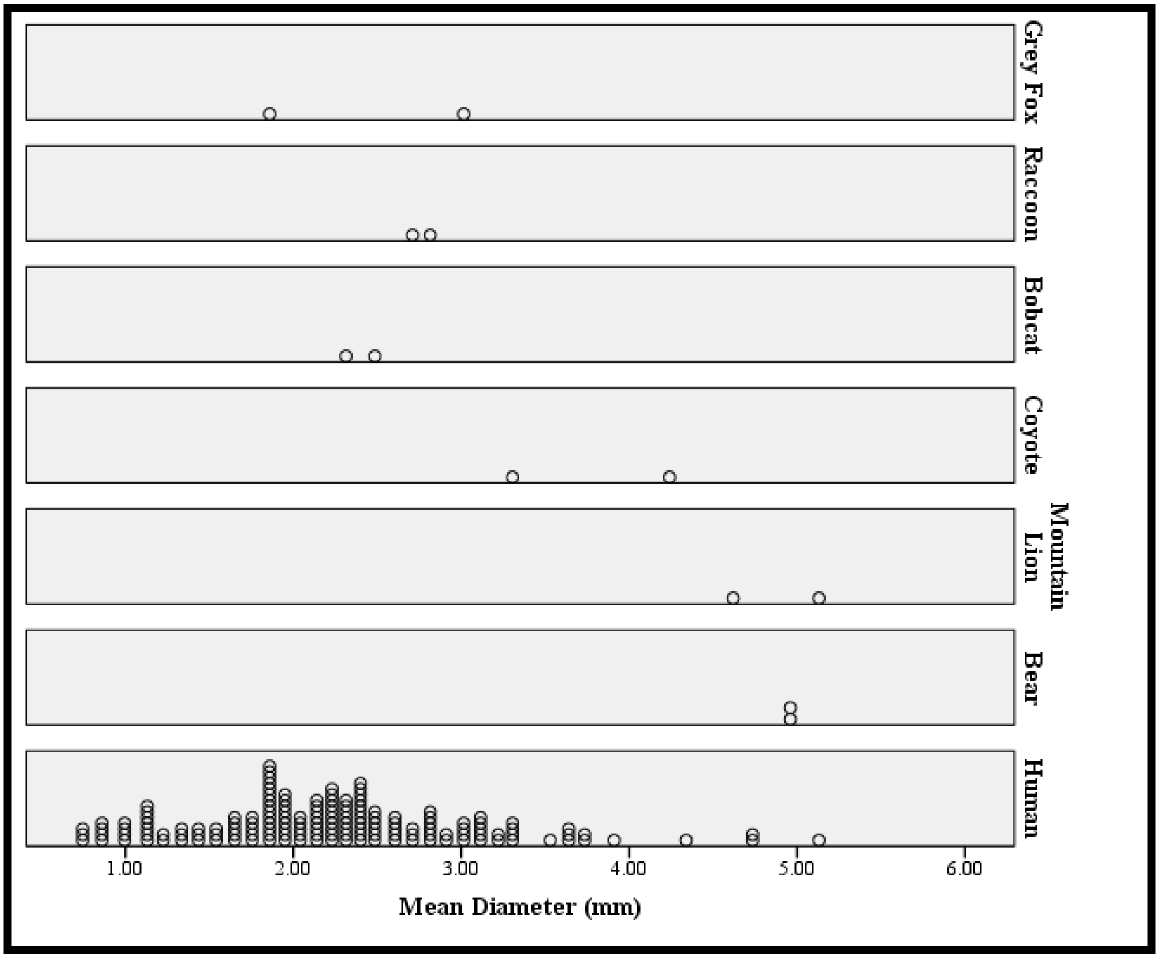

Figure 8. *Maximum canine tip measurements for the maxilla and mandible of each scavenger species compared with the pit marks on the CSUC-HIL sample.*

majority of the pits cluster in the small animal range (e.g. grey fox, raccoon, bobcat and coyote) with the larger outlier pits falling within the large animal range (e.g. bears and mountain lions).

The maximum mesiodistal diameters for both the maxilla and mandible of each scavenger species and the punctures from the CSUC-HIL forensic sample are presented in Figure 9. The bottom row represents the puncture marks on the CSUC-HIL sample. All punctures cluster in the small animal range. The lack of punctures in the large

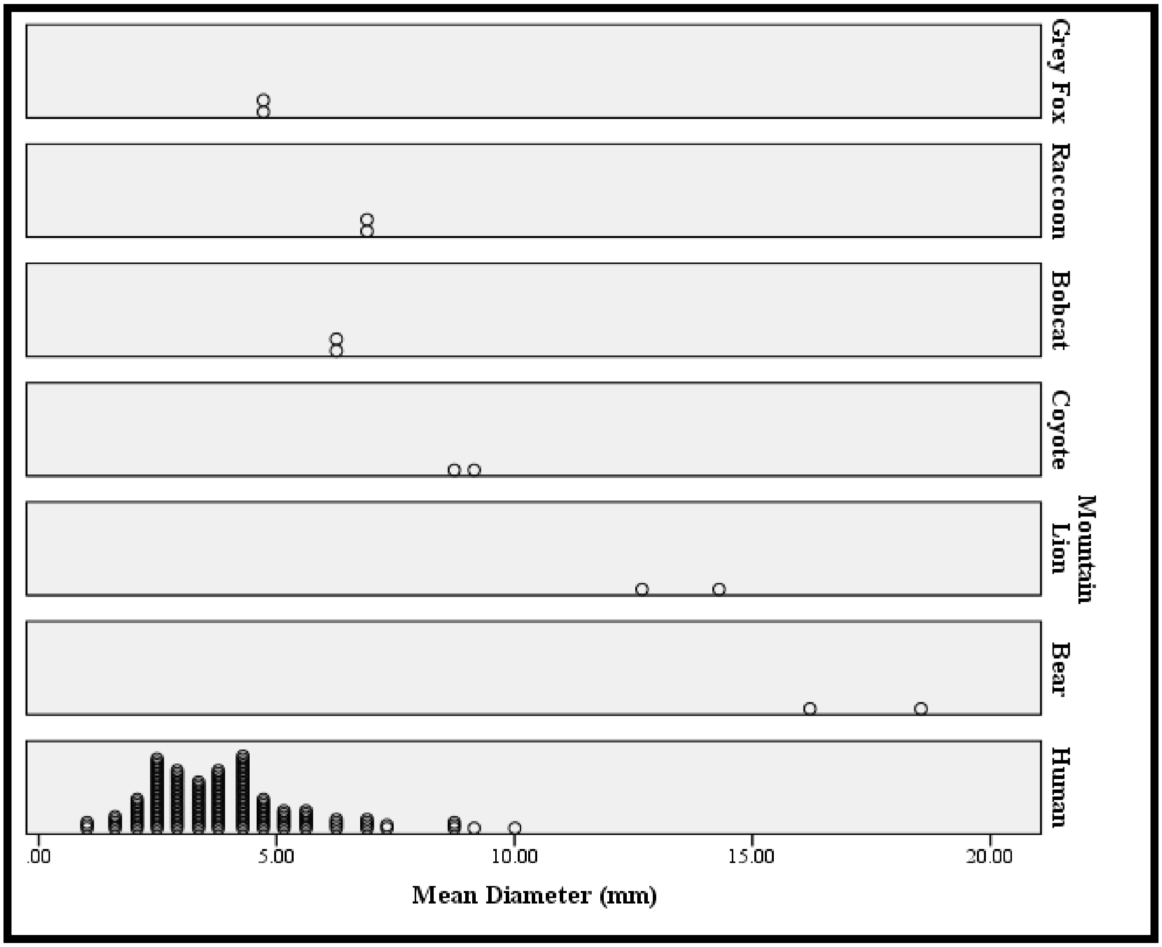

Figure 9. *Maximum mesiodistal diameter for the maxilla and mandible of each scavenger species compared with the puncture marks on CSUC-HIL sample.*

mammal range may be due to several factors. Tooth impacts may never reach the maximum mesiodistal portion of the canine, but may represent any point along the circumference of the canine. Tooth impact marks may also have been produced by the carnassial teeth, rather than the canines. An individual animal's bite force potential also influences the size and depth of punctures. The ability to associate tooth diameter with impact marks of a specific species is greatly hindered by a number of factors. It is also possible that bone can "retract" somewhat when the animal's canine is removed from the bone, due to bone's elastic properties.

Case by Case Tooth Impact Mark Analysis

The distribution of pit and puncture marks was examined for each case. Only cases that were available for measurment and had measurable tooth impact marks are discussed (N = 13). The cases with the greatest number of pits and punctures, cases 2, 19, and 21 are discussed in detail. Table 7 and 8 show the number of pits and punctures per case respectively, as well as the descriptive statistics.

Table 7. *Descriptive Statistics for Pits Presented Case by Case*

Case	Pits (N)	Mean	Median	Minimum	Maximum	Range	Std. Deviation
2	20	2.05	1.93	1.74	1.74	1.09	0.29
3	3	1.65	2.02	0.71	0.71	1.53	0.83
4	2	2.08	2.08	1.58	1.58	1.00	0.71
8	9	2.01	2.16	0.82	0.82	2.81	0.88
9	3	1.74	2.1	0.82	0.82	1.50	0.81
11	3	3.12	2.98	2.72	2.71	0.94	0.46
14	2	2.1	2.1	1.11	1.11	1.99	1.41
15	6	2.16	2.1	1.62	1.62	1.20	0.52
17	2	2.51	2.51	2	2	1.02	0.72
19	11	2.75	2.62	1.92	1.92	1.70	0.55
21	91	2.23	2.19	0.76	0.76	4.39	0.91

Table 8. *Descriptive Statistics of Punctures Presented Case by Case*

Case	Puncture (N)	Mean	Median	Minimum	Maximum	Range	Std. Deviation
2	20	3.55	3.70	0.89	5.78	4.89	1.39
3	7	4.42	4.56	2.35	7.08	4.72	1.61
4	5	2.84	2.43	1.45	4.5	3.05	1.20
5	10	3.77	3.77	1.87	5.75	3.88	1.30
8	5	3.09	2.46	1.48	6.44	4.96	1.93
9	1	2.77	2.77	2.77	2.77	-	-
11	15	4.10	3.43	2.52	8.95	6.43	1.82
14	2	3.23	3.23	1.76	4.7	2.94	2.07
15	14	4.34	3.02	2.09	10.01	7.92	2.69
17	10	4.22	4.22	2.59	7.26	4.67	1.27
19	15	3.98	3.98	2.46	4.95	2.49	0.84
20	1	7.28	7.28	7.28	7.28	-	-
21	64	3.62	3.62	1.57	8.81	7.24	1.44

Distribution of Pits and Punctures

Figure 10 shows the distribution of pits and punctures in case 2. Figure 11 shows the distribution of pits and punctures in case 19. Figure 12 shows the distribution of pits and punctures in case 21. In each case, pits and punctures are distinct from one another. Note that in case 2 the mean pit diameter is 2.05 mm whereas the mean puncture diameter is 3.62 mm, with no overlap (See Table 9). In case 19 the mean pit diameter is 2.75 mm whereas the mean puncture diameter is 3.98 mm, with no overlap (see Table 10). In case 21 the mean pit diameter is 2.23 mm whereas the mean puncture diameter is

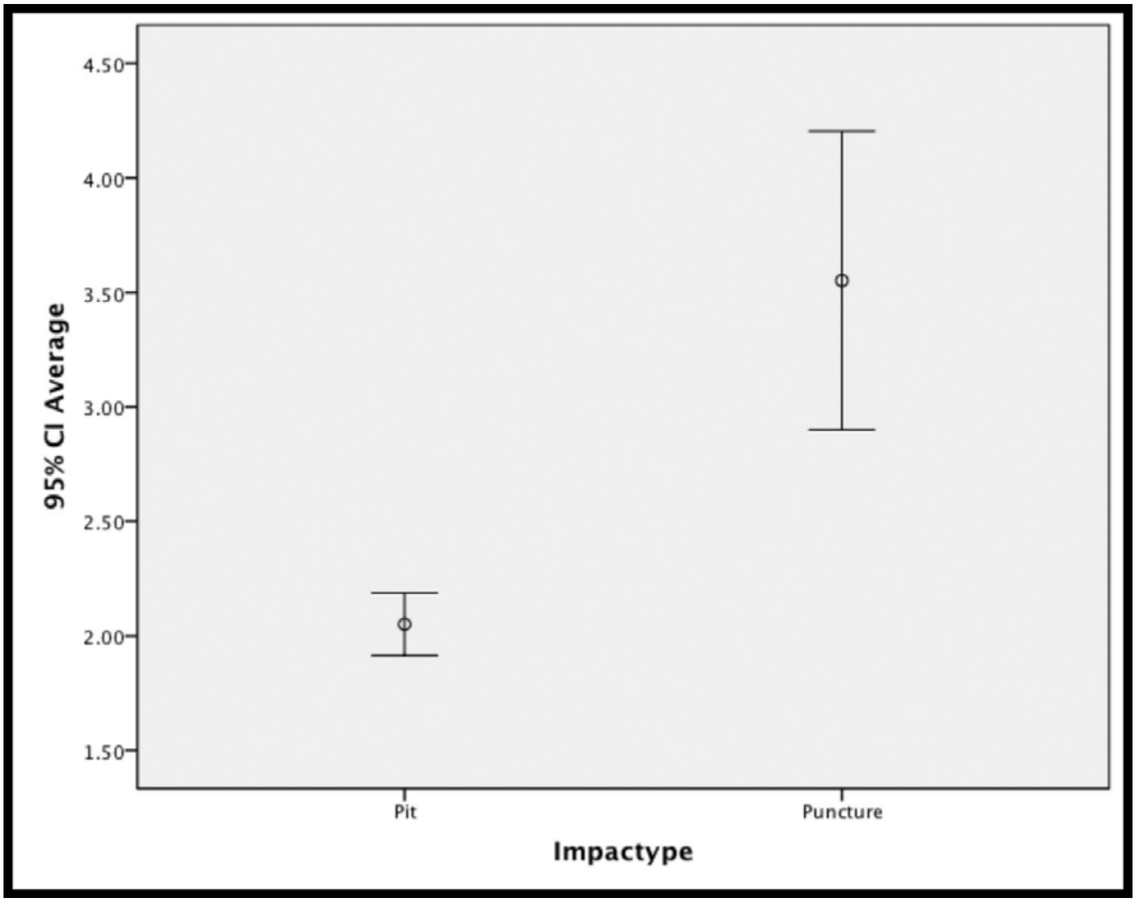

Figure 10. *Ninety-five percent confidence interval for pits and punctures from Case 2.*

3.62 mm, also with no overlap (See Table 11). In cases 2, 19, and 21 the pits and punctures are two distinct groups.

Figures 13, 14, and 15 show the small and large animal canine tip diameters and the pit diameters from case 2, 19, and 21. Note that for each case, the pit diameters overlap with the small animal range only. Tables 12, 13, and 14 show the small and large carnivore tip diameters, means, and standard deviations as well as the pit data from each case. Because the pits only fall within the small animal range, based on the presumptions previously discussed, it would be predicted that the pits were a result of small animal scavenging.

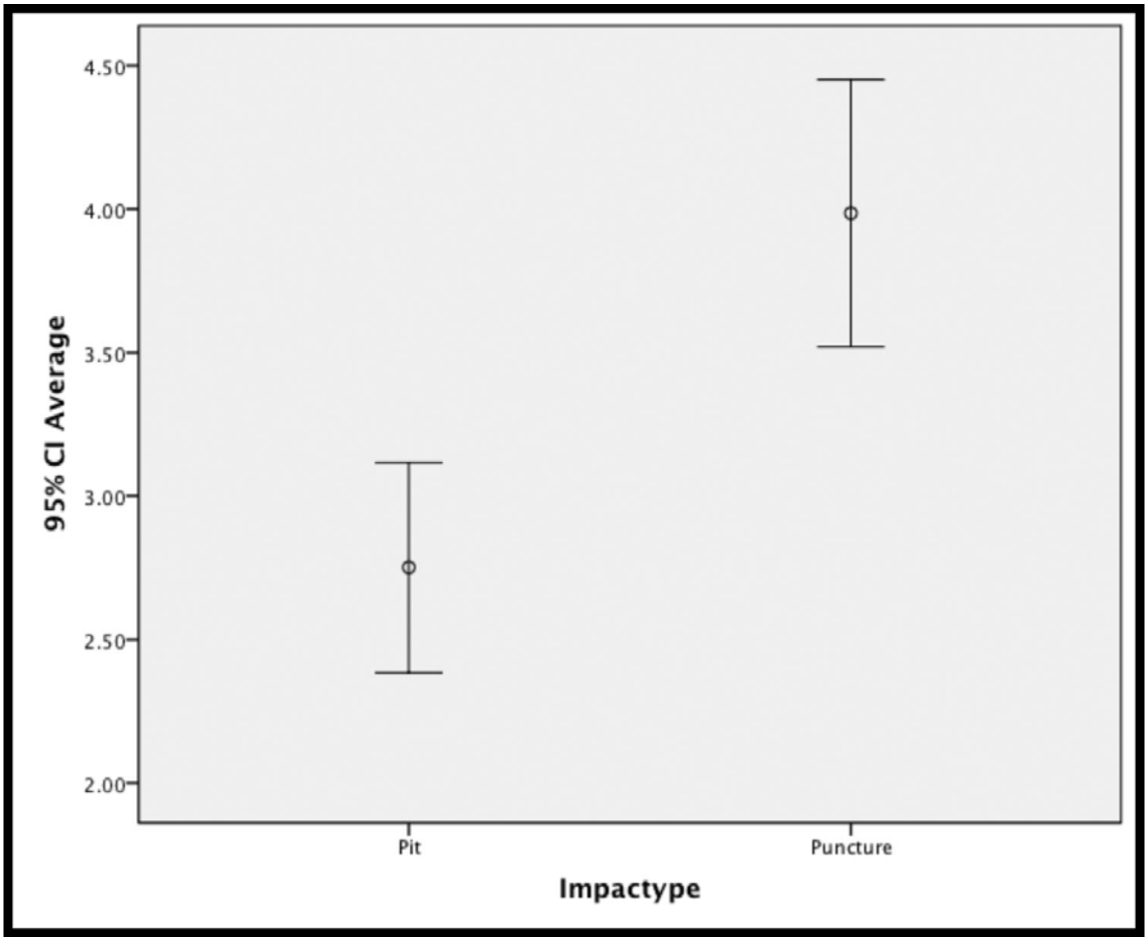

Figure 11. *Ninety-five percent confidence interval for pits and punctures from case 19.*

Figures 16, 17, 18 and Table 15, 16, and 17 show the small and large animal mesiodistal diameters and the punctures from the case studies. The human values show a narrow distribution, which is closer to the small animal mesiodistal diameters than to that of the large carnivores.

Summary

The analysis of inter-element and intra-element patterns indicates that there is significant variation in the distribution of scavenging damage. For example, intensity of scavenging was more directed at cancellous rich bone portions, such as the pubis and

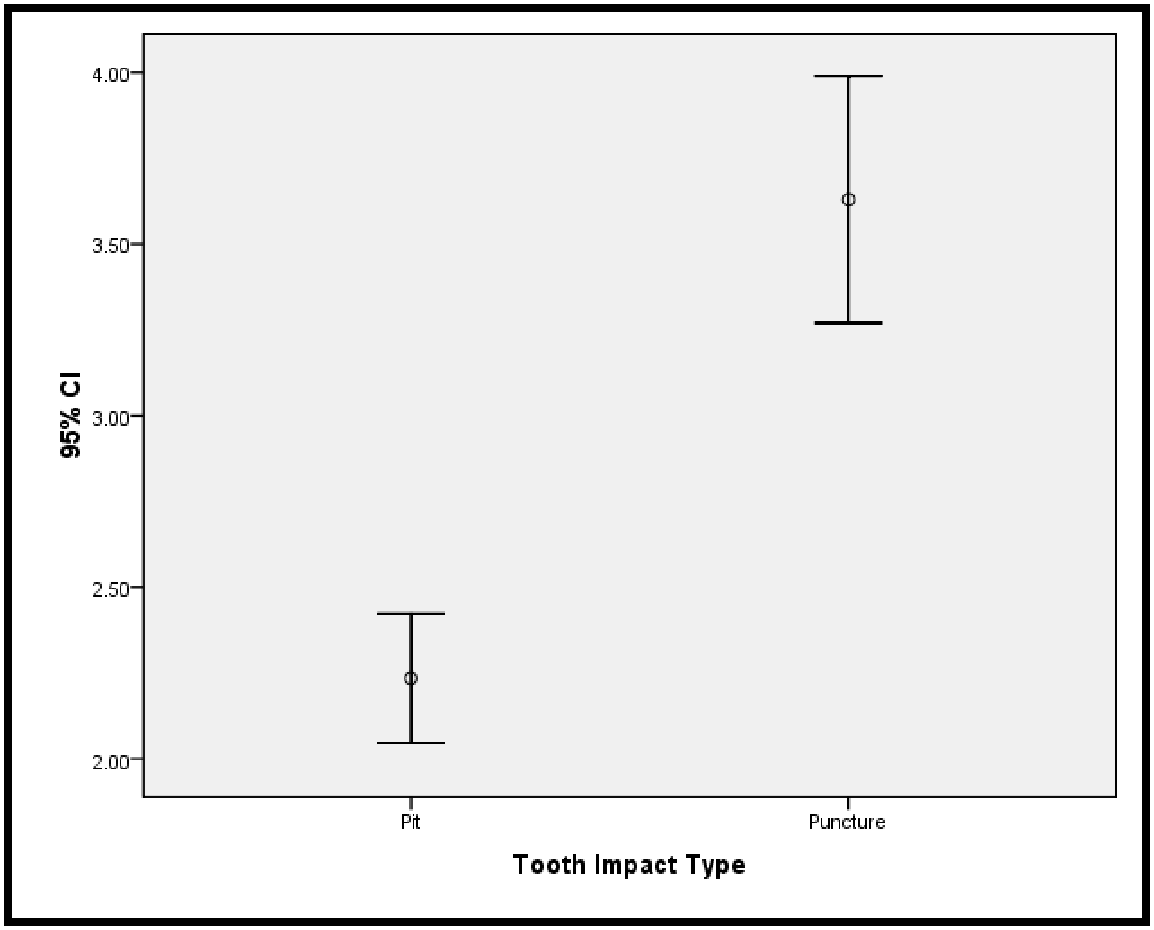

Figure 12. *Ninety-five percent confidence interval for pits and punctures from case 21.*

Table 9. *Case 2 Pit and Puncture Diameter*

Impact Type	**Mean (mm)**	***SD***	***N***
Pits	2.05	0.29	20
Punctures	3.55	1.39	20

Table 10. *Case 19 Pit and Puncture Diameter*

Impact Type	**Mean (mm)**	***SD***	***N***
Pits	2.75	0.55	11
Punctures	3.98	0.84	15

Table 11. *Case 21 Pit and Puncture Diameter*

Impact Type	**Mean (mm)**	***SD***	***N***
Pits	2.23	0.91	91
Punctures	3.62	1.44	64

ischium, closely followed by the more proximal segments of several appendicular elements. Distal appendicular elements of both the upper and lower limb were less intensively scavenged than more proximal segments. Carnivore tooth impact marks were most common on the hand, ribs, and lower limb elements, and rarely observed on vertebrae, sterna, and the skull. Inter-element and intra-element scavenging patterns should be evaluated within the greater context of joint complexes and the overlaying tissue. When animal scavengers are present, behavior is directed at consumption of soft tissues primarily; however, additional bone destruction over the long term may occur by secondary scavenging of the elements themselves. Overall element representation may be

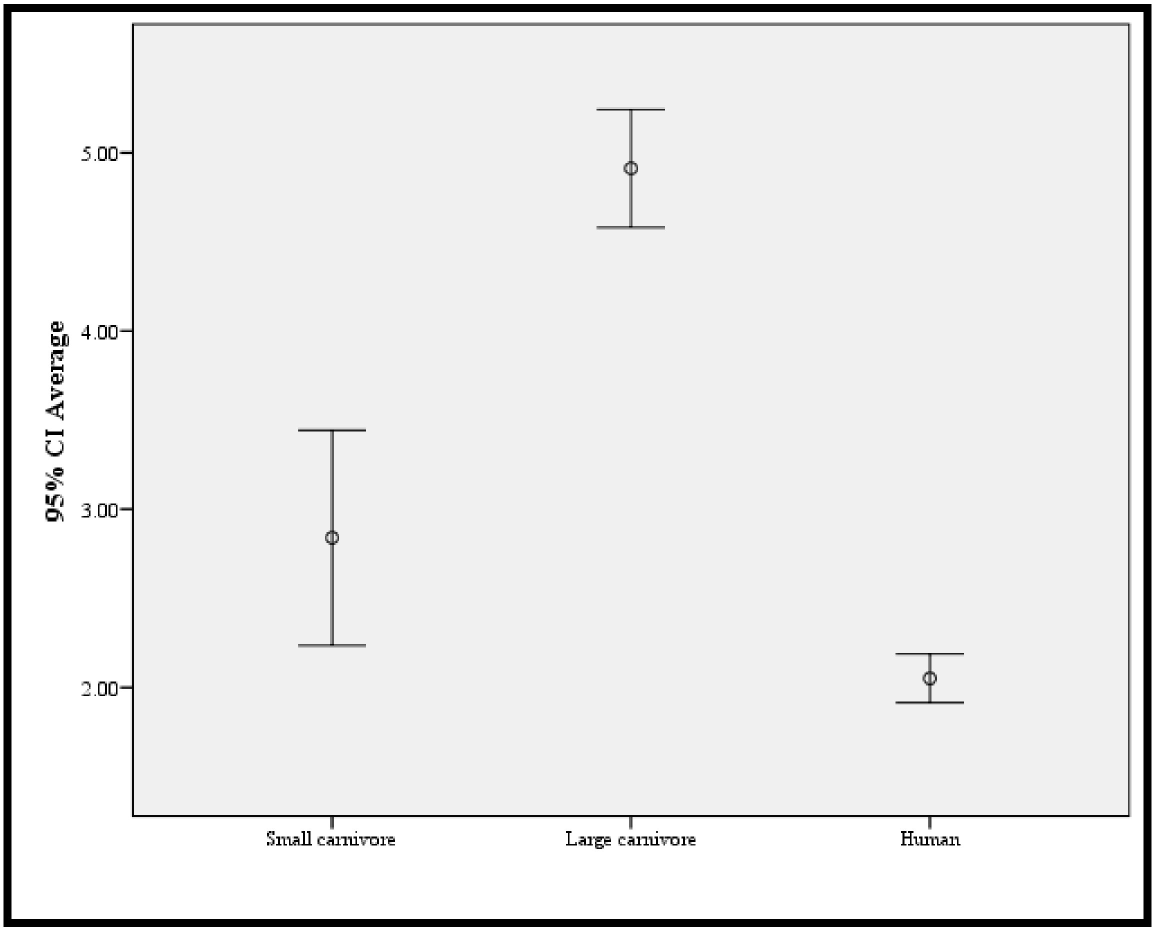

Figure 13. *Ninety-five percent confidence interval for pits Case 2 small and large animal canine tip diameters*.

more indicative of recovery effort than postmortem destruction of elements due to scavenging.

The analysis of pit and puncture diameters indicated that in some cases it may be possible to distinguish scavenging damage caused by small versus large carnivores.

The data suggests that pit and puncture diameters need to be evaluated on a case by case basis, taking into account the distribution of available scavenger species in the area, and the specific environmental context. The differentiation of small versus large carnivore scavenging damage on remains is important because it aids in distinguishing

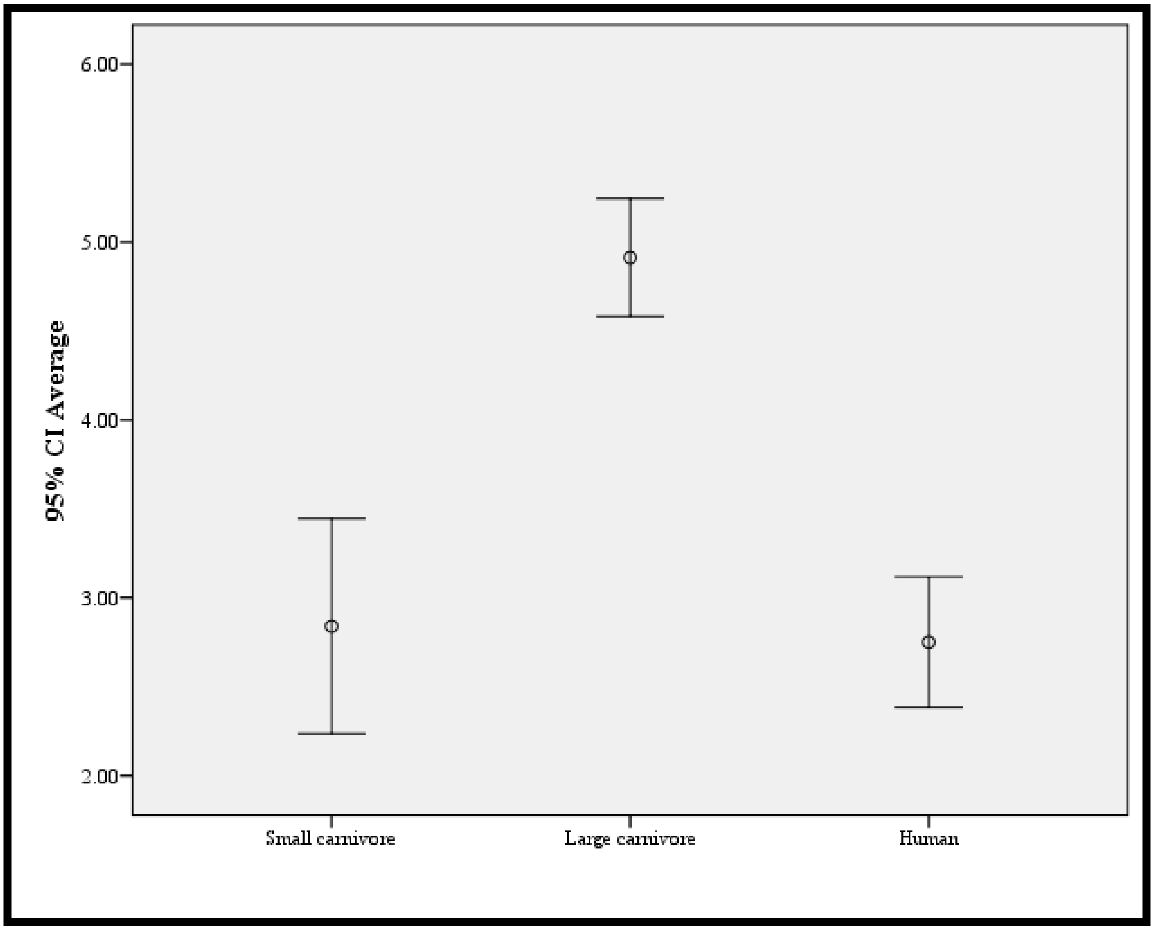

Figure 14. *Ninety-five percent confidence interval for pits Case 19 small and large animal canine tip diameters.*

taphonomic events from possible perimortem trauma. Additionally, understanding animal behavior of key scavenger species aids in higher recovery rates at outdoor scenes.

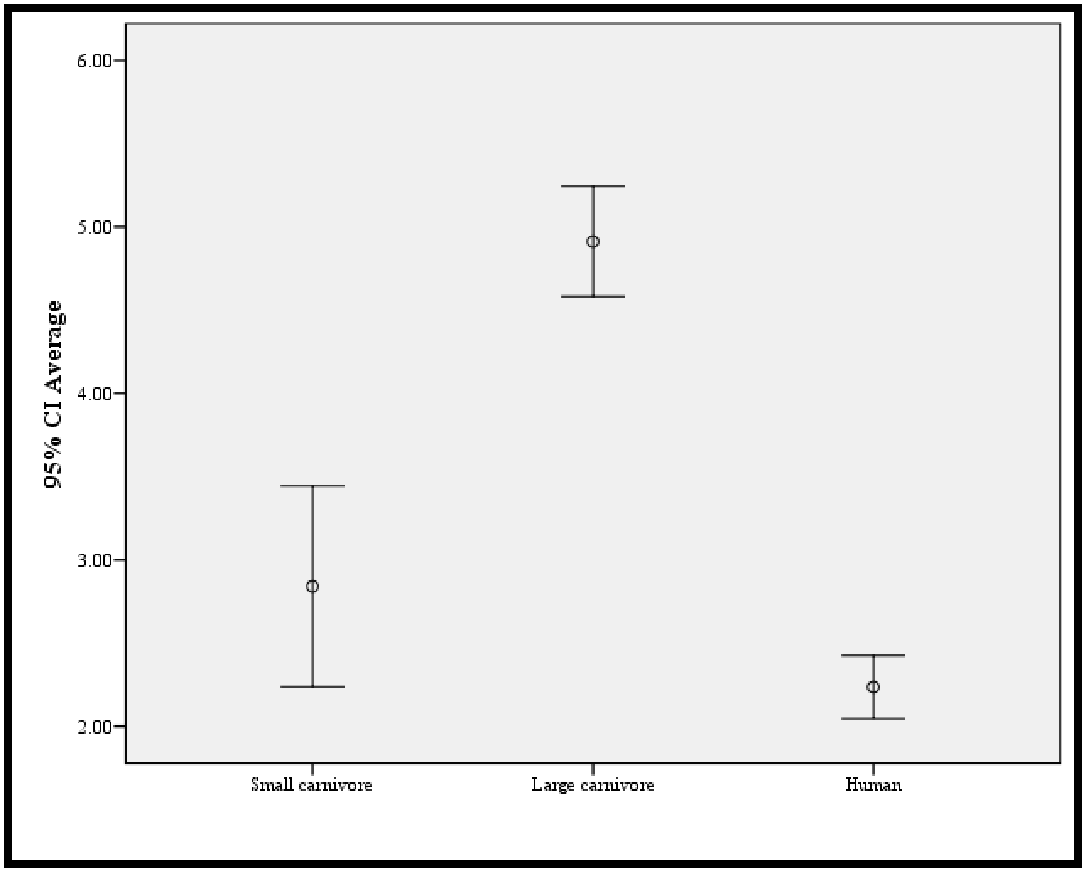

Figure 15. *Ninety-five percent confidence interval for pits Case 21 small and large animal canine tip diameters.*

Table 12. *Case 2 Small and Large Carnivore Tip Diameters and Human Pits*

Impact Type	**Mean (mm)**	***SD***	***N***
Small carnivore	2.84	0.72	8
Large Carnivore	4.91	0.21	4
Human Pits	2.05	0.29	20

Table 13. *Case 19 Small and Large Carnivore Tip Diameters and Human Pits*

Impact Type	**Mean (mm)**	***SD***	***N***
Small carnivore	2.84	0.72	8
Large Carnivore	4.91	0.21	4
Human Pits	2.75	0.545	11

Table 14. *Case 21 Small and Large Carnivore Tip Diameters and Human Pits*

Impact Type	**Mean (mm)**	***SD***	***N***
Small carnivore	2.84	0.72	8
Large Carnivore	4.91	0.21	4
Human Pits	2.23	0.91	91

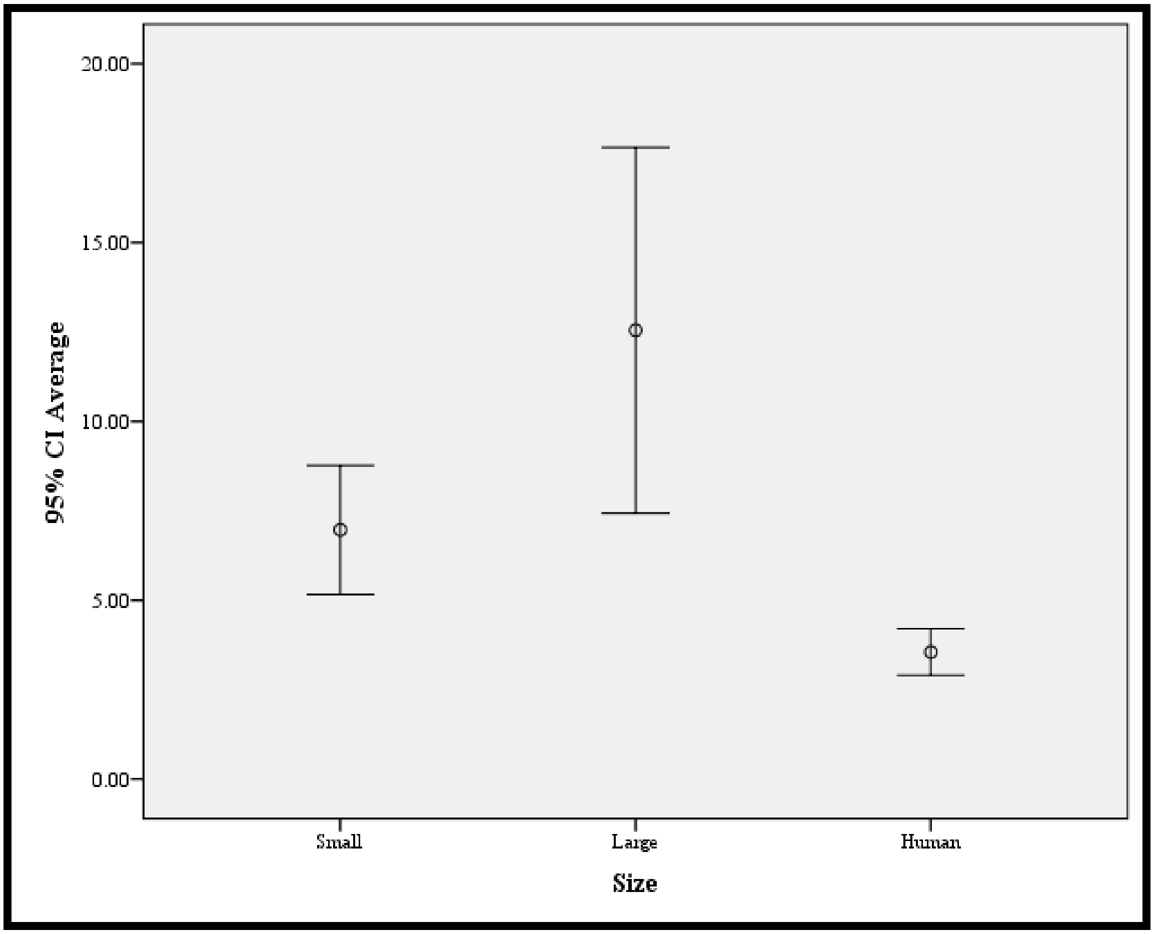

Figure 16. *Ninety-five percent confidence interval for punctures from Case 2 small and large animal canine mexiodistal diameters.*

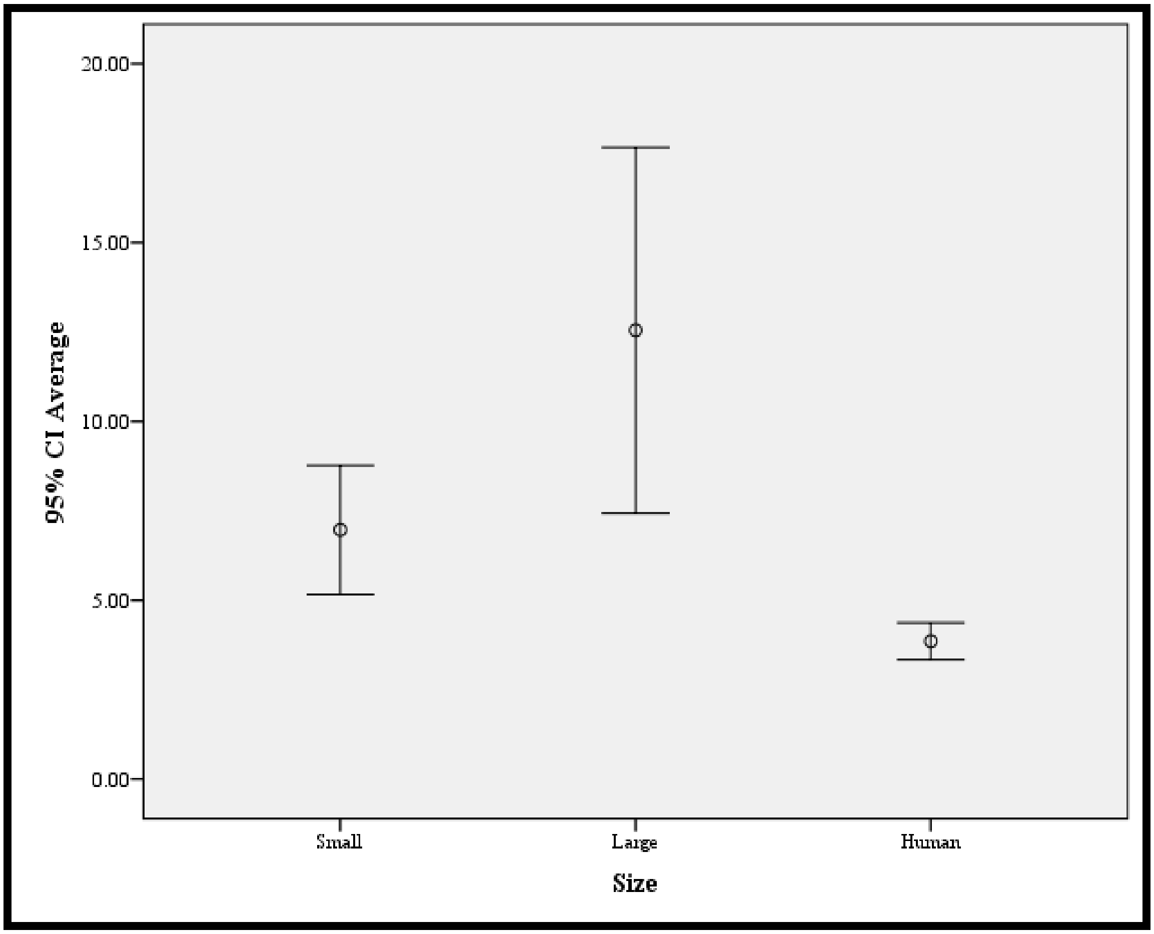

Figure 17. *Ninety-five percent confidence interval for punctures from Case 19 small and large animal canine mexiodistal diameters.*

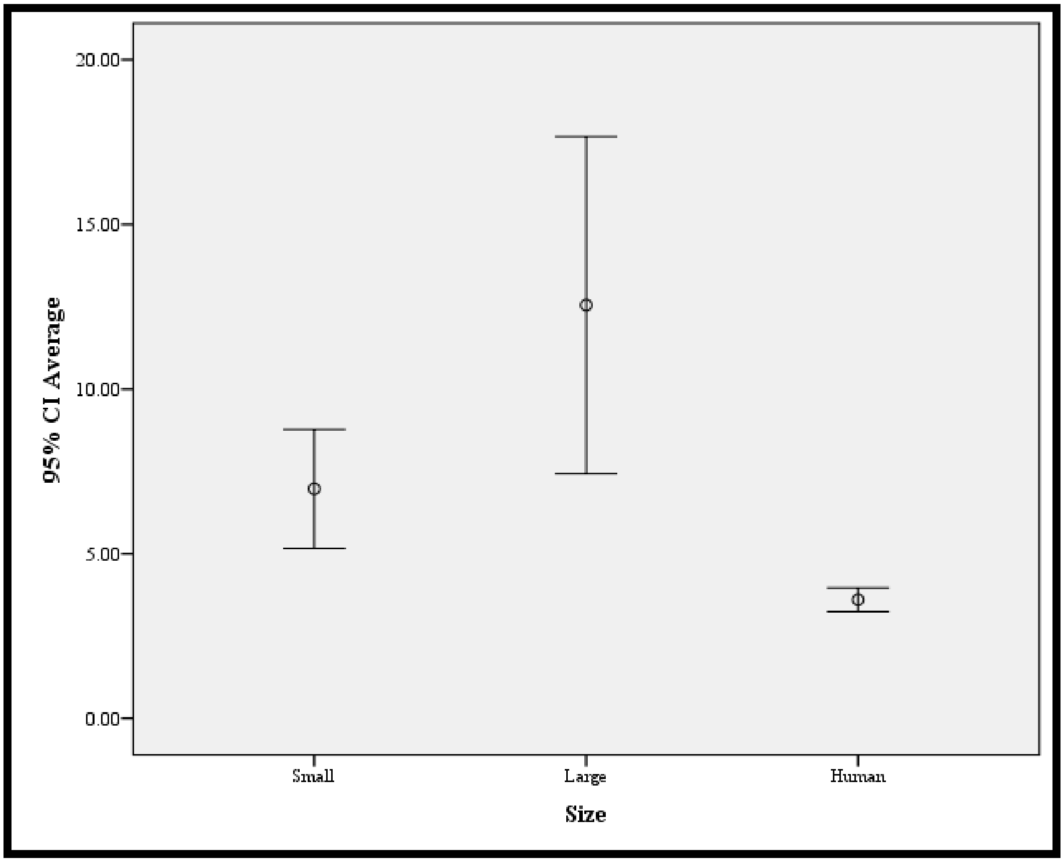

Figure 18. *Ninety-five percent confidence interval for punctures from Case 21 small and large animal canine mexiodistal diameters.*

Table 15. *Case 2 Small and Large Carnivore Mesiodistal Diameters and Human Punctures*

Impact Type	**Mean (mm)**	***SD***	***N***
Small carnivore	6.68	1.61	8
Large Carnivore	15.17	3.02	3
Human Puncture	3.55	1.39	20

Table 16. *Case 19 Small and Large Carnivore Mesiodistal Diameters and Human Punctures*

Impact Type	**Mean (mm)**	***SD***	***N***
Small Carnivore	6.68	1.61	8
Large Carnivore	15.17	3.02	3
Human Puncture	3.98	0.84	15

Table 17. *Case 21 Small and Large Carnivore Mesiodistal Diameters and Human Punctures*

Impact Type	**Mean (Mm)**	***Sd***	***N***
Small Carnivore	6.68	1.61	8
Large Carnivore	15.17	3.02	3
Human Puncture	3.62	1.44	64

CHAPTER V

RESULTS II

Actualistic Experiment

As previously stated, the second phase of this research was to conduct actualistic experiments in an attempt to replicate the patterns of damage observed in the CSUC-HIL forensic sample. This chapter discusses the results of the actualistic field experiments. Five pigs (*Sus scrofa*) were placed at the BCCER on November 1st, 2010. Each carcass was monitored until complete skeletal disarticulation was achieved and a majority of the tissue had been consumed. The daily site reports are presented below, followed by the analysis of the collected skeletal elements, including element representation, inter-element and intra-element scavenging distribution, and an analysis of pit and puncture marks.

Site Environmental Settings

The terrestrial habitats of the BCCER are extremely varied. Figure 19 shows the vegetation distribution at the BCCER. Efforts were made to choose site locations that were similar, but due to the changing landscape at the BCCER, some variation occurred (Figure 20). Sites one (Figure 21), three (Figure 22) and four (Figure 23) are classified primarily as mixed woodland/forest with extensive blue and black oaks present. Site two

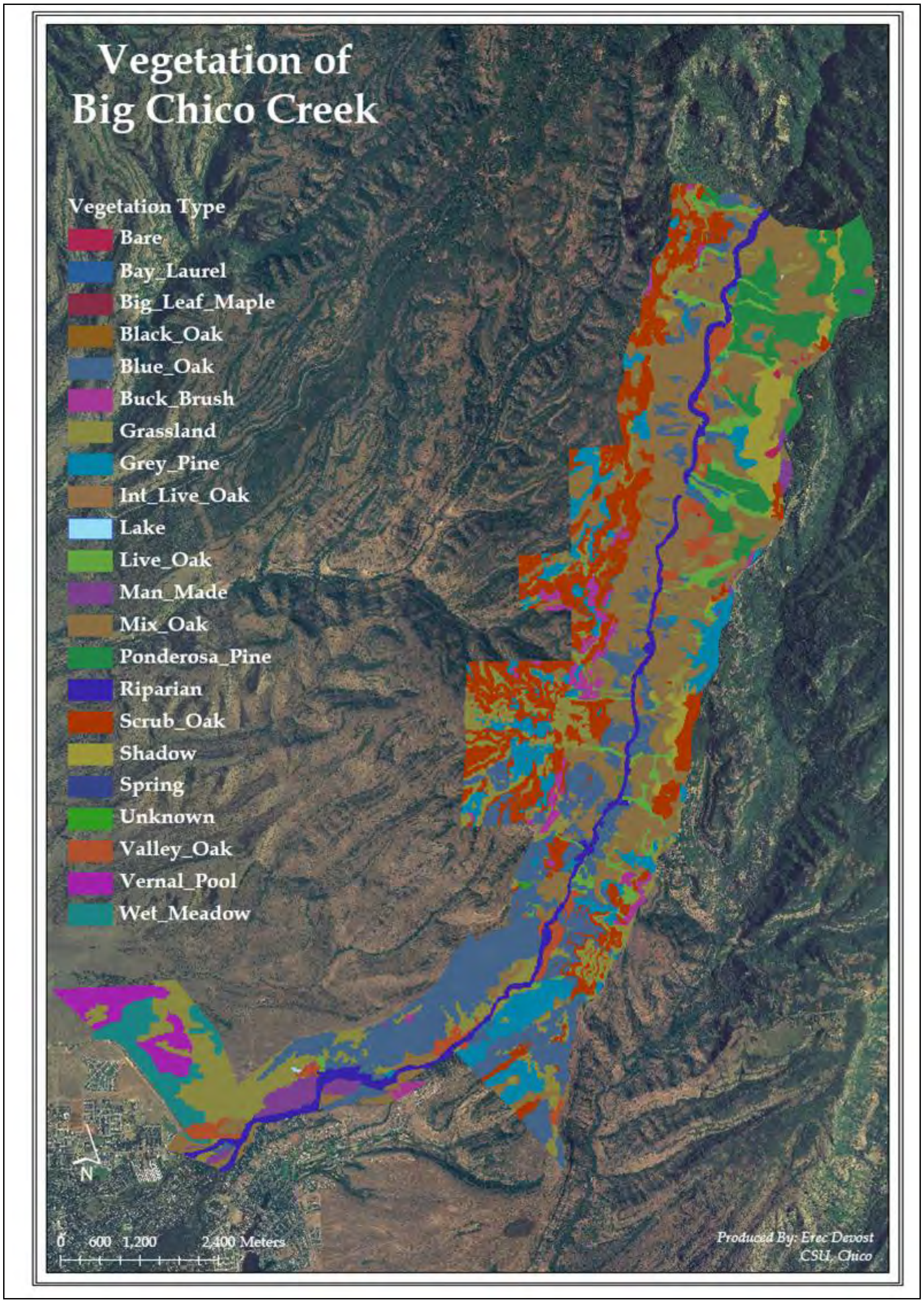

Figure 19. *BCCER vegetation distribution map.*

Source: Colleen Hatfield. Reproduced with permission.

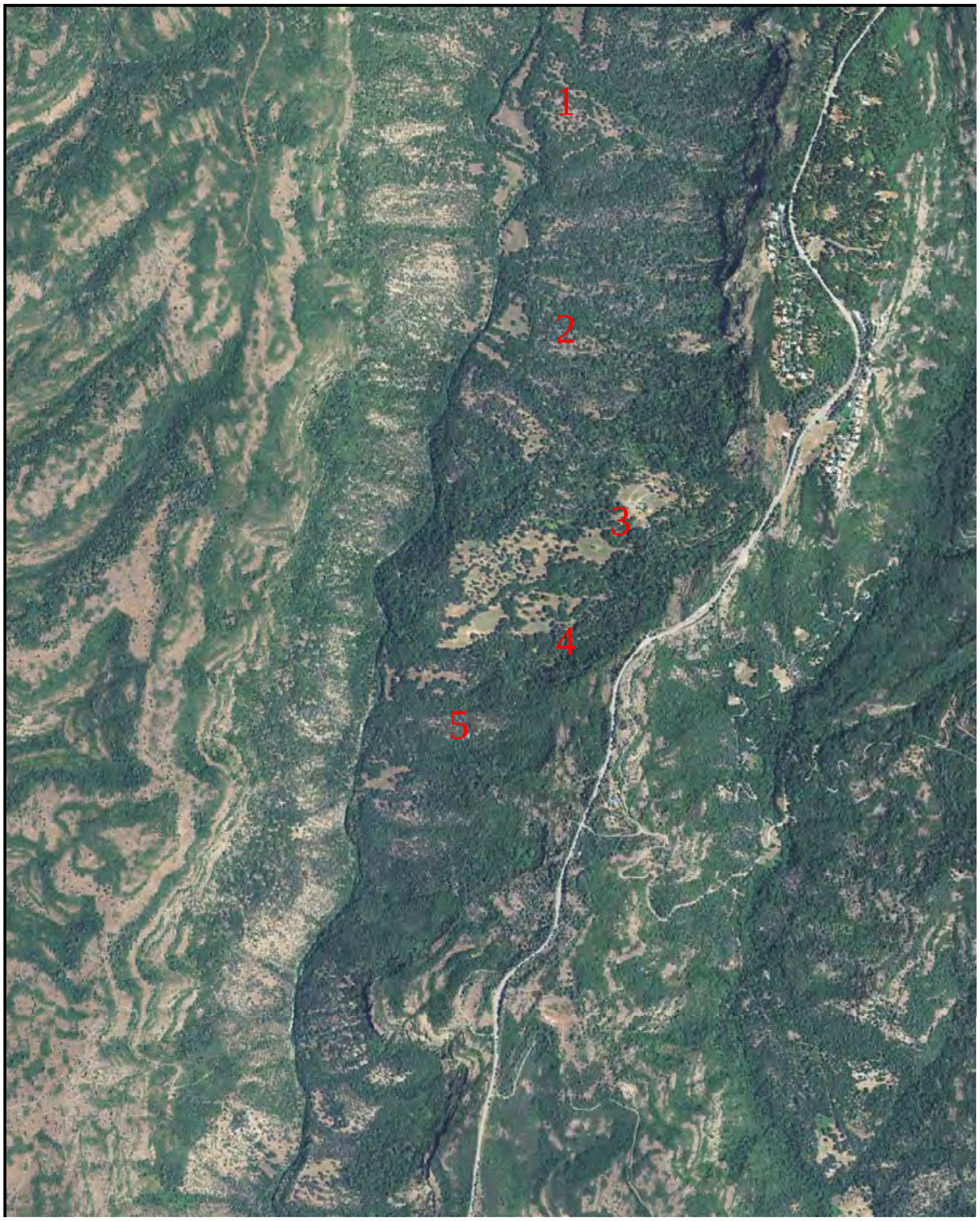

Figure 20. *Aerial view of site distribution at the BCCER.*

Source: Map created with ArcGIS software. This map was created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com.

(Figure 24) is classified as chaparral with some black and blue oaks present. Site five (Figure 25) is blue oak savanna/woodland. Each carcass was held down by wrapping wire

Figure 21. *Site #1 overview showing the surrounding environmental setting.*

around the shoulder and haunch area, which was then staked into the ground with rebar. The camera was attached to a tree approximately two to three meters away from the carcass, aimed directly at the center mass of the carcass (see Figure 1). The motion sensitive camera was set to take two images when the sensor was tripped, with a one-minute delay between pictures. The location of the rebar, center mass of the carcass, and camera were all recorded with the Trimble® GeoHX™ handheld GIS data collection unit.

Mapping

Disarticulated elements were recorded using a Trimble® GeoHX™ handheld GIS data collection unit. The site was mapped if the carcass, or portion of the carcass,

Figure 22. *Site #3 overview showing the wooded and open areas that surrounded the site.*

had been moved from its original position. Each skeletal element was recorded, along with the side, portion, and completeness of the element. The map legend is shown in Figure 26.

Daily Site Activity

An accounting of daily site activity is presented below. The carcasses were monitored daily until disarticulation and large amounts of tissue consumption had occurred. The daily scavenging activity and modifications to the remains are described site by site. Each day the carcass and all disarticulated elements were photographed and recorded with the Trimble® GeoHX™ handheld GIS data collection unit. If the carcass

Figure 23. *Site #4 overview showing the mixed woodland environment.*

had been moved from its previous location, the camera was repositioned to monitor the new location. Each site number will be referenced in regards to the corresponding pig carcasses (i.e., Site #1 = pig #1).

<u>Site 1 - Pig 1</u>

Figure 27 is a map showing the placement of pig #1. On day #1 the carcass was not disturbed, and the field camera did not record any images. On day #2 the field camera recorded 56 images. The first disturbance occurred on November 3rd at 1:20 am. Two black bears (*Ursus americanus*), including an adult female and a first year cub, were observed scavenging the carcass (see Figure 28). Consumption of the carcass continued until 3:06 am. Damage to the carcass is focused on the right hindlimb and right forelimb, although there is a small amount of damage to the thorax (see Figure 29). Figure 28 is an

Figure 24. *Site #2 overview showing the chaparral setting, as well as black and blue oaks. Also pictured is carcass #2 in the blue body bag, Jeff Mott, and the Kubota RTV used to transport the equipment and personnel.*

image taken by the field camera, showing the two bears scavenging the right forelimbs and hindlimbs. The carcass was still tied down and attached to the rebar, thus there was no movement of the carcass from the original placement location.

On day #3 the field camera took 13 pictures. A third bear approached the carcass at 2:07 pm. When the next image was taken at 3:53 pm, the carcass was removed from the view of the camera, and the rebar stakes at the head of the pig was partially pulled out of the ground. At 12:02 am, November 5th, a fourth bear was observed in the area where the pig was originally staked down. A fifth bear entered the site at 4:14 am. In an effort to locate the carcass, an extensive search was undertaken. The carcass was

Figure 25. *Site #5 overview showing the blue oak savanna/woodland environment.*

located 101.37 meters north of its original location, resulting in an elevation change of 18.5 to 36 feet. It was dragged down a ravine, across a small creek, up the other side, and was completely disarticulated. The vertebral column was still articulated to the innominate, as well as to several ribs. The majority of the organs were still present, and did not appear to have been scavenged (see Figure 30). The head, including the mandible, several rib fragments, as well as both forelimbs were present. The right hindlimb could not be located. The camera was relocated to further monitor scavenging of the carcass. Figure 31 is a map showing the scatter of pig #1 on day #3.

On day #4 the field camera recorded 63 pictures. The first photograph was taken at 4:36 pm. Six different bears scavenged the carcass throughout the night. Five of

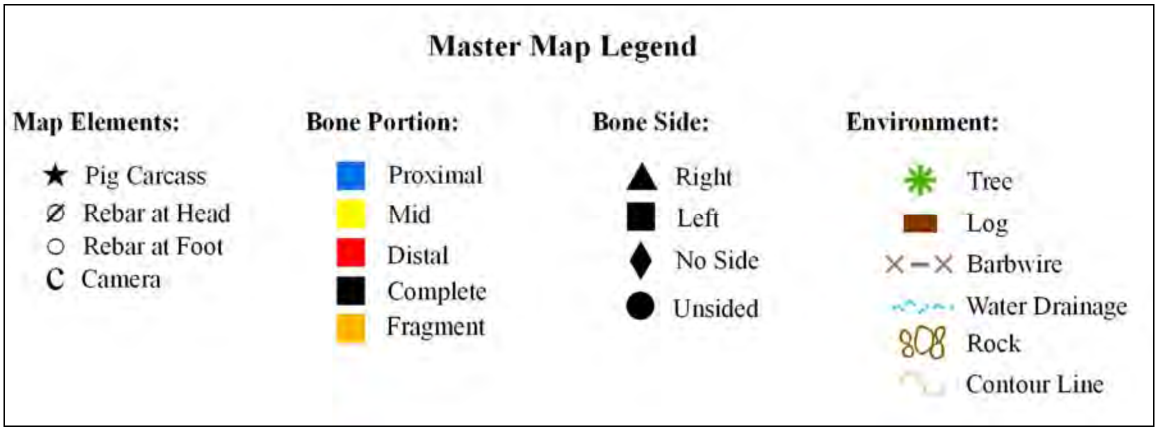

Figure 26. *Master map legend.*

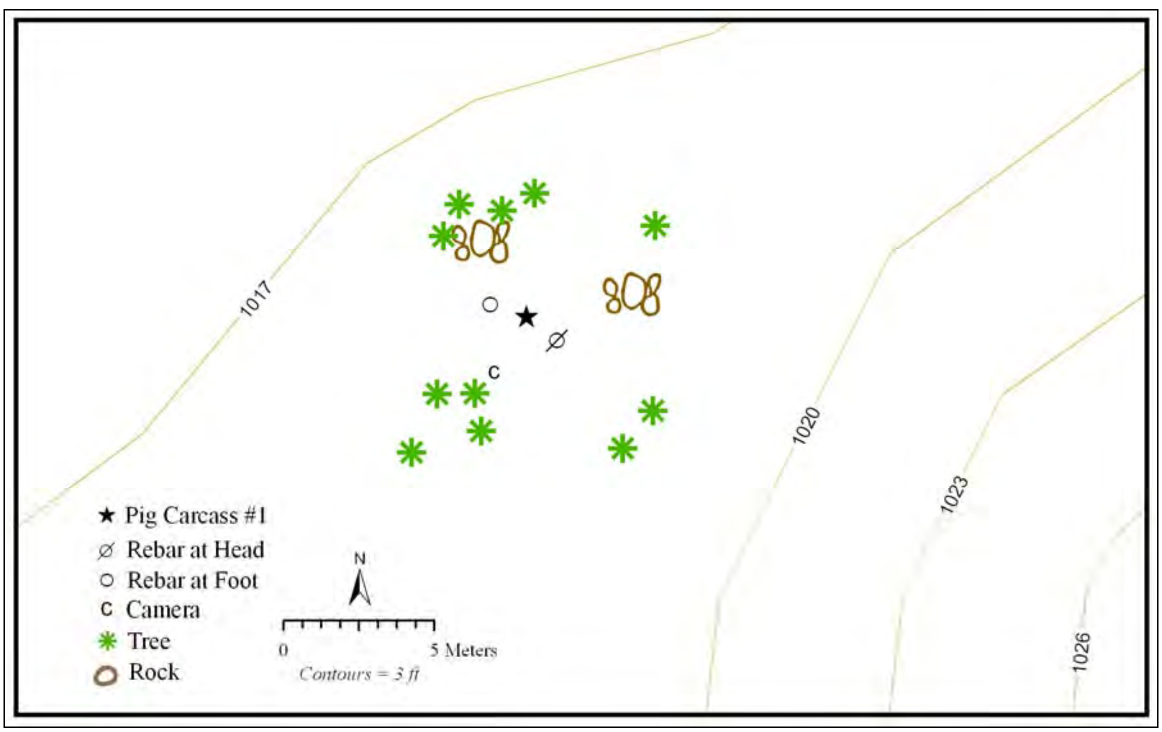

Figure 27. *Site #1 map showing the original placement of the carcass and camera on November 1st, 2010.*

Figure 28. *Site #1 (day #2) Photograph showing a female bear and cub consuming the right hindlimb and forelimb, respectively.*

the bears were previously recorded on day #2 and day #3. What remains of the carcass is highly fragmented and scattered. Figure 32 shows the two largest fragments recovered, representing the frontal bone. The map of the scatter is shown in Figure 33. All located skeletal elements were collected.

Site 2 – Pig 2

Figure 34 is a map showing the placement of pig #2 at the second site on day #1. There was no scavenging activity on this carcass for twenty-two days. Two young bears were observed scavenging the carcass from November 22nd – 28th. Unfortunately, weather and logistical problems prevented examination of the site until December 4th. At the time the carcass was consumed it had considerable bloat and maggot activity

Figure 29. *Site #1 (day#2) Photograph showing damage to forelimb and hindlimb produced by scavenger activity seen in Figure 28.*

concentrated at the head (see Figure 35). After considerable searching, none of the remains could be located for analysis.

<u>Site 3 – Pig 3</u>

Figure 36 is a map showing the placement of pig #3 at the third site on day #1. On day #2 the field camera recorded five images of a single bear scavenging the carcass, starting at 7:56 pm. When the site was checked on November 2nd the carcass has been removed from the original location. The carcass was located 20.78 meters upslope next to a fallen tree. The right forelimb (including the scapula) and head had been removed and were located on the opposite side of the log and slightly downhill. The head had cervical vertebrae 1 and 2 still attached. Scavenging on the head was concentrated to the inferior

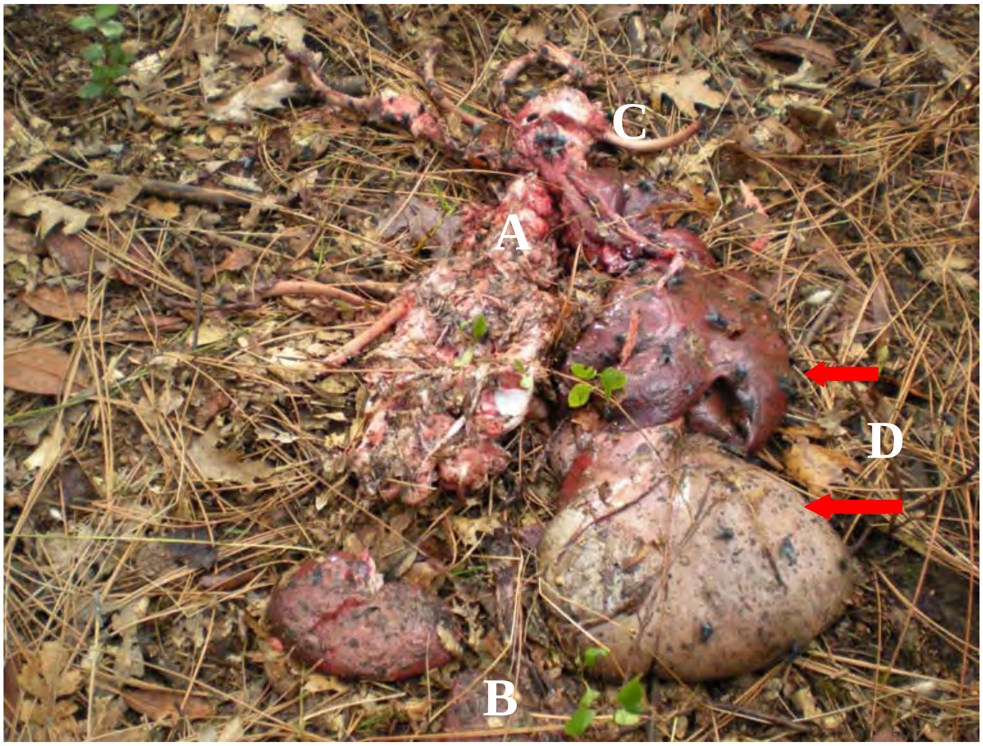

Figure 30. *Site #1 (day #3) photograph showing the vertebral column (A), innominate (B), ribs (C), and organs (D).*

portion, with all of the tissue surrounding the mandible and base of the skull removed (see Figure 37).

The rest of the carcass was complete. Almost all of the skin had been removed and tissue damage is most extensive on the neck, shoulder area and hindlimbs (see Figures 38 and 39). The carcass was secured with new wire and rebar at its current location. The camera was also repositioned to monitor the carcass. The disarticulated head and limb were left at their current location. Figure 40 is a map of the scatter from day #2.

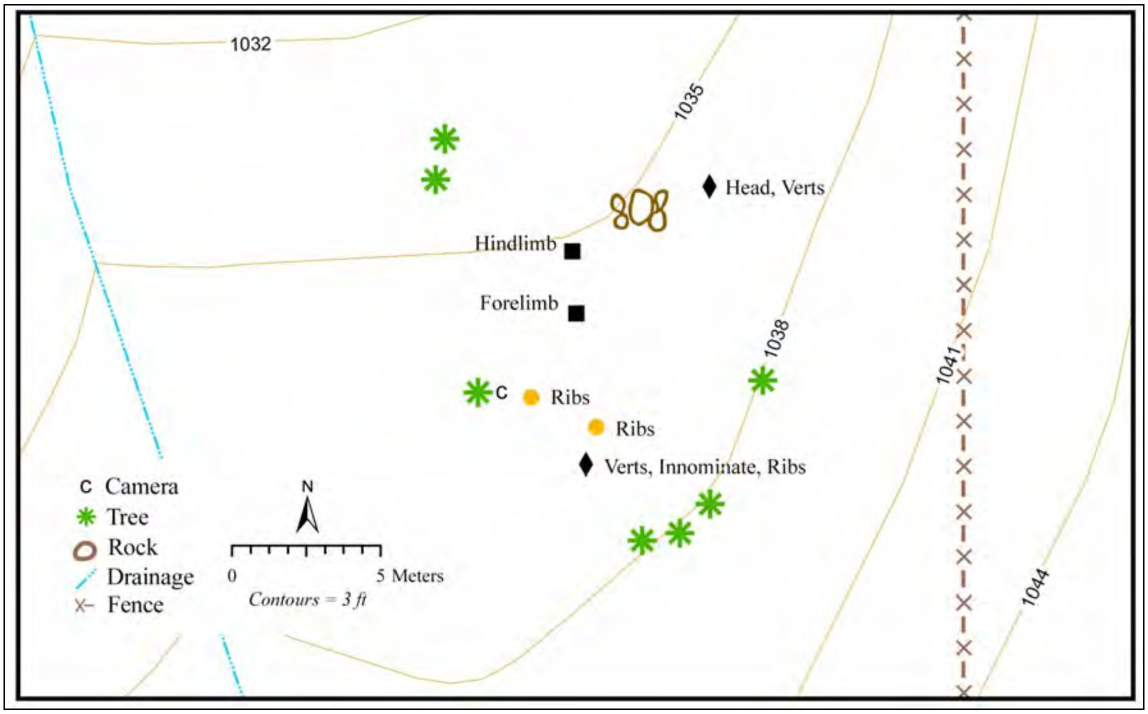

Figure 31. *Site #1 (day #3) Map showing the scatter of elements.*

On day #3 the field camera recorded 261 photographs. A large bear scavenged the carcass at 7:09 pm[1], on November 2nd. A second large bear began scavenging the carcass at 8:31 pm, and remained with the carcass until 8:07 am. He was observed sleeping next to the carcass, consuming tissue, and transporting the pigs head out of view (see Figure 41). Common ravens (*Corvus corax*) entered the area at 7:58 am, shortly after sunrise. When the bear left at 8:07 am, the ravens began scavenging the carcass (see Figure 42).

A juvenile red tailed hawk (*Buteo jamicensis*) was recorded at 10:58 am, but was not observed feeding directly from the carcass (see Figure 43). Skeletally, the carcass is complete, but completely disarticulated and scattered around the hillside. The mandible

[1] Note the field cameras date was incorrectly set to one day ahead. It was corrected for the next days photographs.

Figure 32. *Site #1 (day #4) Photograph showing fragments of the frontal bone.*

was disarticulated from the rest of the skull and both portions were nearly devoid of soft tissue. The lower half of the vertebral column was still articulated with the innominate and the wire used to a secure the carcass was still wrapped around it (see Figure 44). All four limbs were articulated (forelimb includes the scapula) and most of the tissue was consumed, with the exception of the area surrounding the hoof.

The thoracic vertebrae were still articulated and the right and left ribs were articulated on most vertebrae (see Figure 45). The remains were left at the site and the camera continued to record any additional scavenging activity. Figure 46 is a map of the carcass scatter from day #3.

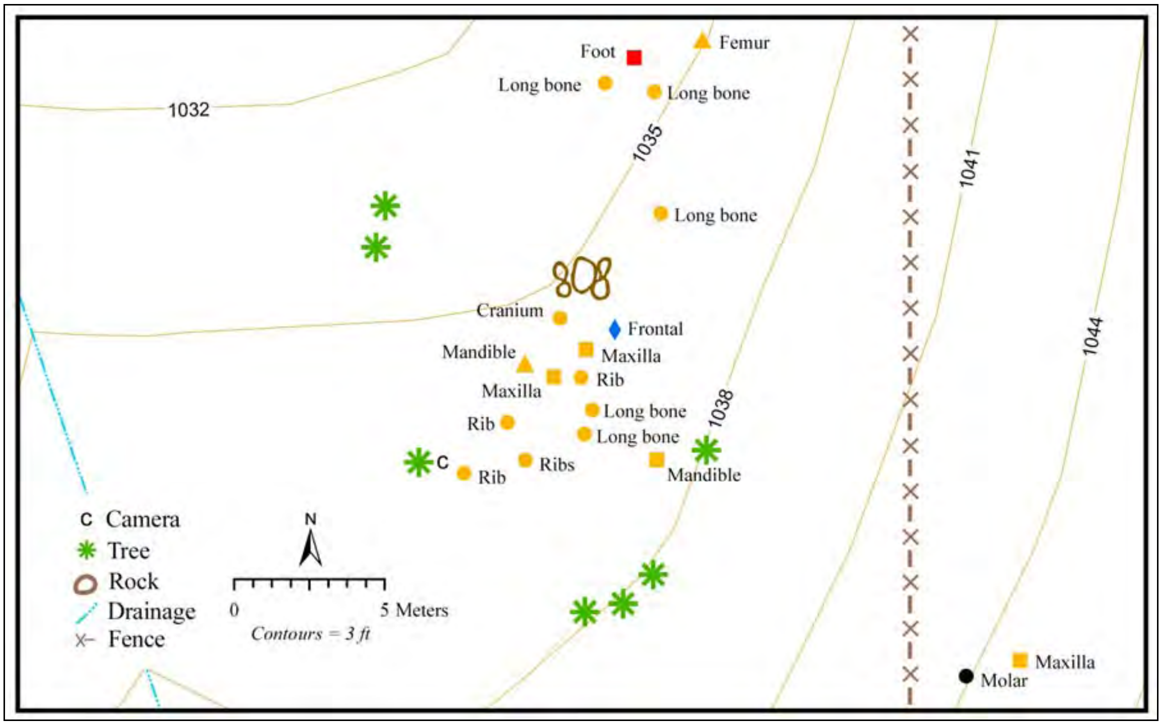

Figure 33. *Site #1 (day #4) map showing the scattering of the carcass.*

On day #4 the camera recorded 60 photographs. Ravens returned to the site at 1:28 pm on November 3rd. The juvenile red tailed hawk returned and scavenged the vertebral column (see Figure 47). The ravens continued to feed until 4:38 pm. The bear returned at 8:55 pm and continued feeding until 5:42 am. The ravens returned shortly after sunrise at 7:59 am and left the site at 8:21 am. After intensive searching of the surrounding area no skeletal remains could be located. Additional searches of the area on November 5th located the right forelimb down slope of the previous carcass location. It was fully articulated and included the scapula. The field camera recorded the juvenile red-tailed hawk returning to the site, but no other scavengers. Figure 48 is a map of the forelimb's location.

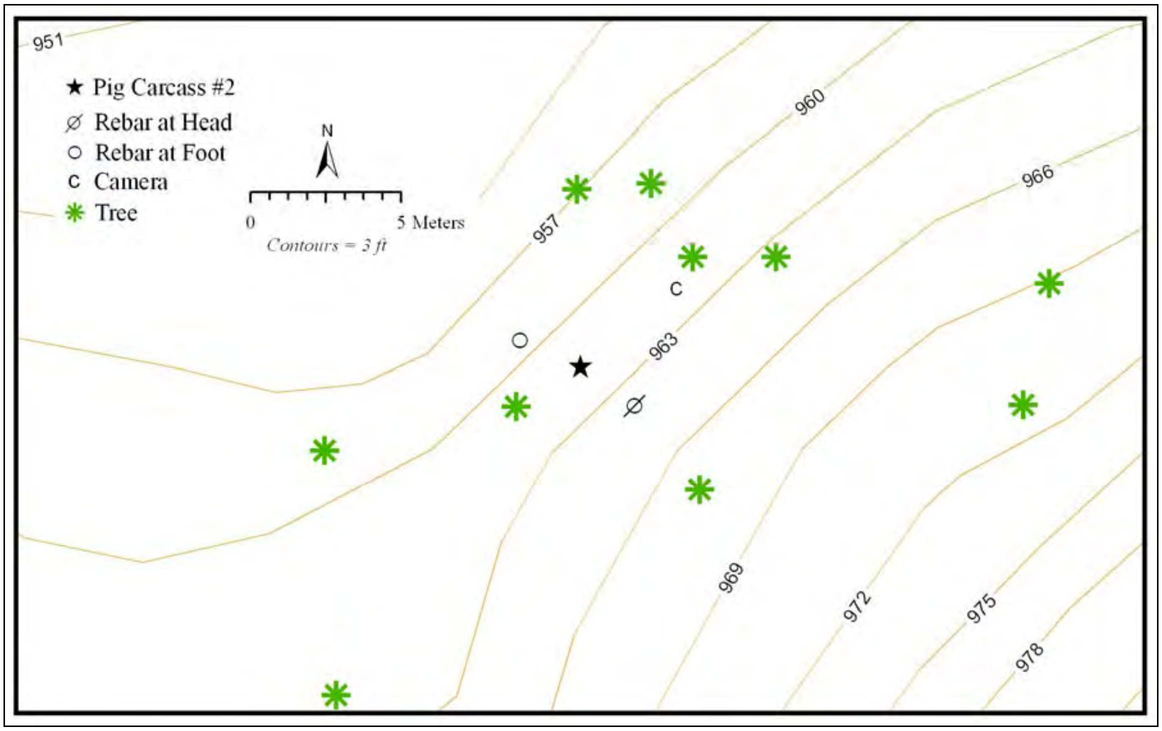

Figure 34. *Site #1 map showing the original placement of the carcass and camera on November 1st , 2010.*

On November 6th, additional help was recruited to conduct 10 meter transects of the surrounding area, and included a 500 meter search of the area surrounding the carcass site. In addition to the 10 meter transects, surface scrapes of the surrounding area were performed to remove the surface duff. Only the mandible was recovered (see Figure 49). The area was searched again on November 7th, but no additional remains were recovered.

Site 4 – Pig 4

Figure 50 is a map of carcass #4's placement on day #1. The field camera recorded two photographs of animal activity. A small, juvenile bear approached the carcass at 10:20 am, on November 1st. The only damage to the carcass was a single four-

Figure 35. *Site #2 (day #14) photograph showing the decomposition of the carcass.*

inch wide hole on the pig's right side (see Figure 51). The damage is only to the outer most layers of tissue, as the viscera can be seen and is not damaged. The carcass was still attached to the rebar, and thus had not moved from its original location.

On day#2 the field camera recorded 10 photographs. A medium sized bear was observed scavenging the carcass. After three images, the carcass was removed from the camera's view field. The carcass was dragged 14.39 meters down slope. Damage was concentrated in the head and shoulder region. Figures 52 and 53 show the scavenging damage from day #2. The thorax had not been further damaged, and slight bloating can be observed through the hole (see Figure 52). The carcass was staked down again. Figure 54 is a map of the carcass movement and scatter.

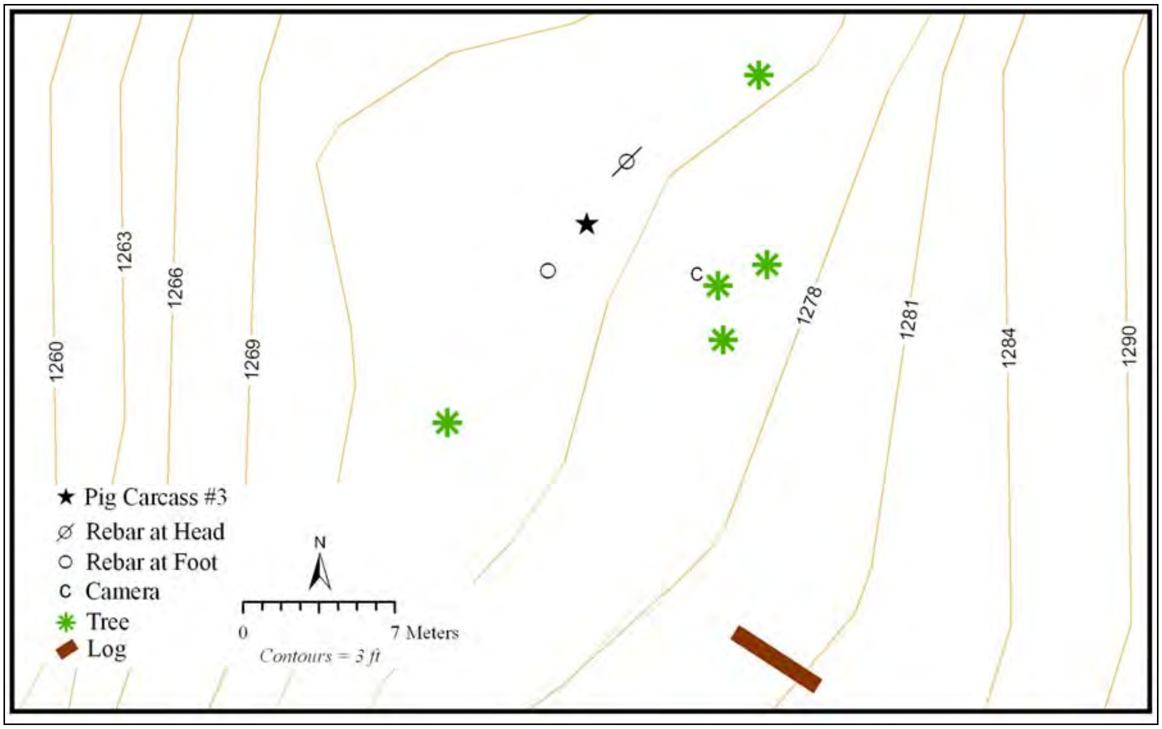

Figure 36. *Site #3 day #1 map showing the original placement of the carcass and camera on November 1st, 2010.*

On day #3 the field camera recorded two images. Unfortunately, the camera was tilted upwards and the carcass was no longer in view. The carcass had been moved further north, and once again, slightly uphill. The head was completely disarticulated from the body. Damage to the carcass was concentrated in the head region and along the back. The ribs and hindquarters were exposed (see Figure 55). The head was moved 35 meters southwest of the carcass. The mandible was disarticulated from the skull; both the skull and mandible have had large amounts of soft tissue removed (see Figures 56 and 57). Figure 58 is a map of the scatter.

On day #4 the camera recorded 37 photographs. Ravens entered the site at 1:24 pm, November 4th. A turkey vulture (*Cathartes aura*) began scavenging the carcass

Figure 37. *Site #3 (day #2) photograph showing the disarticulation and partial consumption of the head.*

at 2:55 pm (see Figure 59). At 6:14 pm at large bear was observed scavenging the carcass. The next image was taken at 1:58 am and the carcass was removed. The carcass had been moved 19.45 meters upslope. The head and mandible were in the same general area as the day before, south of the original carcass location. The carcass was completely disarticulated and heavily scavenged. Figure 60 is a map of the scatter from day four.

<u>Site 5 – Pig 5</u>

Figure 61 is a map showing the placement of pig #5 site #5 on day #1. The field camera did not record any images, and the carcass was not disturbed. On day #2 the field camera recorded 16 images. The first image was recorded at 5:54 pm on November 2nd. A single adult bear scavenged the carcass. At 6:14 pm the carcass was no longer in

Figure 38. *Site #3 (day #2) photograph showing the removal of the skin and consumption of tissue on the shoulders.*

view. The carcass was located 62.11 meters up hill (elevation change from 742.4 feet to 779 feet) from its previous location at the base of a fallen tree. Entrails and blood were spread across the hill and the right forelimb was located down slope of the main carcass. Scavenging was concentrated along the back, the shoulder area, and at the base of the skull (Figure 62). Though the organs were visible, none had been consumed. The map of the scatter can be seen in Figure 63.

On day three the field camera recorded 18 images. In addition to bears, a single golden eagle (*Aquila chrysaetos*) was observed at the carcass location (Figure 64). A bear visited the carcass at 11:22 pm and physically obscured the view of the carcass in the subsequent images. The carcass was moved 17.44 meters further uphill (elevation

Figure 39. *Site #3 (day #2) photograph showing the hind quarter tissue consumption and skin removal.*

change of 779 feet to 797 feet), next to the base of a tree. Most of the skin has been removed, and feeding concentrated on the shoulder, back, rear, and base of the skull. The organs were still present, and had not been scavenged (Figure 65). The right forelimb had not been disturbed and down slope from the carcass. The left forelimb was located up slope from the carcass. Figure 66 is a map of the scatter.

On day #4 the field camera recorded eleven images. A single bear entered the site at 6:25 pm, November 4th. The next image was recorded at 6:50 pm and the carcass was removed from the field of view. The carcass was located 51.35 meters uphill (elevation change of 797 feet to 855 feet) in a depression near a group of trees. The forelimbs had been moved and were down slope from the carcass. The right ulna, radius,

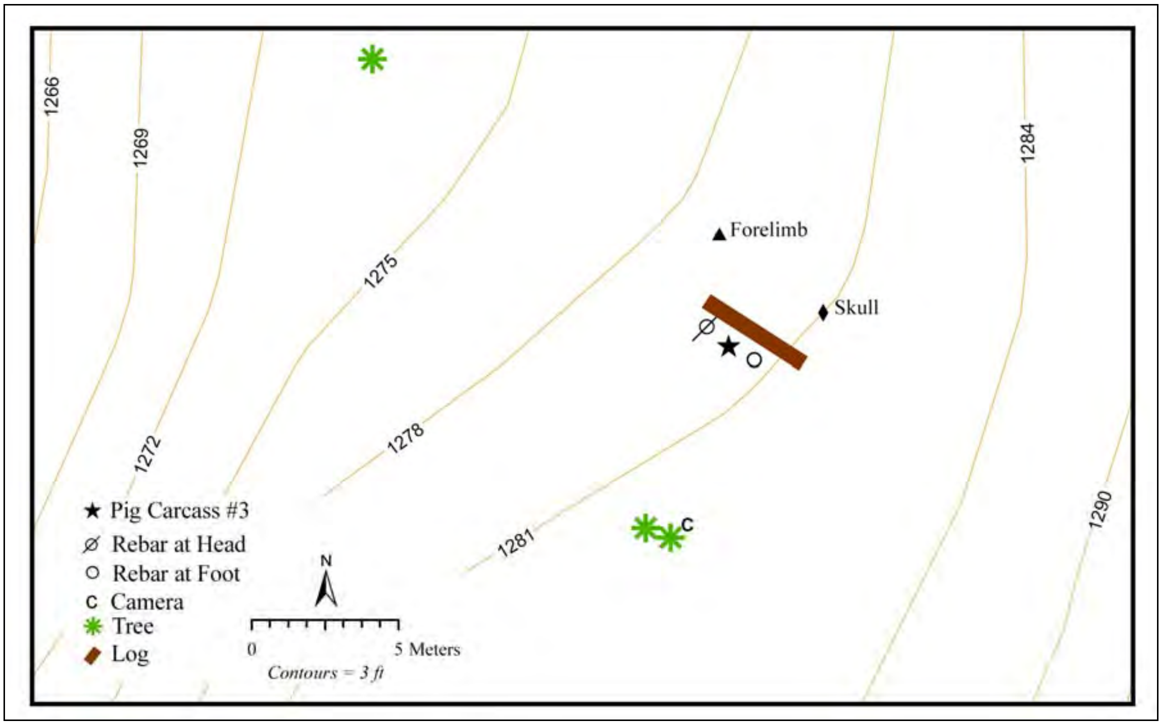

Figure 40. *Site #3 (day #2) map of carcass movement and scatter.*

and hoof had been disarticulated from the humerus, whereas the left forelimb was complete. The carcass was disarticulated, but not scattered. Many of the organs were still present and had not been scavenged (Figure 67). Figure 68 is a map of the scatter.

On day #5 the field camera recorded four images. A bear approached the camera at 8:44 pm on November 5th and knocked it off of its mount, thus no photographs were recorded. The carcass was completely disarticulated and the ribs and vertebral column were highly fragmented. Most of the soft tissue was consumed (Figure 69). Figure 70 is a map of the scatter.

Figure 41. *Site #3 (day #3) a large bear is shown transporting carcass #3's head.*

Element Representation

The complete skeletal inventory and documentation of presence or absence of scavenging damage is provided in Appendix E. Element representation varied substantially between pigs, from nearly complete recovery for pig #4 to complete absence of elements for pig #2. Table 18 reports the percent of available elements that showed evidence of carnivore and rodent scavenging. Carnivore damage was present on nearly every element recovered, but rodent gnawing was absent. The lack of rodent gnawing may be due to the short length of time the elements were at the BCCER. The literature suggests that rodents prefer to gnaw on dry bones (Klippel and Synstelien 2007), and at the time of collection all skeletal elements were moist.

Figure 42. *Site #3 (day #2) common ravens shown scavenging carcass #3's vertebral column (indicated with a red arrow).*

Differential recovery of the remains may account for the variation in the representation of elements. A concerted effort was made to locate all of the elements, but it is possible that many were missed during the search effort. Therefore, missing elements cannot be assumed to be missing due to total consumption. Although the absence of the elements from the original placement site, or their last known location, was due to scavenging activity, the missing elements were not scored as scavenged because they were not present for assessment.

It can also be expected that some of the bones were located outside of the search parameters. Factors limiting search areas included rough terrain, geographic limitations such as the Big Chico Creek and deep ravines, and the physical boundary of

Figure 43. *Site #3 (day #2) juvenile red tailed hawk (highlighted within the red box).*

the BCCER. The reserve is surrounded by private property, so searches were limited to land owned by the BCCER. It is possible that some of the remains traveled outside of the limits of the BCCER. Black bears (*Ursus americanus*) typically have large home ranges of 25-125 km^2 that overlap with other bears (Koehler and Pierce 2003). It can be expected that the range of any of the adult black bears in the reserve extends beyond the reserve, thus portions of the pig carcass may have been transported over larger distances than searched.

Figure 44. *Site #3 (day #3) Photograph showing the innominate, lumbar and thoracic vertebrae and rib fragments surrounded by wire attached to the hindlimb rebar (indicated by the red arrow).*

Scavenging Distribution

Approximately 54 percent of all elements examined showed evidence of animal scavenging, all of which were affected by carnivores. Carnivore tooth impact marks were most common on the mandible, humerus, and scapula.

Element Scavenging Intensity

The scavenging intensity for each portion of an element was totaled. The averages are that total divided by the total possible ranking score for all present portions of that element. Table 19 shows scavenging intensity scores for all elements and portions that showed scavenging damage. Due to the small sample size of elements with visible scavenging damage, further statistics could not be run.

Figure 45. *Site #3 (day #3) Photograph showing the thoracic vertebrae and ribs.*

Tooth Impact Marks

Of the four pigs with elements recovered, measurable pit and puncture marks were present only on pigs #1, #3, and #4. A complete inventory of the canine pit and punctures diameters is provided in Appendix F. Figure 6 presents the distribution of the maximum tip and mesiodistal canine diameters of the various carnivore species. Figure 71 shows the distribution of pits and punctures in the pig carcass sample. The extreme outlier in the punctures was a tarsal, which went through cancellous bone and

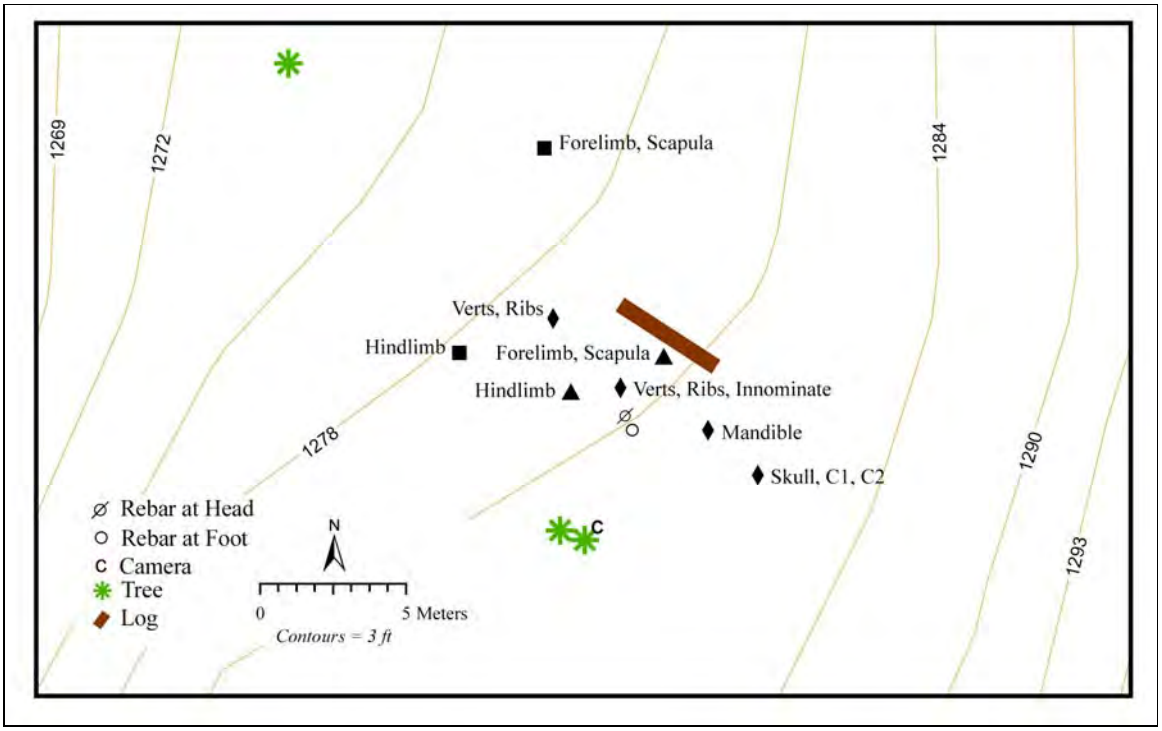

Figure 46. *Site #3 (day #3) map showing the scatter of carcass #3.*

would have allowed for more deformation around the impact site. Tables 20 and 21 show the descriptive statistics of the pits and punctures recorded from the pig elements.

Pig #1

Figure 72 shows the distribution of pit diameters in pig #1 compared to the canine tip dimensions of large and small carnivores. The pits overlap with the small carnivores only. Figure 73 shows the distribution of puncture diameters in pig #1 compared to the mesiodistal diameters of large and small carnivores. The punctures also overlap with the small carnivores only.

Pig #3

Figure 74 shows the distribution of pit diameters in pig #3 compared to the canine tip dimensions of large and small carnivores. The pits do not over lap with either

Figure 47. *Site #3 (day #3) ravens and red-tailed hawk (highlighted in red box) shown scavenging.*

group, and fall below the small carnivores. Figure 75 shows the distribution of puncture diameters in pig #3 compared to the mesiodistal diameters of small and large carnivores. The pits also do not overlap with either group, and fall below the small carnivores.

<u>Pig #4</u>

Figure 76 shows the distribution of pit diameters from pig #4 compared to the canine tip diameters of small and large carnivores. The pit diameters overlap only with the small carnivores. Figure 77 shows the distribution of puncture diameters from pig #4 compared to the mesiodistal canine diameters of the small and large carnivores. The punctures do not overlap with either group, and fall below the small carnivores.

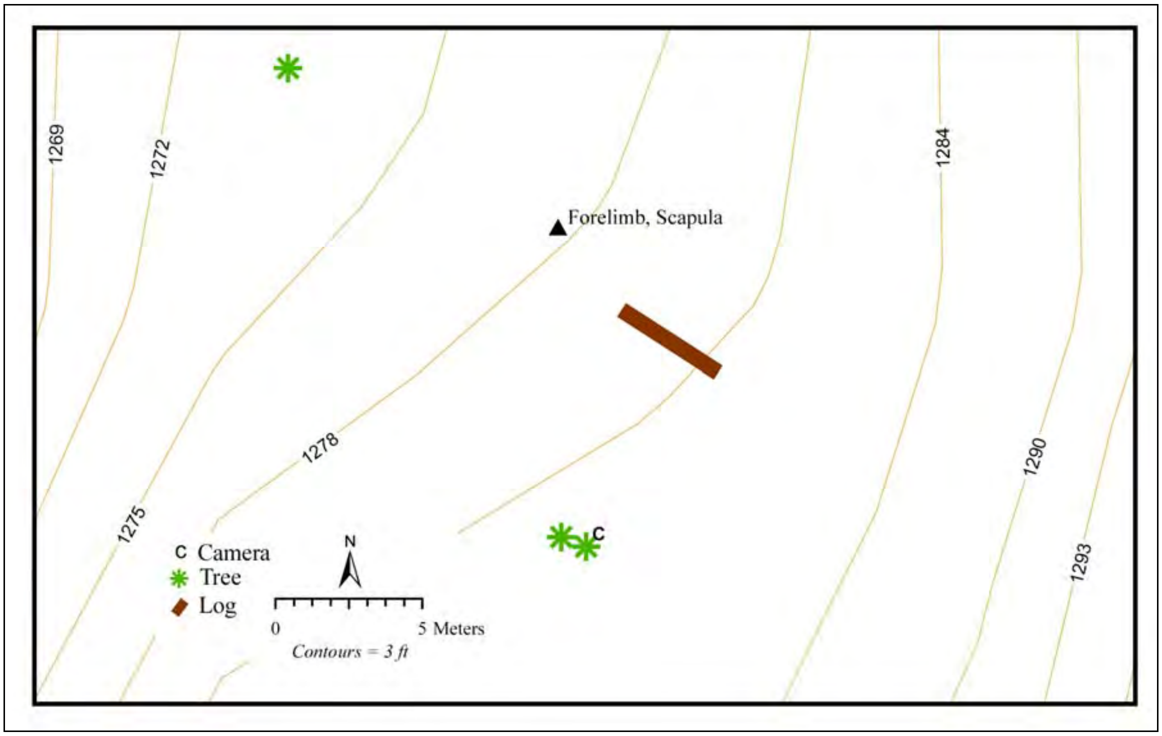

Figure 48. *Site #3 (day #4) map showing the location of the right forelimb.*

Summary

Animal scavenging activity was limited to bears and birds. The bears were the primary scavengers, arriving first to the carcass and consuming the majority of the tissue. The bears were also responsible for the majority of the skeletal damage. Carcasses were consumed in a specific order: skin, followed by the head, shoulder, haunch, stomach tissue, organs. The consumption sequence seems to follow from areas richest in fat to areas with the smaller amounts of fat. The differential fragmentation observed between carcasses is likely the result of the number of bears involved. Carcass #1 was the most fragmented, and five bears of varying ages and sizes were observed scavenging on the remains. Pigs #4 and #5 were the least fragmented, and a single bear was documented scavenging each.

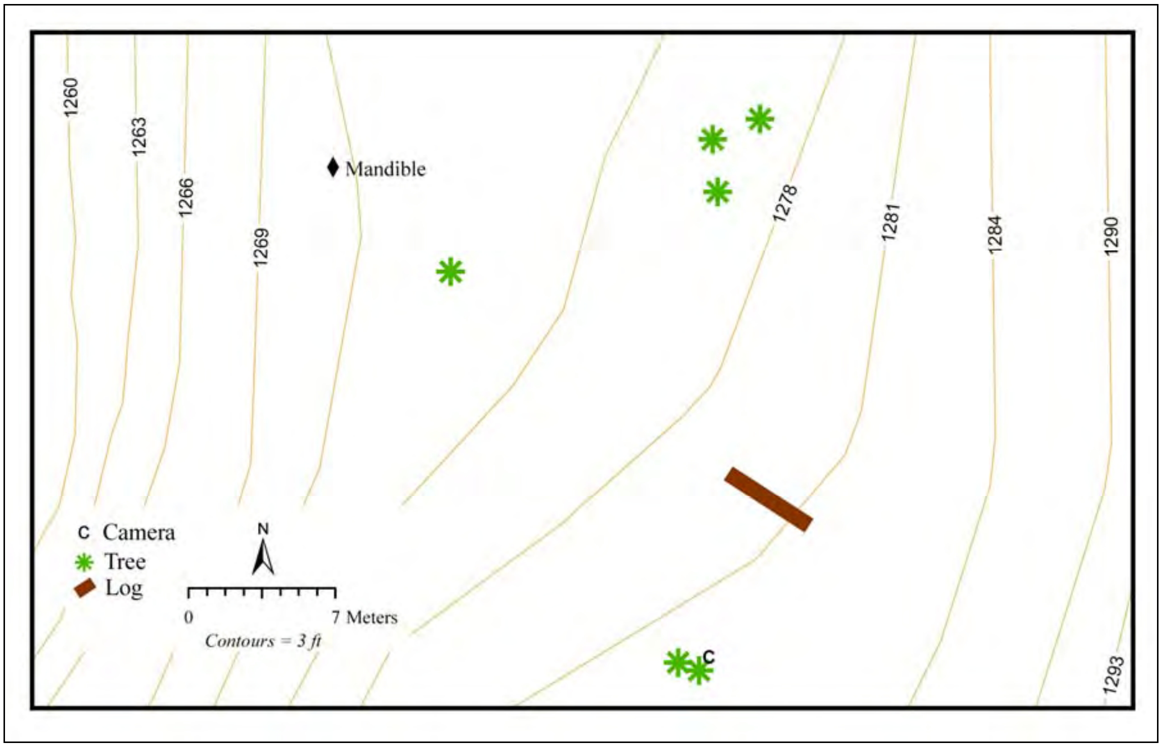

Figure 49. *Site #3 (day #5) map showing the placement of the disarticulated mandible.*

A robust analysis of the inter-element and intra-element scavenging patterns is not possible due to the small sample size. However, several patterns have emerged. Similar to the human sample discussed in the previous chapter, long bone midshafts had a low scavenging intensity ranking. Carnivore tooth impact marks were most common on the long bones. Overall, elements that were recovered were intensively damaged. It is possible that elements that were not recovered were more heavily modified than those recovered. The size and maturity of the pigs must also be taken into consideration. The pigs were five months old, thus skeletally immature. Most of the bones had not fused yet, thus facilitating disarticulation and fragmentation. Pigs #1, #2, #3, and #4 were at the same development stage, but pig #5 was less developed. A majority of pig #5's skeleton had not fused yet, most notably the vertebrae and innominate. The small size of the

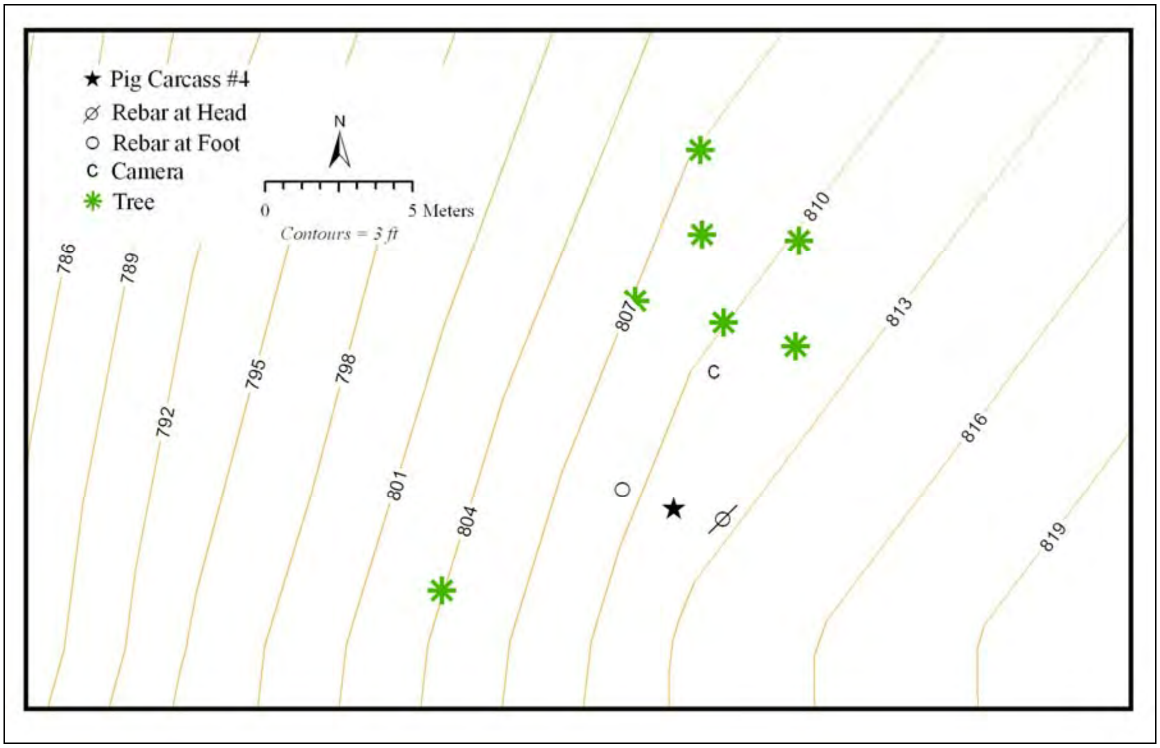

Figure 50. *Site #4 day #1 showing the original placement of the carcass and camera on November 1st , 2010.*

unfused immature bones would make total consumption and transportation of these elements highly likely. Only small fragments of vertebral bodies were recovered from pig #5.

Pits and punctures recorded from the pig skeletal elements all fell within, or below the range of small carnivores. In the measured carnivore sample, local black bears were classified as large carnivores. There are several possible explanations for the pig and puncture marks not classifying within the large carnivore range. The bears that consumed the carcasses ranged in size from a first year cub to a large adult male. The size of the teeth may vary, as well as the individual bite force potential of each animal. It is also possible that the carnassial molars caused the pit and puncture damage, not the

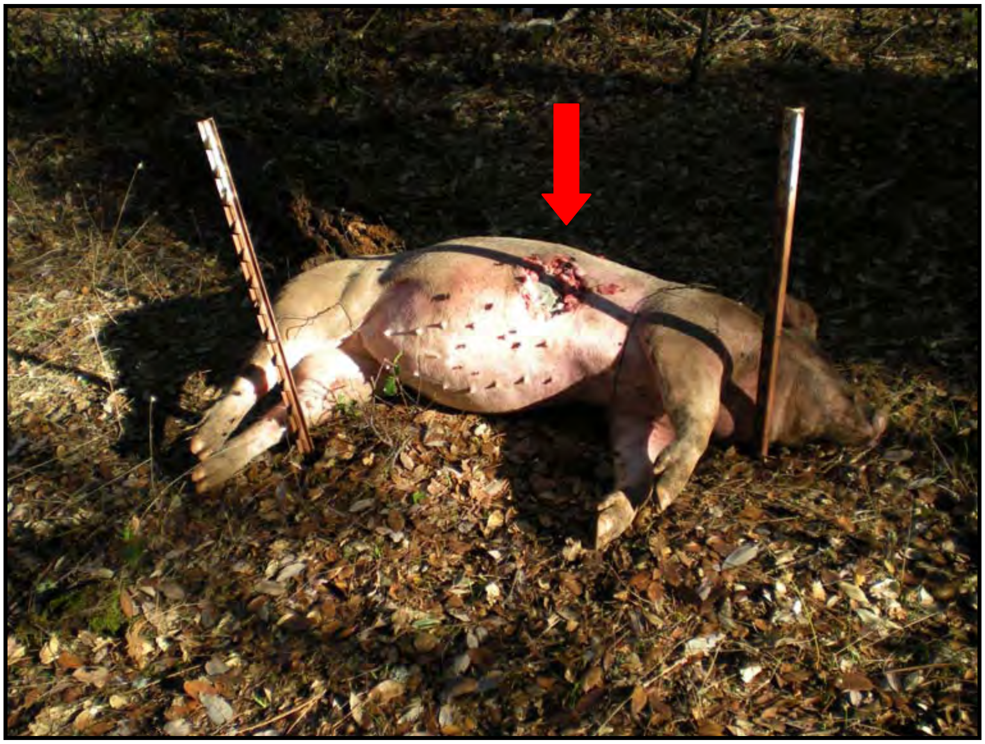

Figure 51. *Site #4 (day #2) Photograph showing damage to carcass #4's thorax (indicated by the red arrow).*

canines. This chapter presented results from the actualistic study. A comparison and discussion of this study and the CSUC-HIL forensic sample will be presented in the following chapter.

Figure 52. *Site #4 (day #2) Photograph showing the previous damage to the thorax and the head.*

Figure 53. *Site #4 (day #2) Photograph showing a close up of scavenging damage to the head.*

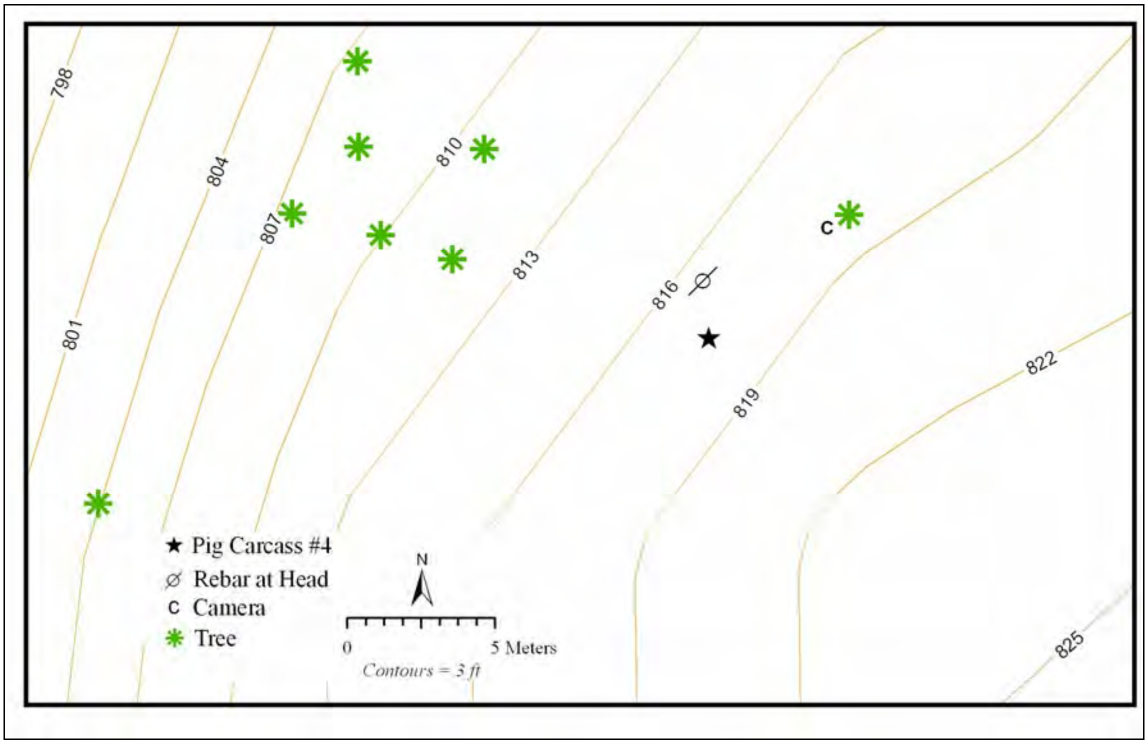

Figure 54. *Site #4 (day #2) map showing the relocation of the carcass.*

Figure 55. *Site #4 (day #3) Photograph showing disarticulation of the skull and damage along the thorax and hindquarters.*

Figure 56. *Site #4 (day #3) Photograph showing the disarticulated skull.*

Figure 57. *Site #4 (day #3) Photograph showing the disarticulated mandible.*

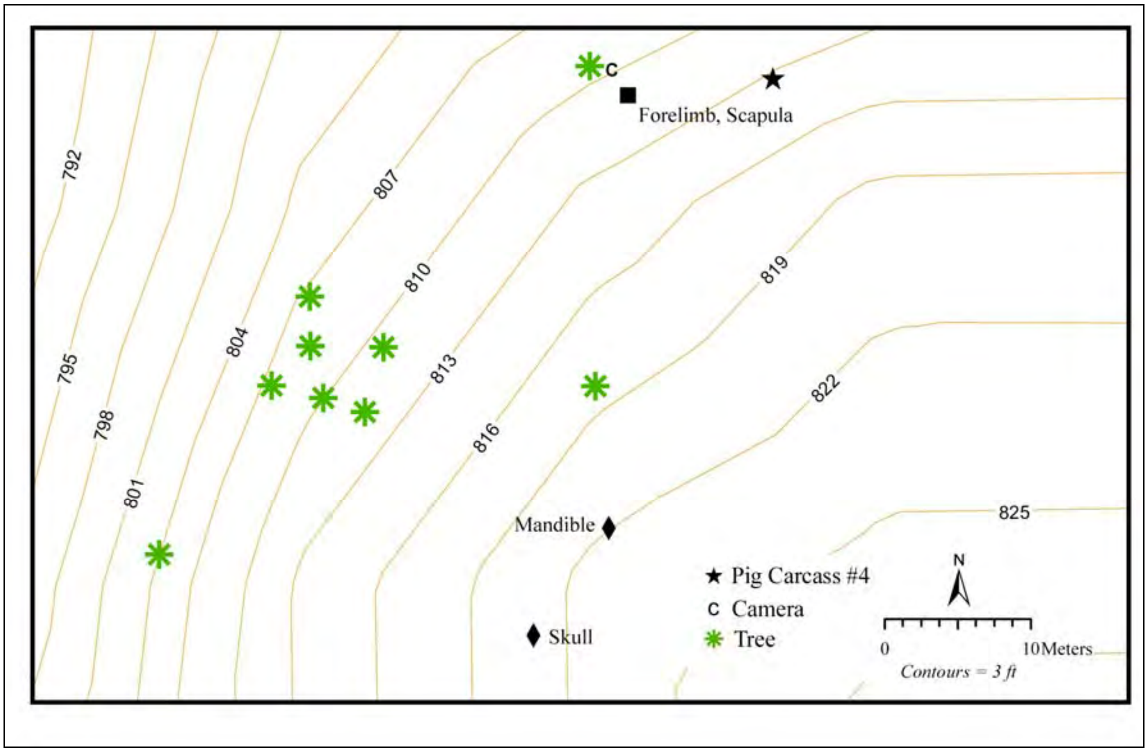

Figure 58. *Site #4 (day #3) map showing the scatter of the skull, mandible, and forelimb.*

Figure 59. *Site #4 (day #4) ravens and a turkey vulture (highlighted in the red box).*

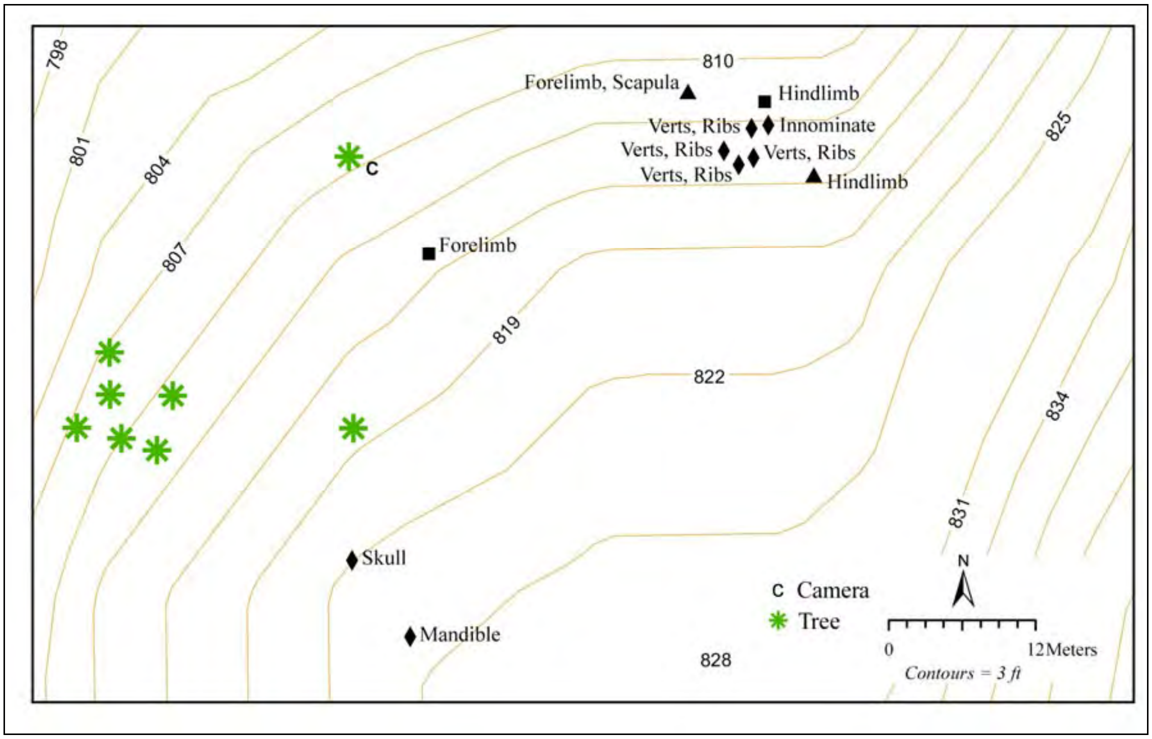

Figure 60. *Site #4 (day #4) map of the scatter of elements.*

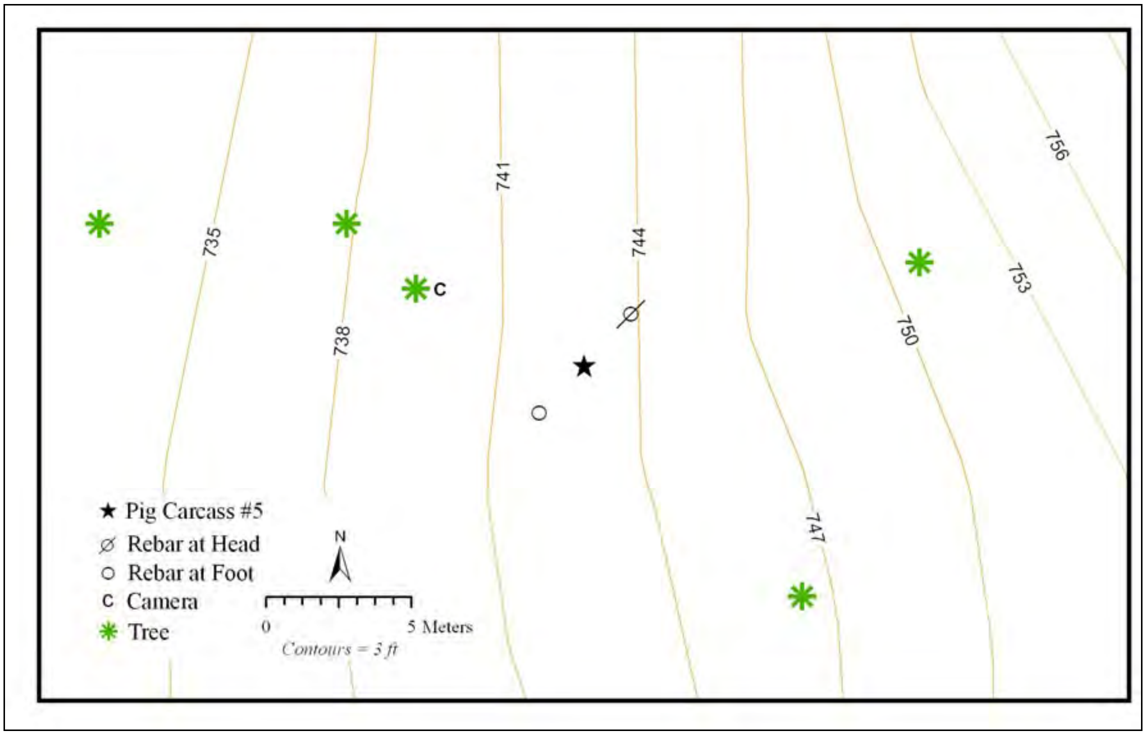

Figure 61. *Site #5 (day #1) map of the original location of the carcass on November 1st, 2010.*

Figure 62. *Site #5 (day #2) Photograph showing scavenging damage to the carcass. Note that the damage is concentrated to the head, shoulder, and thorax.*

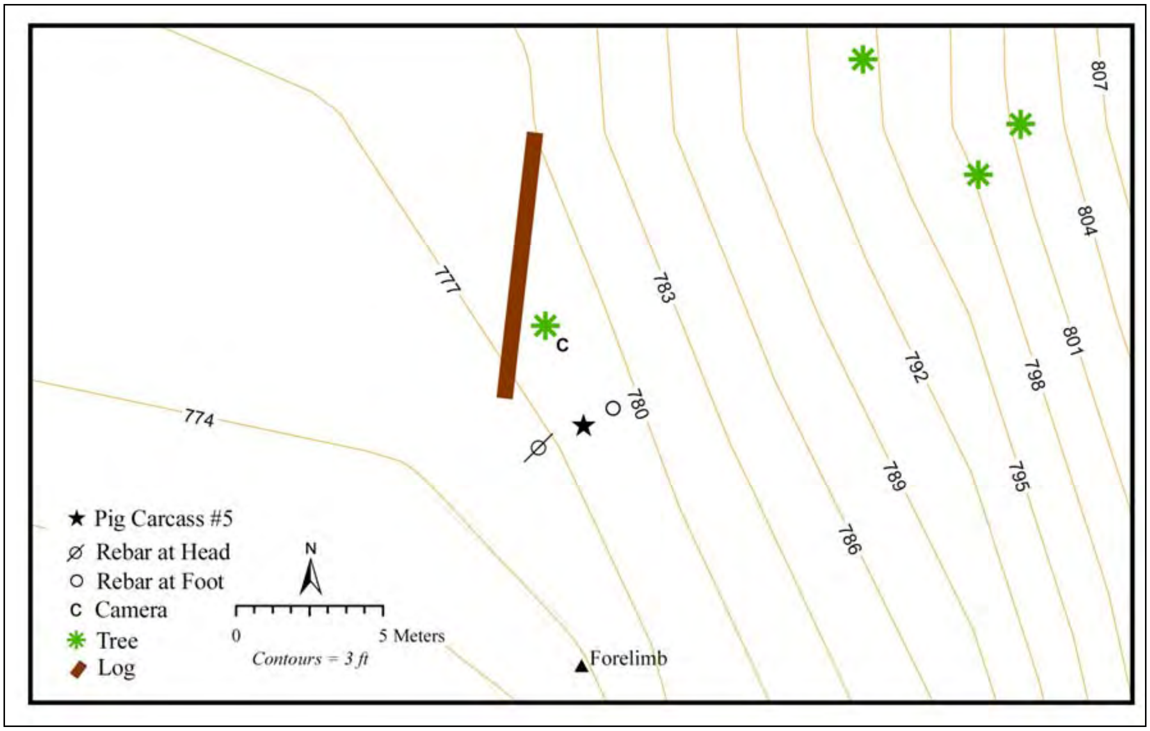

Figure 63. *Site #5 (day #2) map of the carcass location and forelimb scatter.*

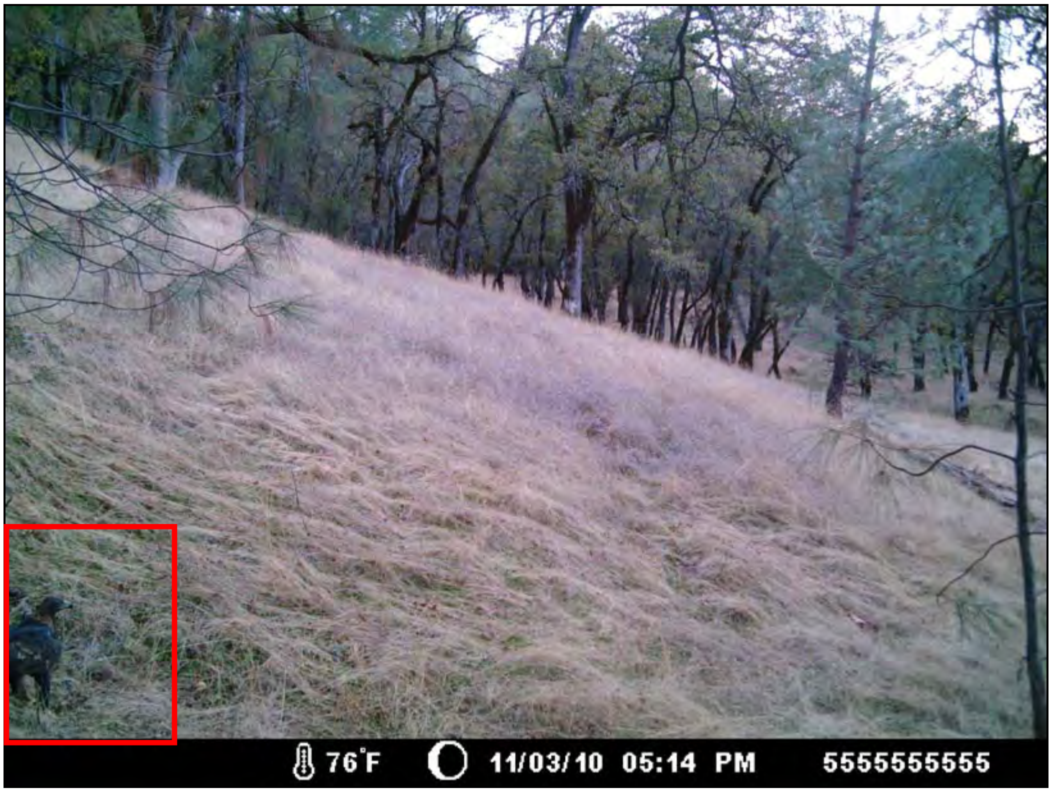

Figure 64. *Site #5 (day #3) golden eagle (highlighted in the red box).*

Figure 65. *Site #5 (day #3) Photograph showing damage to the shoulder and thorax. Note that most of the skin has been removed.*

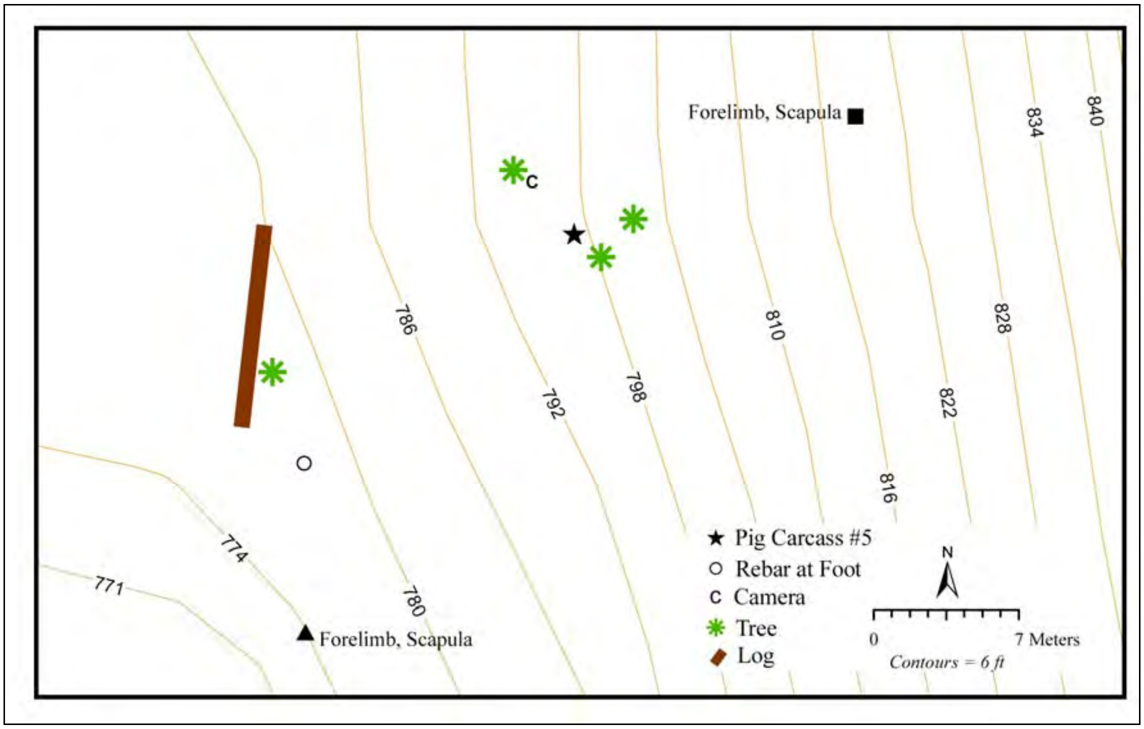

Figure 66. *Site #5 (day #3) map showing the scatter.*

Figure 67. *Site #5 (day #4) Photograph showing the carcass. The red arrow shows the location of the organs.*

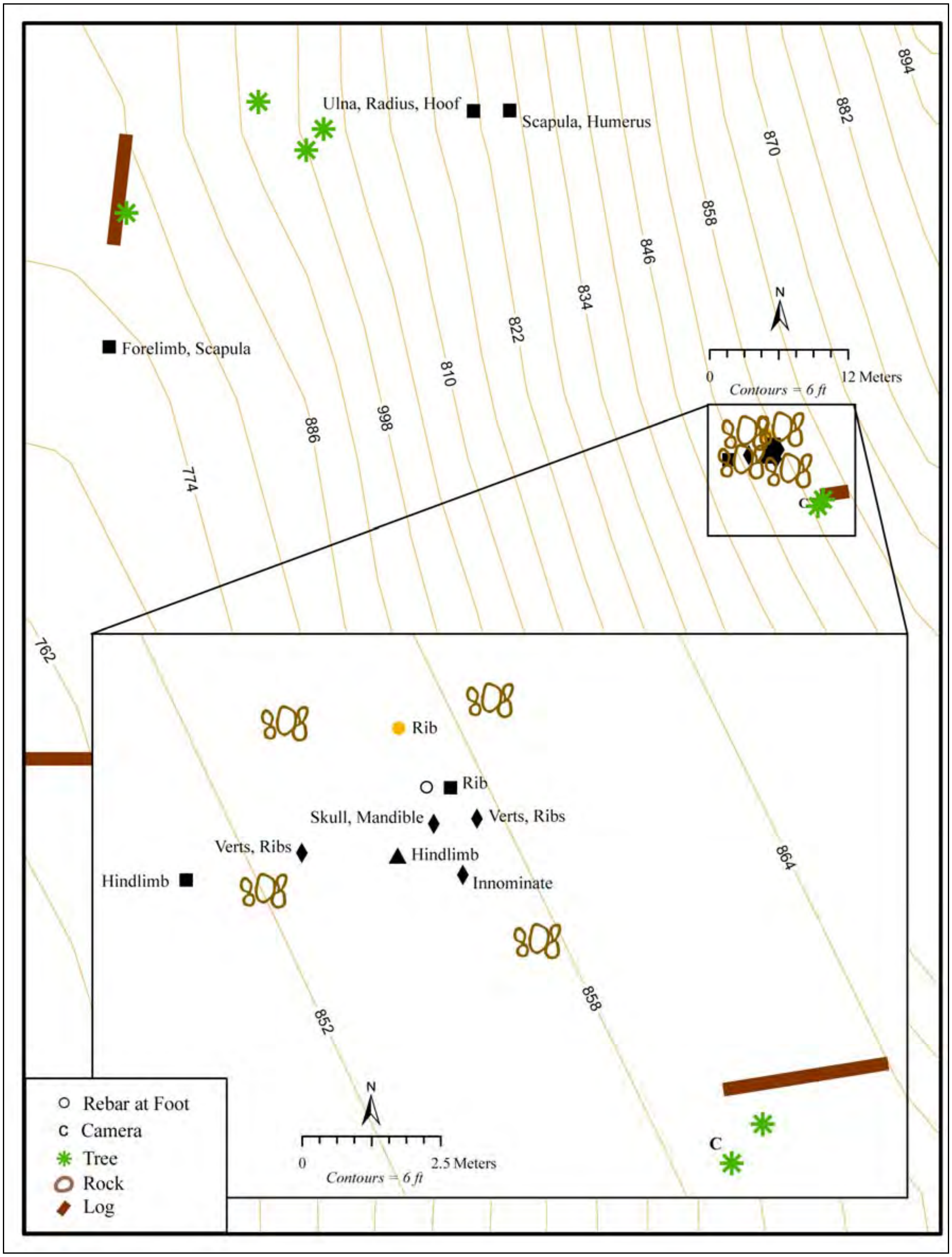

Figure 68. *Site #5 (day #4) map of the scatter. The insert shows the location of the scatter concentration.*

Figure 69. *Site #5 (day #5) Photograph showing the scatter concentration (arrows highlight the skull and left forelimb).*

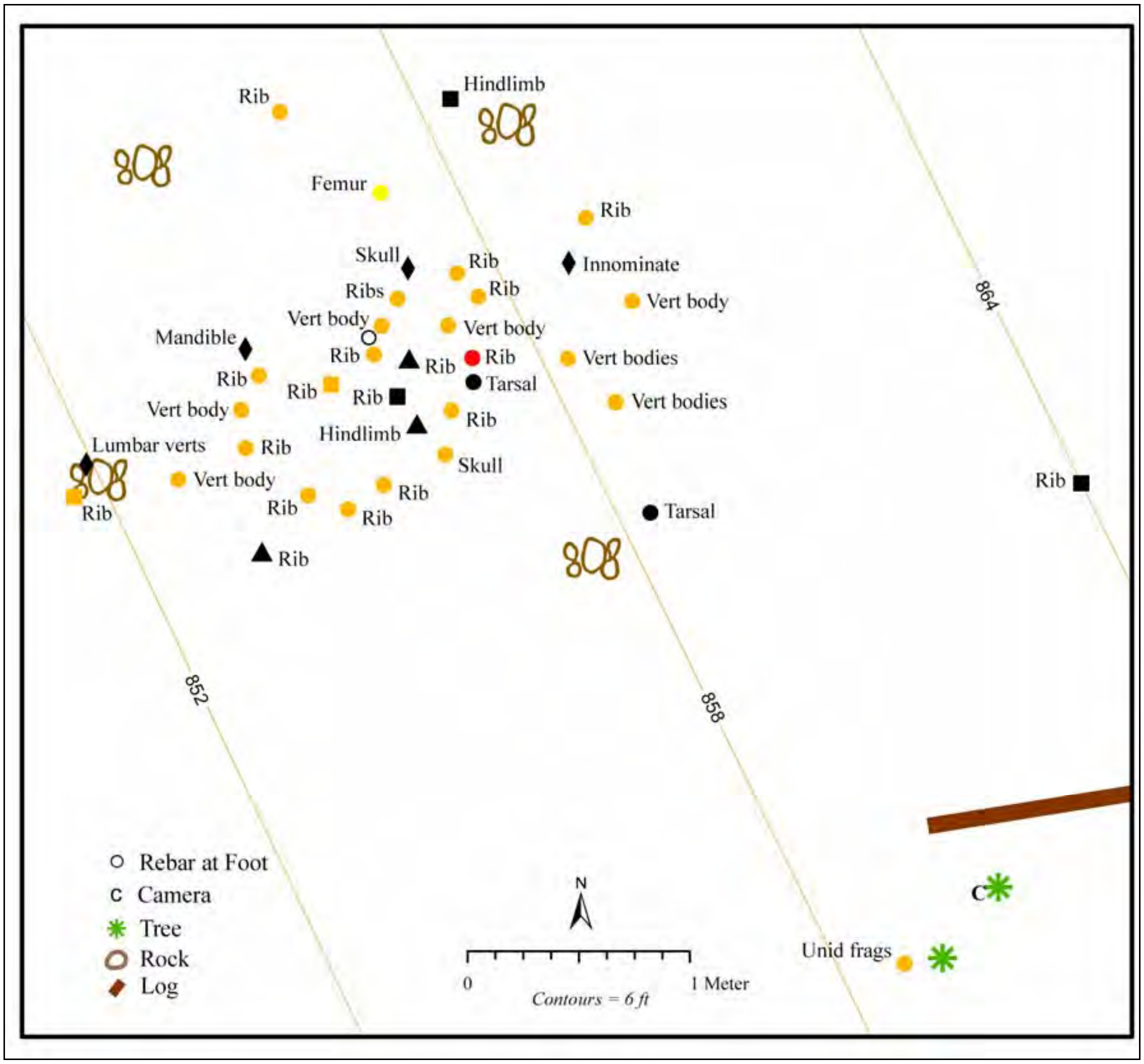

Figure 70. *Site #5 (Day #5) map of the element scatter.*

Table 18. *Element Representation and Scavenging*

Element	***N***	**% Represented**	**% Carnivore**	**% Rodent**	**% Total**
Femora	3	30.0	33.3	0.0	33.3
Tibiae	5	50.0	40.0	0.0	40.0
Fibulae	4	40.0	50.0	0.0	50.0
Humeri	6	60.0	66.7	0.0	66.7
Innominates	5	50.0	100	0.0	100
Back Hoof	4	40.0	0.0	0.0	0.0
Radii	5	50.0	60.0	0.0	60.0
Front Hoof	6	60.0	16.7	0.0	16.7
Ulnae	5	50.0	60.0	0.0	60.0
Ribs	6	60.0	100	0.0	100
Scapulae	5	50.0	60.0	0.0	60.0
Sacrum	1	10.0	0.0	0.0	0.0
Patellae	4	40.0	0.0	0.0	0.0
Crania	3	30.0	66.7	0.0	66.7
Mandibles	4	40.	75.0	0.0	75.0

Table 19. *Pig Scavenging Intensity by Element Portion*

Element	% Scavenged	*N*
Proximal Femur	80	1
Distal Femur	90	1
Proximal Tibia	60	2
Midshaft Tibia	40	2
Distal Tibia	50	2
Distal Fibula	35	2
Proximal Humerus	30	4
Midshaft Humerus	10	4
Distal Humerus	30	4
Proximal Radius	33	3
Midshaft Radius	66	3
Distal Radius	73	3
Ilium	32	5
Ischium	32	5
Pubis	28	5
Medial Scapula	26	3

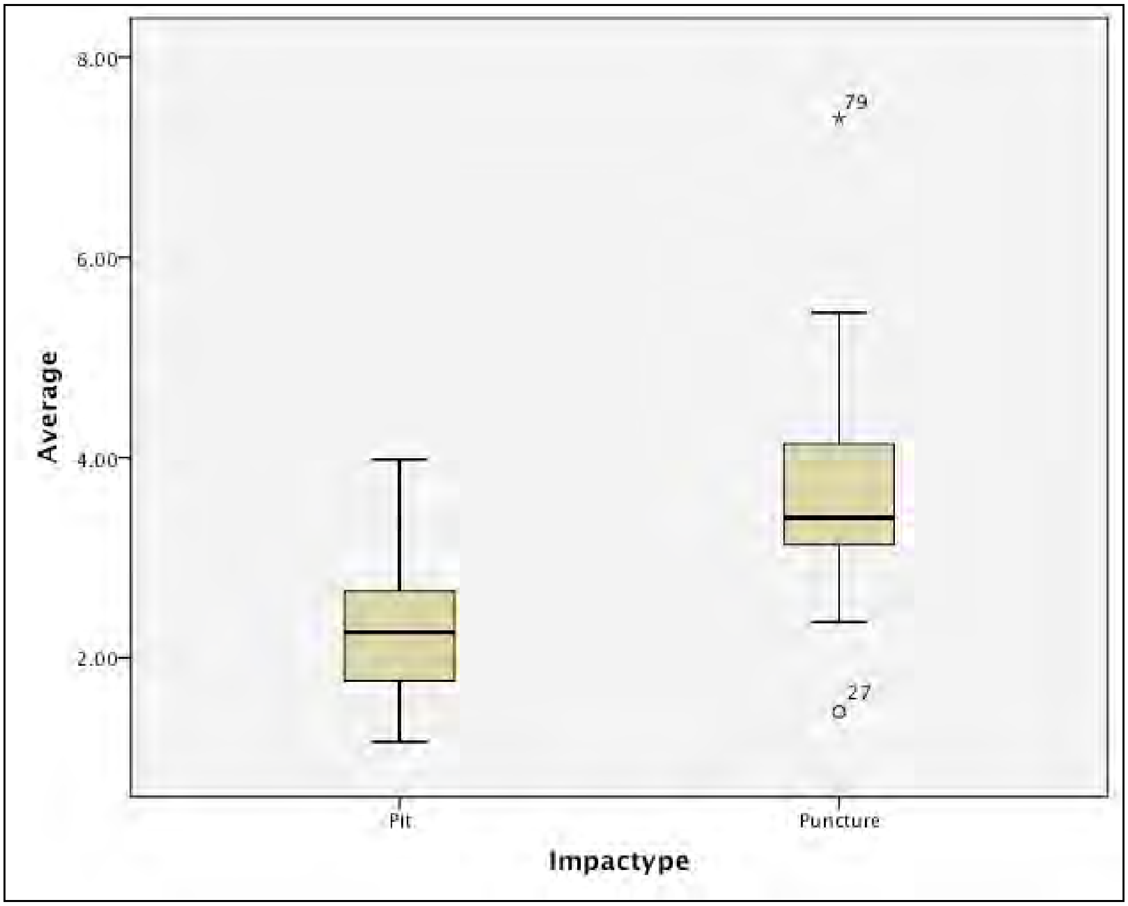

Figure 71. *Distribution of pits and punctures recorded in the pig sample.*

Table 20. *Pig Pit Descriptive Statistics*

Pig	*N*	Mean	Median	Minimum	Maximum	Range	Std. Deviation
1	65	2.20	2.21	1.16	3.98	2.82	.62
3	4	2.65	2.67	2.21	3.07	.86	.39
4	5	2.78	2.72	2.33	3.37	1.04	.44

Table 21. *Pig Puncture Descriptive Statistics*

Pig	*N*	Mean	Median	Minimum	Maximum	Range	Std. Deviation
1	6	3.02	3.22	1.46	3.81	2.35	.80
3	3	3.31	3.18	2.73	4.02	1.29	.65
4	15	3.99	3.5	2.36	7.39	5.03	1.27

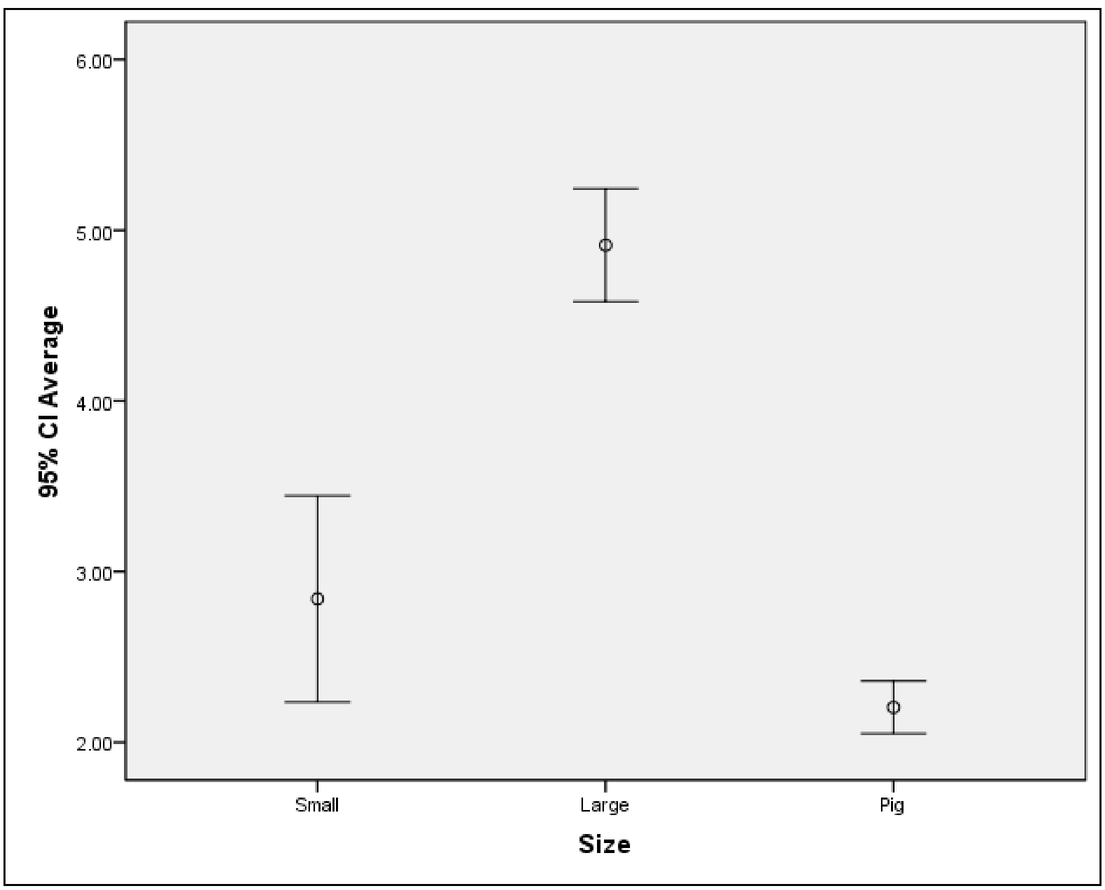

Figure 72. *Pig #1 pits versus the canine tip diameter of small and large carnivores.*

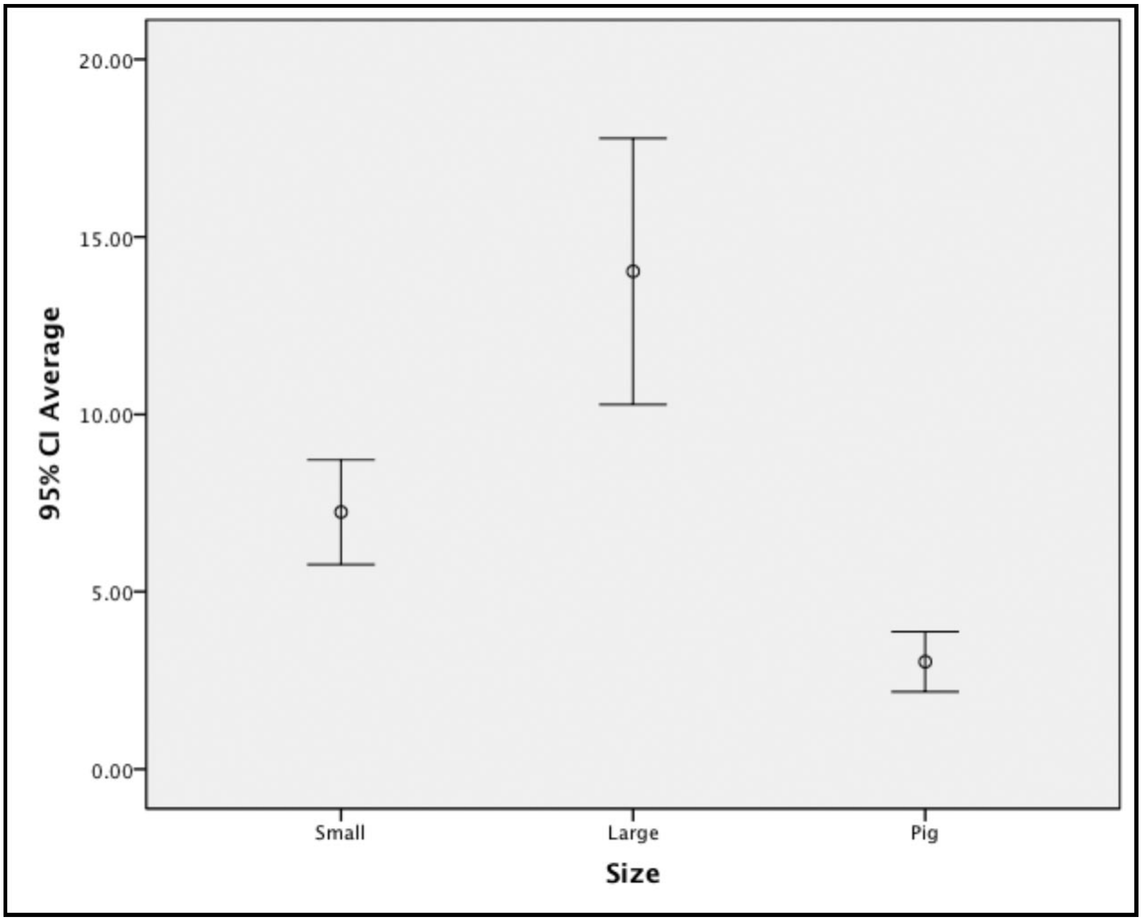

Figure 73. *Pig#1 puncture diameters versus the mesiodistal diameter of small and large carnivores.*

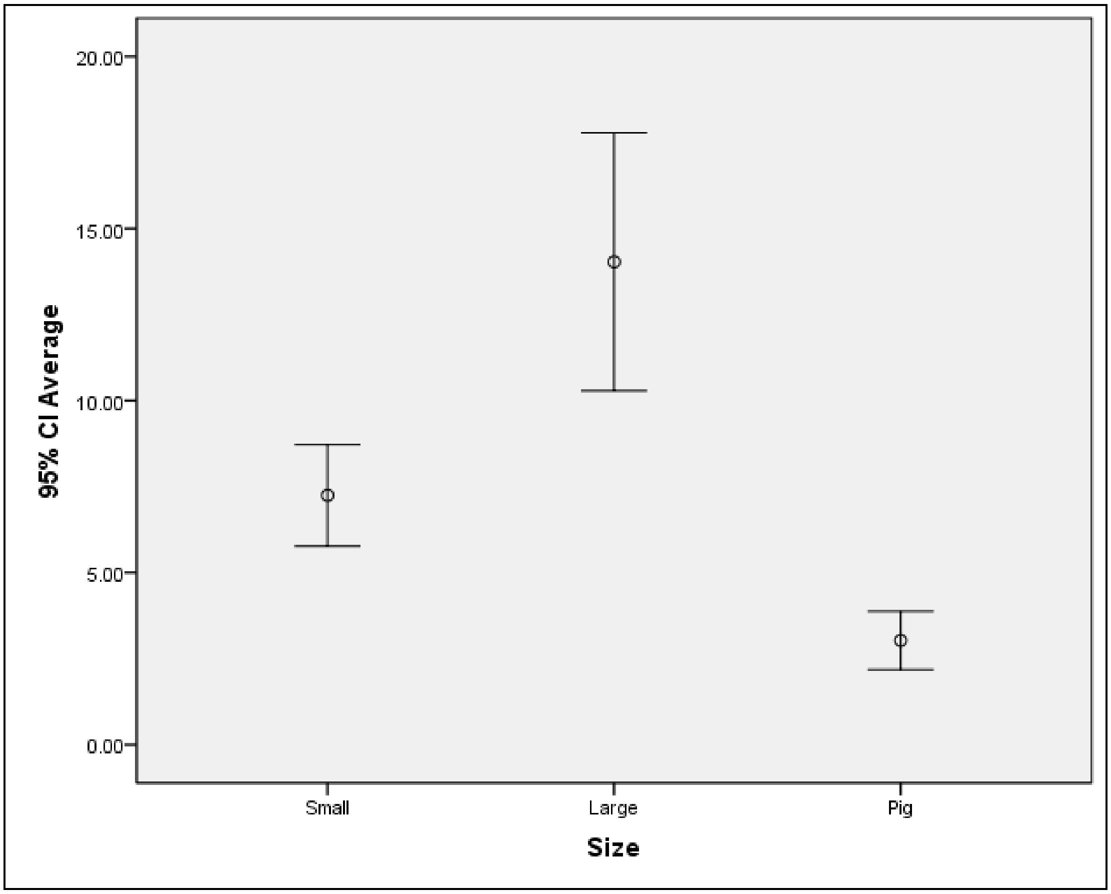

Figure 74. *Pig #3 pits versus the distal tip diameter of small and large carnivores.*

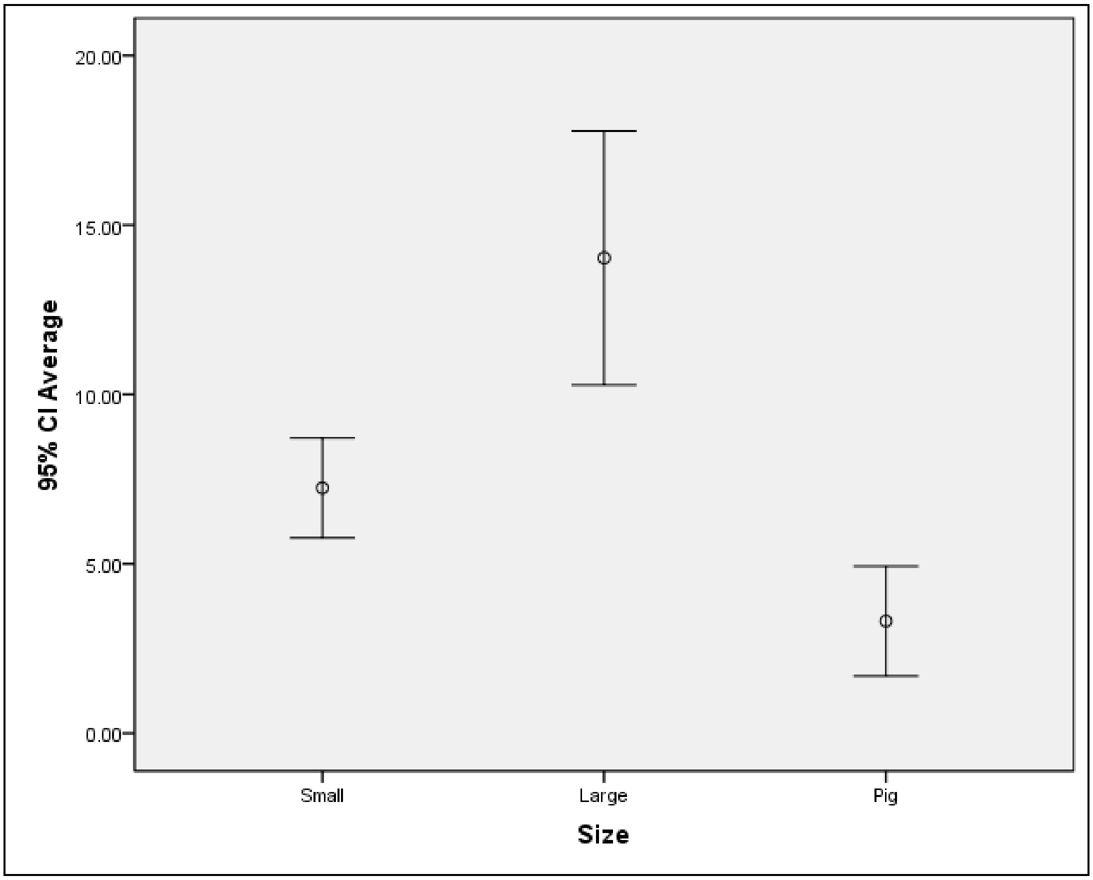

Figure 75. *Pig #3 punctures versus the mesiodistal diameter of small and large carnivores.*

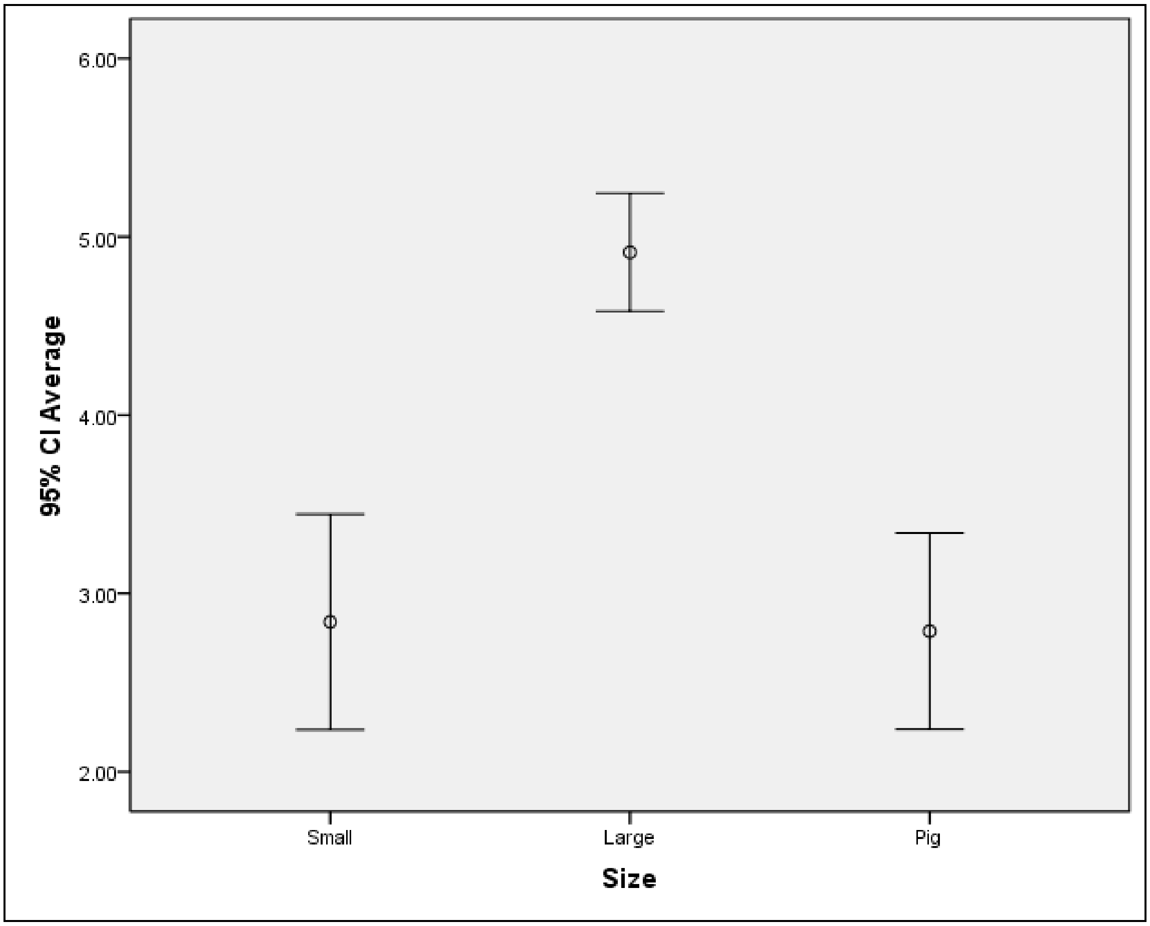

Figure 76. *Pig #4 pits versus the distal tip diameter of small and large carnivores.*

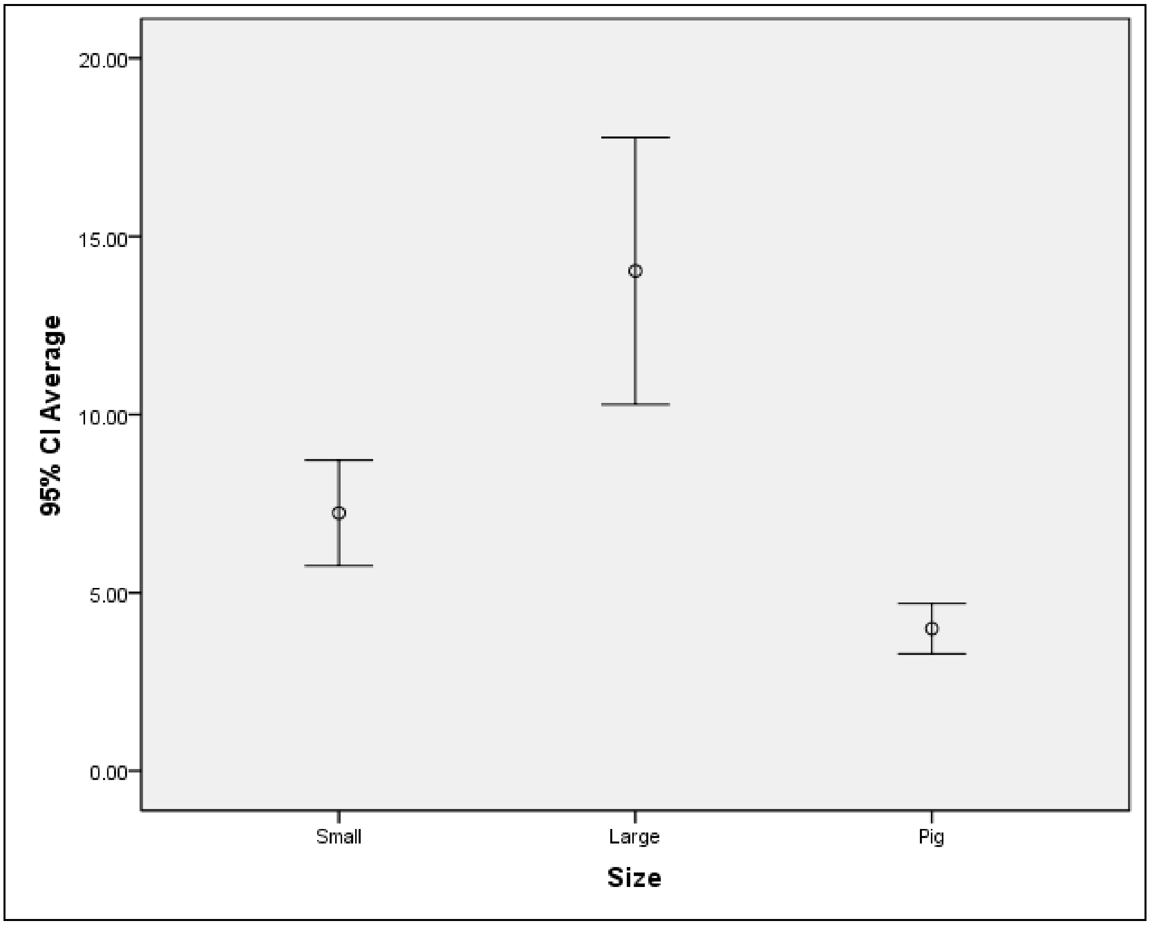

Figure 77. *Pig #4 puncture diameters versus the mesiodistal diameter of small and large carnivores.*

CHAPTER VI

DISCUSSION

This study provided a critical evaluation of Haglund's (1989, 1992) model regarding scavenging damage and disarticulation of human remains. Haglund's model was chosen because it is widely cited, but has not been evaluated for accuracy. This chapter discusses the results from both the CSUC-HIL forensic sample and actualistic experiments. Results indicate that pig carcasses are consumed in a specific order, and that there is a predictable inter-element and intra-element pattern of scavenging damage on the human forensic sample.

Carnivore Sequencing

It was hypothesized that carnivores utilize carrion in a specific order, with larger carnivores arriving and scavenging the carcass before smaller carnivores are given access. The results from the actualistic study suggest that larger carnivores arrive at the carcass before other smaller scavengers. Black bears (*Ursus americanus*) were the first animal at each site and produced most of the damage to the carcasses. No other large mammals were observed scavenging the carcasses, and birds were the only other documented scavengers.

Selva and Fortuna (2007) suggest that the structure of a scavenger community is highly nested. The use of carrion resources by facultative scavengers is a complex process mediated by environmental factors, facilitation processes, and behavioral adaptations (Selva et al. 2003, 2005, Selva and Fortuna 2007). This concept of nestedness as applied to scavengers makes the carcasses the ‘islands’ and the scavengers the ‘inhabiting species’. Scavenger nestedness is a non-random structural pattern and may describe the complex patterns of carcass use within diverse niches of scavengers (Selva and Fortuna 2007:1102). The black bear can be considered the highest trophic level in the food chain of the reserve. Their early presence at the carcasses, and intensive consumption, may have prevented other lower trophic level scavengers from accessing the carcass.

The seasonal distribution of migratory animals at the reserve must also be considered. Turkey vultures are one of the few animals that have developed specific adaptations that aid in carrion location and feeding (DeVault 2003), so their presence would be expected at the carcasses. However, only a single turkey vulture was documented visiting carcass #4. This may be explained by the migratory behavior of the turkey vulture. During the fall turkey vultures follow an inland path south through the California Central valley and western foothills of the Sierra Nevada (Goodrich and Smith 2008:83). Because the study took place in November it is possible that a majority of the turkey vultures had already migrated out of the area. The red-tailed hawk and golden eagle are also migratory birds, but travel shorter distances than the turkey vulture (Goodrich and Smith 2008). Common ravens were the most common bird recorded at the carcasses, which represent a species that does not migrate out of their home ranges (Roth et al. 2004).

One possible limitation of the study was the geographic location of the pig sites. Every site was located on the west side of the creek along the valley floor. The bears tend to stay within the valley floor, while other medium to large bodied scavengers such as the coyote (*Canis latrans*) and mountain lion (*Puma concolor*) tend to stay at higher elevations along the canyon ridge. It is possible that if different site locations had been chosen that the sequence of carnivore involvement may have been different. Further research into geographic variation in carnivore sequencing is necessary.

Another limitation is the time of year the study was conducted. Differences in temperature, precipitation, and seasonal behavior of the animals all may have affected the results of this study. It is possible that the order the animals arrived at the carcass may have been different in the winter, spring or summer. This is discussed in more detail later in this chapter.

Pig #2, unlike the other four pigs, was not consumed until the 22nd day and showed substantial maggot activity, bloating, and putrification. There are several possible explanations for the delayed activity at the site. The environmental setting at site #2 was more chaparral than the other sites, with a greater amount of canopy cover. It is possible that this prevented avian scavengers from locating the carcass. This site also recorded slightly cooler temperatures than the other locations. It is also possible that the lower temperatures kept the carcass cooler, resulting in less of a scent for scavengers to detect.

Site #2 was also located closer to a man-made structure than any of the other sites. A cabin used by researchers was located several hundred meters west of the site. However, BCCER staff reported that the cabin had not been used in several field seasons. It is possible prior human activity near the site deterred bears from frequenting this area.

Element Scavenging Sequence - Pigs

It was hypothesized that the sequence in which skeletal elements are scavenged would not follow the sequence proposed by Haglund (1989, 1992, 1997): ventral thorax, followed by the upper limb, lower limb, vertebral column, and finally the skull. Although the anatomy of a pig differs from that of a human, the morphology is similar enough that the sequence for humans was expected to be reproduced in the pig carcasses. The use of pigs in taphonomic experiments has been standard practice in forensic taphonomic studies (Adair and Kolz 1998; Anderson and VanLaerhoven 1996; France et al. 1992, 1997; Hewadikaram and Goff 1991; Kjorlien et al. 2009; Komar and Beattie 1998a, 1998b, 1998c; Komar 1999). Several studies suggest that the sequence of disarticulation of the forelimbs and hindlimbs of non-human mammals will be slightly different from humans (Haynes 1981, 1982; Hill 1979; Hill and Behrensmeyer 1984; Toots 1965). The results indicate that the pigs were not scavenged in the sequence proposed by Haglund. Generally the head was the first to be disarticulated and scavenged, followed by the forelimb, hindlimb, thorax, and vertebral column.

There are several differences between the present study and the research by Haglund: 1) the largest scavengers Haglund's sequence was applied to were canids; 2) his study took place in the Pacific northwest; and 3) it was comprised of forensic related human remains. Haglund's disarticulation and soft tissue consumption sequence is directed toward canid-scavenged remains, and suggests that the disarticulation takes place in a relatively consistent sequence. It is likely that bears and canids scavenge in different a manner, resulting in different disarticulation and consumption sequences. Black bears are much larger than canids, and have the greater potential to produce a greater amount of damage. The behavior of the two animals also differs greatly, and thus their methods of scavenging may also differ.

This study took place from November to December, a time when the black bear is preparing for hibernation, a process known as hyperphagia. Black bears demonstrate hyperphagia by increasing their daily caloric intake from 8,000 to 15-20,000 kcal (Nelson et al. 1983). The ingestion of food sources high in fat would be beneficial for several reasons; the calorific value of fat is higher then protein or carbohydrates by a ratio of 9:4 (Outram 2001), which would make fat rich tissue a more desirable food choice. The more fat a bear can consume before hibernation, the more beneficial it will be to their survival. Unlike other hibernating mammals, bears conserve protein tissues and depend more heavily on fatty tissue (Harlow et al. 2002). The bear's penchant for consuming fat rich foods in the fall may explain the order in which the pig carcasses were consumed.

Body fat is distributed in different anatomical locations as subcutaneous, perirenal, intermuscular or intramuscular fat. In swine subcutaneous fats account for 60-70 percent of total body fat, intermuscular for 20-30 percent, and perirenal for roughly 5 percent. In modern commercially produced pigs, total carcass fat is kept at approximately 20 percent. Fat distribution in pigs is the greatest subcutaneously, followed by intermuscular fat, and finally intramuscular fat. There is a greater amount of fat in the forequarter than then hindquarter (Kouba et al. 1999, Kouba and Sellier 2011, Monziols et al. 2005, Wood et al. 2004). The saturation degree of the fat deposits follows a negative gradient from the outside to the inside (Dean and Hilditch 1933, Monziolis et al. 2005). The pigs were consumed in order of the greatest amount to the least amount of fat.

The first portion consumed was the skin, and the last was the organs. The bears were concentrating on areas with the largest amounts of fat because they provided the greatest caloric returns.

A pilot study was conducted in October of 2009 using a deer carcass (adult female) in place of a pig. During this trial, multiple black bears were recorded scavenging the deer carcass over the course of two and a half days. However, the deer carcass was consumed in nearly the opposite order as the pig carcasses. Scavenging damage occurred first to the thorax and anal region. All of the internal organs were removed and consumed. The deer was completely skeletonized, disarticulated and scattered by the second day. All skeletal elements, with exception of both scapule and several ribs, were located. The majority of the skin was also located.

The stark difference in the consumption sequence of the deer versus the pigs highlights the importance of using analogs that are as close to humans as possible in forensic experiments. The difference in the consumption sequence may be due to the differences in body fat levels. As previously stated, commercially raised swine have a body fat level of approximately 20 percent (Kouba and Sellier 2011). This is very similar to the average American, with women having 22-25 percent body fat and men having 17-19 percent (MedlinePlus 2011). The mule deer has substantially lower body fat than farm-raised pigs. Total body fat of an adult female mule deer ranges from 3.7 percent in the spring to 10.8 percent in the fall (Torbit et al. 1988). Even in the fall when the mule deer’s fat deposits are at their largest, they still have half of the amount of fat a typical farm-raised pig or human has. It can be hypothesized that a human would likely be consumed in the same or very similar sequence to the pigs.

It is also possible that the geographic and thus environmental differences between the Pacific Northwest and northern California played a part in the differences seen between this study and Haglund's. Haglund's observations are based off of 85 forensic cases that were recovered between 1979 and 1990. A majority of the cases were from the King County area of Washington State. The climate of King County, Washington is characterized by mild temperatures (with average highs not reaching above 70° F) and a defined rainy season (Haglund 1992). The climate of northern California, and specifically the study area at the BCCER, is much more varied than conditions present in Haglund's study. Most of northern California experiences a cool, wet season and a warm, dry season that allows for a variety of different habitats and diverse fauna. Because Haglund's study area was so specific (limited mainly to a single county) it may only be applicable to that specific area, or similar areas.

Another factor to take into consideration is the use of pigs in this study. It is possible that Haglund's consumption and disarticulation sequence was not produced because the anatomy and size of the pigs used varied too greatly from the average adult human. The pigs were juveniles that weighed approximately 100 pounds. Both their size and developmental stage may have biased the scavenging patterns. Haglund's forensic sample comprised mainly adult females. The weight differences and lack of fusion in the pigs must also be considered. The immature nature of the pig's skeletal elements may have allowed for a greater degree of damage and easier transport away from the study area.

Carson et al. (2000) state that bear scavenging can be distinguished from canid scavenging based on the representation of skeletal elements at the scene. This conclusion is based on comparisons between Haglund's (1997b) data set and cases acquired in New Mexico. The authors state that bears are more likely to exploit the axial skeleton, specifically causing greater damage to the vertebrae, ribs, and sterna, whereas canids preferentially scavenge the appendicular skeleton and organ cavities. However, the results from this study, where bears were the only documented mammalian scavenger, do not support their conclusion.

The degree of fragmentation and exploitation of skeletal elements varied substantially from site to site. Pig #1 was highly fragmented, with intense consumption of both the axial and appendicular skeleton. Nearly all vertebrae and many ribs were recovered from pig #4, versus pig #5 where only fragmentary portions of vertebral bodies and ribs were recovered. This degree of variation shows that the presence or absence of specific elements is not reliable for differentiating between canid and bear scavenging.

Another possible limitation of the study is the recovery of the pig skeletal elements. Though the best effort possible was made to locate all elements, it is likely that some were missed. Recovery efforts were limited by several factors. Searching could only occur within the physical boundaries of the reserve as it is boarded in many locations by private property. The physical terrain of the reserve also restricted search areas, as the safety of the researchers was a priority. Conducting the study in the fall may have also obscured elements as the deciduous trees were losing large amounts of leaves, specifically at site #3. Surface scrapes were conducted in an effort to remove the duff from the immediate surrounding areas, but it was not possible to remove the leaves from the entire surrounding area. All of these factors may have served to bias the skeletal elements that were recovered.

CSUC-HIL Forensic Sample

To examine overall trends in scavenging damage the data collected from the forensic sample was compared with the sequence proposed by Haglund (1989, 1992) and with data collected from the experimental portion of this study. The overall patterns within the forensic sample do not correspond with the sequence proposed by Haglund; however, Haglund's sequence does not deal with inter-element and intra-element sequences in detail.

It should be noted that there were some limitations due to the nature of the CSUC-HIL sample. Recovery of remains was primarily conducted by law enforcement, thus the representation of elements may be more informative of the recognizability and size of skeletal elements than element survivorship. Many law enforcement officials have little to no osteological or archaeological training which may have biased the represented elements.

According to Haglund's sequence, the elements that were disarticulated earlier should show the most amount of damage. Haglund (1989, 1991) states that in the initial stages of scavenging the ventral thorax and removal of one or both upper extremities including the scapulae and clavicles occurs. Therefore high rates of damage to the associated skeletal elements should be seen. Ribs are present in 19 cases (35.5 percent with carnivore damage), sterna in 12 (8.4 percent with carnivore damage), scapulae in 19 (29 percent with carnivore damage), and clavicles in 18 (2 percent with carnivore damage); according to Haglund's sequence, these elements should show the greatest amount of damage, but those in the forensic sample do not.

The elements with the greatest amount of damage seen in the CSUC-HIL collection are the innominate, ulna, tibia, humerus, radius, and fibula (see Table 2). One pattern that became evident was that proximal segments of long bones were more intensively scavenged than distal segments. The proximal ulna, tibia, humerus, and radius all ranked higher than their distal segments (see Figure 4). This pattern is best understood when the context of the joint anatomy and skeletal articulations are considered. I have proposed that animals scavenge areas of a carcass in order of the potential energetic return. Fat rich areas provide a higher caloric, and thus energetic, return than protein or carbohydrate rich areas. Thus, areas that are richer in fat should have a higher degree of scavenging intensity than areas lower in fat.

The proximal humerus articulates into the glenoid fossa, a relatively shallow fossa. The head of the humerus is easily disarticulated from the scapula, making it susceptible to scavenging damage; the arm, including the scapula, is easily disarticulated from the rest of the body. Fat is also more abundant on the upper arm than on the forearm; specifically the armpit and the medial surface of the brachialis muscle are surrounded with a substantial amount of fat (Goldfinger 1991). The high degree of scavenging on the proximal ulna and radius is understandable when their articulation with the distal humerus is considered. When articulated, the proximal ulna and radius essentially cover the distal portion of the humerus. Scavenging of the elbow joint would likely damage the ulna and radius before the humerus.

The portion of the skeleton with the highest intensity of scavenging is the pubis (54.5 percent) and ischium (43.3 percent), which may be due to the overlaying tissue and fat, rather than its specific morphology. The muscles overlaying the innominate are large and fatty, making them preferential tissue choices. The mons pubis, a triangular fat pad, sits directly anterior to the pubic symphysis. This fat pad creates a fatty bridge between the thighs and continues into the fat near the femoral head (Goldfinger 1991). Scavengers attempting to consume this fat pad would likely damage the pubis and ischium. The buttocks are also heavily muscled with ample fat stores. The posterior gluteal fat pad develops on the inferior border of the gluteus maximus and extends inferiorly onto the back of the thigh. The upper edge of the fat pad is clearly defined at the edge of the sacrum; however it does not go over the posterior superior iliac spine. Rather, it passes around the side of the buttock and terminates near the greater trochanter of the femur (Goldfinger 1991). Scavengers attempting to consume this fat would likely damage the sacrum and ischium.

In a fashion similar to the humerus, the tibia is easily disarticulated from the femur. The morphology of the proximal tibia may also predispose it to larger amounts of scavenging damage. The proximal tibia, compared to the distal femur, is a relatively flat surface that may allow tooth impact marks more readily. The adjacent proximal fibulas would be expected to show similar damage.

Fat is more abundant on the thigh than the lower leg, and is distributed as an outer, inner, and anterior thigh fat pad. The outer thigh fat pad sits on top of the vastus lateralis, slightly inferior to the greater trochanter. This fat pad meets the posterior gluteal fat pad at the back of the thigh. The inner thigh fat pad tapers inferiorly and extends to the inner knee where it meets the vastus medialis. There is an absence of fat on the front of the thigh. The lower anterior thigh fat pad is located on the distal end of the thigh, just superior to the patella (Goldfinger 1991). The femur is minimally scavenged even though ample fat is present. However, the thigh also has some of the highest density of muscle in the body, thus the femur may not be as readily exposed to direct scavenging. The proximal portion of the femur is also protected by its articulation with the innominate.

The infrapatellar fat pad is located inferior to the patella and patellar ligament. On the back of the knee the popliteal fat pad is situated between the inferior portions of the hamstrings and the superior end of the heads of the gastrocnemius (Goldfinger 1991). Scavengers attempting to access this fat would damage the proximal portion of the tibia and the patella. The patella was represented in 28.6 percent of cases, with only 12 patellae recovered. Areas of high scavenging intensity can be understood within the context of their functional morphology, articulations, and overlaying fat and muscle tissue.

Tooth Impact Marks

Based on current scavenging studies, it has been suggested that it is possible to determine species-specific scavenging based upon canine tooth impact marks on bone. It was hypothesized that the tooth impact marks can be successfully used to determine which specific species produced the damage to the bone. However, a species-specific determination could not be made, rather only a potential determination of small versus large sized carnivore.

In the CSUC-HIL sample there was a high degree of overlap in pit and puncture diameters; however there was a statistically significant difference ($p<.001$) between the two. Similar to Delaney-Rivera et al. (2009), cancellous rich elements, such as the innominate and sacrum, showed greater variability in tooth impact mark dimensions. It is possible that the results are slightly biased as location of the impact mark was not a variable taken into consideration. Delaney-Rivera et al. (2009) cautions that elements should be stratified by region as scavengers of different size classes can produce similar tooth impact mark sizes depending on the region. The authors argue that tooth impact marks on the epiphysis, followed by the metaphysis, provide the strongest correlation between body mass and tooth pit dimension, with the diaphysis showing the weakest correlation (2009:1600). Most of the recorded tooth impact marks in the CSUC-HIL sample occurred on the epiphysis and diaphysis, but since this was not considered in the statistical analysis, future research should separate tooth impact marks by location.

All pit and puncture outliers fell above the 95 percent confidence interval ranges. It is possible that multiple animals of both size classes scavenged a single set of remains, resulting in the wide range of diameters. Nearly all of the pits and punctures classified in the small animal range (see Figures 8 and 9). It was not possible to attribute pits or punctures to a specific scavenger species. Rather the range of pits and punctures fell within the small or large carnivore size classes previously established. Even when cases were examined individually, the pits and punctures only fell within the small carnivore size range. It is possible that only small sized carnivores scavenged the forensic sample, but it is also possible that the tooth impact mark sizes are not a good predictor of animal class size due to the degree of overlap.

In the pig sample, tooth impact marks were present only on pigs one, three, and four. In all three pigs, the pits and punctures classified at or below the small carnivore size ranges. However, aside from birds, only large carnivores (black bears) were documented scavenging the carcass. There are several possible explanations for the misclassification of the tooth impact marks. First, it is possible that tooth impact diameter is not a valid means of accessing carnivore size class. Second, the age and size of the bears scavenging the pigs varied substantially. The bears ranged from first and second year cubs, to adult females and males. Though the adult permanent teeth have fully erupted age one (Marks and Erickson 1966) a range of tooth sizes is still probable. Third, Haynes (1983) suggests that most bears do not gnaw heavily on bones after the soft tissue has been removed. Rather, bears tend to grind and crush bone, rather than gnaw on it. The tooth impact mark sample size was also small, which may have biased the results.

Element Scatter Pattern

It has been suggested that scavenging activity produces predictable patterns in surface skeletal remain scatters. The question was posted regarding the specific distribution pattern of the elements after disarticulation and scavenging activity and it's relationship to the order in which they were scavenged. Kjorlien et al. (2009) argue that the non-random pattern that scavenging produces is directionally away from human activity. Haglund (1997c) and Kjorlien et al. (2009) state that ribs and vertebrae are more likely to remain near the original placement site.

The first things to be disarticulated were the forelimbs and skull. With pigs #3, #4, and #5, the forelimbs were disarticulated and transported away from the carcass at the very early stages of scavenging. Anatomically, this is to be expected as the scapula is easily removed from the tissue that connects it to the thorax, thus allowing the forelimb to be removed as a single unit. The skull was also disarticulated in the early stages of scavenging at pigs #3 and #4. The skull was transported away from the carcass. However, the degree of scavenging varied substantially from pig to pig, and the elements that were disarticulated from the pig earlier did not necessarily show a greater degree of scavenging.

Ribs and vertebrae were never located at the original placement site. In all cases the entire carcass was moved from the original placement site before intensive scavenging occurred. This difference may be due to the different scavengers that were documented in this study as compared to Haglund (1997c) and Kjorlien et al. (2009). The authors documented nothing larger than a canid, whereas this study had ample black bears. It is possible that the smaller scavengers would not have the ability to move the complete carcass the distances that were observed in this study. The overall trend was for the carcasses to be moved uphill and deposited as the base of trees.

Summation of Hypotheses and Test Implications

Research Hypothesis

The second hypothesis related to the specific sequence in which different skeletal elements are scavenged. The current prevailing scavenging sequence is that proposed by Haglund (1989, 1991), which states that scavengers first target the thorax, followed by the upper limb, lower limb, vertebral column, and finally the skull. Haglund’s scavenging sequence was tested using the five pig carcasses. The results indicate that this disarticulation sequence does not hold for northern California. The anatomical regions of the pigs were scavenged in the order of the highest amount of fat to the lowest. Skeletally, damage occurred first to the upper limbs, followed by the skull, thorax, lower limb, and finally the vertebral column. However, it is possible that the differences between Haglund's sequence and the actualistic experiment could be due to differences in the morphology of pigs and humans.

Test Implication One

Carnivore accessibility to carrion differs among scavenger species, thus it can be expected that larger carnivores, such as bears, will scavenge a carcass before smaller carnivores, such as canids. This hypothesis was supported. Bears were the first scavenger to access the carcasses, followed by birds. The lack of other mammalian scavengers may be due to the intensive involvement of bears, who were the first to access the carcasses.

Test Implication Two

Data collected from the CSUC-HIL forensic sample was not expected to follow the sequence proposed by Haglund (1989, 1991), but instead was expected to coincide with the data collected from the actualistic experiments. This hypothesis was supported. According to Haglund, skeletal elements such as the clavicle should show higher rates of damage because they are scavenged first. These damage patterns were not seen in the CSUC-HIL forensic sample.

Test Implication Three

It has been suggested that there is a relationship between tooth impact marks and the determination of carnivore body size. The diameter of pits and punctures has been correlated with scavenger body size, and in some instances a specific species. It can be expected that the tooth impact diameter can be used to estimate the size class of a species based upon tooth size of the animal. This hypothesis was not supported. When viewed case by case in both the forensic and pig samples, all tooth impact marks classified as small carnivores. However, in the pig sample tooth impact marks were only produced by bears, which were classified as large carnivores.

Summary

This chapter discussed results obtained from the CSUC-HIL forensic sample and the actualistic experiment. Both portions indicate that Haglund's carcass consumption and disarticulation model does not apply to forensic cases within northern California. The pig carcasses were consumed in order of highest amount of fat, and it is likely that the inter-element and intra-element patterns of damage in the CSUC-HIL forensic collection are also related to body fat distribution and anatomical morphology. Species level identification based on tooth impact marks was not obtainable. The general pattern of skeletal element surface scatters was for the head and forelimbs to be removed first and the rest of the carcass to move uphill and near trees. The following chapter will summarize this thesis.

CHAPTER VII

CONCLUSIONS

The aim of this thesis was to test Haglund’s models regarding scavenging damage and disarticulation sequences for northern California. This research examined the role of animal scavenging and its relationship to intra-element scavenging damage patterns in northern California forensic anthropology cases. This chapter summarizes the findings of this research and discusses future research possibilities.

Scavenging Patterns

Both the CSUC-HIL forensic and actualistic experimental portions of this thesis produced valuable data concerning animal scavenging patterns of human remains. The patterns observed in both samples are predictive of scavenger behavior. The results seen can be best understood when the remains are viewed as a food source and animal feeding behavior and consumption patterns are considered. Research into regional variation of scavenger behavior and motivation is crucial to understanding scavenging damage as it relates to forensic taphonomy.

The scavenging damage documented in the CSUC-HIL forensic sample and the pig carcasses can be understood with respect to skeletal anatomy and the overlaying soft tissue, specifically fat deposits. Fat consumption is a driving motivation for animal scavenging behavior. It represents a great potential source of energy, and seems to be preferentially consumed over non-fatty tissues. The tooth impact mark portion of this thesis produced unexpected results, with nearly all pits and punctures classifying as small carnivores. This indicates that further research, and methodological revision (e.g. using fleshed complete remains and natural settings) are needed to build better predictive models for scavenging of human remains.

Haglund's scavenging disarticulation sequence model was not supported for northern California. Instead, the CSUC-HIL forensic sample and the actualistic experiment showed a different pattern and sequence of involvement.

Future Research

The inter-element and intra-element and actualistic portion of this study are the first to be conducted in northern California. Scavenging research would benefit from similar studies in other regions of California, the United States, and elsewhere. It is necessary to see if scavenger sequencing is patterned regionally or if there are over-arching patterns that bridge regional environments. There are many variations of this study that could be performed. Increasing sample size would provide more robust statistical models. Another research variation would be to clothe the pigs. It is possible that an increased human scent and the physical barrier of the clothing itself could alter scavenger behavior. Placing pigs at different locations within the BCCER may also provide valuable data regarding micro-environmental differences. Carcasses placed on the west side of the creek and at high elevations along the ridge would aid in the study of scavenger succession in different locations. Repeating this experiment at different times of the year to test seasonal changes in animal behavior would also produce a wealth of important data.

The tooth impact mark portion of this research requires further validation. Future research related to tooth impact marks on human skeletal remains should focus on acquiring a larger sample size, and employing multiple methods for impact mark data collection. It is recommended that in future studies the specific anatomical placement of impact marks be considered. There may also be limitations with using pit and puncture diameter as the sole means of determining scavenger size. Pits and punctures may be produced by any point along a tooth's circumference and are most likely not limited to the canine.

Animal scavenging represents one of the greatest contributions to the postmortem alteration of human remains. Understanding the patterns behind it is crucial for analyzing the individual post-depositional contexts forensic remains come from. By connecting animal behavior with the scavenging patterns on the remains, it may be possible in the future to increase skeletal element recovery rates and to develop better postmortem interval predictions. It is important for researchers to understand the role of scavenger behavior in forensic cases recovered from outdoor contexts. It is understandable that researchers lean towards highly controlled environments such as zoos to conduct scavenging research. However in order to produce an accurate understanding of scavenger activity it is necessary to conduct experiments in locations that are as close to the actual environment where forensic cases derive (e.g., remote forested areas). It is also important for future research to continue using complete animal carcasses. Most current and past research uses only limb bones of goats and cattle. An understanding of scavenger exploitation of complete carcasses is necessary if we ever wish to truly understand the impact of scavengers on forensic cases.

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APPENDIX A

Case	Cranium		Mandible		Sternum		Clavicle		Scapula		Humerus		Radius		Ulna	
	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present	Scavenging	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R
1	0/0	4/4	0/0	4/4	0	0	0/0	4/4	0/0	4/4	1/1	1/1	0/0	4/4	0/0	4/4
2	1/1	0/0	1/1	0/0	1	0	1/1	0/1	0/1	4/0	1/1	0/0	1/0	0/4	1/0	0/4
3	1/1	0/0	1/1	0/0	1	1	1/0	0/4	1/0	1/4	0/1	4/0	0/1	4/0	0/1	4/0
4	1/1	3/3	0/0	4/4	0	4	1/1	0/1	0/1	4/1	1/0	3/4	0/0	4/4	1/1	4/1
5	1/1	0/0	1/0	0/4	1	0	1/1	1/0	1/1	0/0	1/1	0/0	1/1	0/1	1/1	0/1
6	1/1	0/0	1/1	0/0	1	0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	1/1	1/1	0/0
7	1/1	2/0	0/0	4/4	0	4	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4
8	1/1	0/1	0/0	4/4	0	4	0/0	4/4	0/1	4/0	1/1	1/1	1/0	3/4	1/0	3/4
9	1/1	0/0	1/1	0/0	1	0	1/1	0/0	1/1	0/0	1/1	0/1	1/1	0/0	1/1	0/1
10	1/1	0/0	1/1	0/0	1	0	1/1	0/0	1/1	1/1	1/1	0/1	1/1	0/1	1/1	0/1
11	1/1	0/0	1/1	1/1	0	4	0/0	4/4	0/1	4/1	0/1	4/1	0/1	4/1	0/1	4/1
12	1/1	0/0	1/1	0/0	0	4	1/1	0/0	1/1	1/1	0/1	4/1	1/0	1/4	1/1	1/0
13	1/1	0/0	1/1	0/0	1	0	1/1	0/0	1/1	0/0	0/0	4/4	0/0	4/4	0/0	4/4
14	1/1	2/0	1/1	2/2	1	0	1/1	0/0	1/1	0/1	0/1	4/1	0/0	4/4	0/0	4/4
15	1/1	0/1	1/1	2/2	0	4	0/1	4/1	1/1	1/3	0/1	4/1	1/1	1/0	1/1	1/2
16	0/0	4/4	0/0	4/4	1	1	1/1	0/1	1/1	0/1	0/1	4/1	1/0	1/4	1/0	1/4
17	1/1	0/1	1/1	0/0	1	0	1/0	1/4	1/1	1/1	0/0	4/4	0/0	4/4	0/0	4/4
18	1/1	0/0	1/1	0/0	1	0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0
19	1/1	0/0	0/0	4/4	1	0	1/1	1/1	0/1	4/1	0/1	4/1	0/1	4/1	0/1	4/1
20	1/1	0/0	0/0	4/4	1	0	1/0	0/4	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0
21	1/1	0/0	1/1	0/0	0	4	1/1	1/1	1/1	1/1	0/1	4/1	1/1	1/1	1/1	1/1
22	1/1	0/0	1/1	0/0	1	0	1/1	0/0	1/1	1/0	1/1	1/0	1/1	1/1	1/1	1/1

Presence:	Scavenging:
0 - absent	0- none
1- present	1- carnivore
	2- rodent
	3- both
	4 - not assessable

Case	Hand		Innominate		Femur		Tibia		Fibula		Patella		Foot	
	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R	Present L/R	Scavenging L/R
1	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4
2	1/1	0/1	0/0	4/4	1/1	1/1	0/1	4/0	1/0	1/4	1/1	1/4	1/1	0/0
3	0/0	4/4	1/1	0/0	0/1	4/1	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4
4	0/0	4/4	1/1	3/1	1/1	1/1	1/1	1/0	1/1	0/0	0/0	4/4	0/0	4/4
5	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	1/1	0/1	1/1	1/1	1/1	0/0
6	1/1	1/0	1/1	0/0	1/1	1/1	1/1	0/1	1/1	1/1	0/0	4/4	1/1	0/0
7	0/0	4/4	0/0	4/4	1/1	1/3	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4
8	0/0	4/4	1/1	3/1	1/1	1/1	0/1	4/1	0/0	4/4	0/0	4/4	0/0	4/4
9	1/0	0/4	1/1	0/0	1/1	1/0	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4
10	1/1	0/1	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	1/0
11	0/0	4/4	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	4/4	0/1	4/1
12	0/0	4/4	1/1	1/1	1/1	1/1	1/1	1/0	1/1	1/1	1/0	0/4	1/1	1/1
13	0/0	4/4	1/1	1/1	1/1	1/1	0/1	4/1	0/1	4/1	0/0	4/4	0/0	4/4
14	0/0	4/4	0/1	4/3	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4	0/0	4/4
15	0/0	4/4	1/1	3/3	1/1	3/1	1/1	3/3	0/0	4/4	0/0	4/4	1/1	0/0
16	0/0	4/4	1/1	1/1	1/0	1/4	1/0	1/4	0/0	4/4	0/0	4/4	0/0	4/4
17	0/0	4/4	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	4/4	0/1	4/1
18	1/1	2/2	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	1/1
19	0/0	4/4	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	4/4	1/1	1/1
20	1/1	1/0	1/1	0/0	1/1	0/0	1/1	0/0	1/1	0/0	1/0	0/4	1/1	0/0
21	0/0	4/4	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
22	0/1	4/1	1/1	1/1	1/1	0/1	1/1	1/1	1/0	1/4	0/0	4/4	0/0	4/4

Presence:	Scavenging:
0 - absent	0- none
1- present	1- carnivore
	2- rodent
	3- both
	4 - not assessable

Case	Cervical Vert		Thoracic Vert		Lumbar Vert		Sacrum		Ribs	
	Present	Scavenging	Present	Scavenging	Present	Scavenging	Present	Scavenging	Present L/R	Scavenging L/R
1	0	4	0	4	0	4	0	4	0/0	4/4
2	1	0	1	0	1	0	1	1	1/1	0/0
3	1	0	1	0	1	0	1	0	1/1	1/1
4	0	4	1	1	1	1	1	1	1/0	1/0
5	1	0	1	0	1	0	1	1	1/1	1/1
6	1	0	1	0	1	0	1	0	1/1	1/1
7	0	4	0	4	0	4	0	4	0/0	4/4
8	0	4	0	4	0	4	0	4	0/0	4/4
9	1	0	1	0	1	0	1	0	1/1	0/0
10	1	0	1	0	1	0	1	0	1/1	0/0
11	0	4	0	4	0	4	0	4	1/0	1/4
12	1	0	0	4	0	4	1	0	1/1	1/1
13	1	0	1	0	1	0	1	0	1/1	1/1
14	0	4	1	0	1	1	1	1	1/1	0/0
15	0	4	0	4	0	4	1	1	1/1	1/1
16	1	1	0	4	0	4	0	4	0/1	4/1
17	1	1	1	1	1	1	1	1	1/1	1/1
18	1	0	1	0	1	0	1	0	1/1	1/1
19	1	1	1	1	1	1	1	1	1/1	1/1
20	1	0	1	0	1	0	1	0	1/1	0/0
21	1	1	1	1	1	1	1	1	1/1	1/1
22	1	0	1	0	1	0	1	0	1/1	1/1

Presence:	Scavenging:
0 - absent	0- none
1- present	1- carnivore
	2- rodent
	3- both
	4 - not assessable

APPENDIX B

Table B.1 Tooth impact marks from case #2, measurements (in mm)

Element	Pit	Puncture
Sacrum		0.89
		1.13
		1.14
Femur, Left Proximal	2.18	4.31
	2.41	3.36
	1.92	5.45
	2.3	4.33
	2.48	4.29
	1.76	
Femur, Left Distal	2.33	5.27
	1.83	2.88
	1.82	5.78
	1.93	4.11
	2.83	4.95
Femur, Right Proximal	1.93	2.86
	1.87	2.78
	1.89	
	1.79	
	1.74	
Femur, Right Distal	2.11	3.06
	2.1	2.95
	1.78	4.1
	2.01	

Table B.2 Tooth impact marks from case #3, measurements (in mm)

Element	Pit	Puncture
Scapula, Left		2.35
Femur, Right Distal	2.24	5.36
	2.02	2.87
	0.71	4.56
		3.68
		7.08
		5.09

Table B.3 Tooth impact marks from case #4, measurements (in mm)

Element	Pit	Puncture
Scapula, Right		1.45
Clavicle, Right		2.23
Vertebrae	2.58	4.5
	1.58	3.59
Innominate, Left		2.43

Table B.4 Tooth impact marks from case #5, measurements (in mm)

Element	Pit	Puncture
Innominate, Right		4.85
		5.75
		5.34
Innominate, Left		3.82
		3.46
		4.11
Femur, Right Proxmal		3.73
		2.17
		1.87
		2.61

Table B.5 Tooth impact marks from case #8, measurements (in mm)

Element	Pit	Puncture
Humerus, Left Proximal		6.44
Femur, Left Distal	1.24	
	3.63	
	2.16	
Femur, Right Distal	2.51	2.46
	2.38	1.48
	0.99	
Skull		2.31

Table B.6 Tooth impact marks from case #9, measurements (in mm)

Element	Pit	Puncture
Humerus, Right Proximal	2.32	
Radius, Right Proximal	0.82	
	2.10	
Femur, Left Proximal		2.77

Table B.7 Tooth impact marks from case #11, measurements (in mm)

Element	Pit	Puncture
Innominate, Left		4.30
Innominate, Right	3.66	3.33
Scapula, Right		6.99
Femur, Left Proximal		2.78
		3.43
Talus		8.95
Tibia, Right Distal	2.72	3.16
	2.98	4.23
		5.45
		3.88
		2.87
		2.52
		4.61
Mandible, Right		2.54
		2.55

Table B.8 Tooth impact marks from case #14, measurements (in mm)

Element	Pit	Puncture
Humerus, Right Distal	1.11	1.76
Innominate, Right	3.10	4.70

Table B.9 Tooth impact marks from case #15, measurements (in mm)

Element	Pit	Puncture
Scapula, Right		2.78
Sacrum	1.91	4.10
	2.82	2.85
Humerus, Right Proximal	1.64	2.09
	2.30	2.22
	2.68	2.39
	1.62	
Humerus, Right Distal		2.59
Innominate, Left		10.01
		2.46
		8.64
		8.53
		4.10
		3.19
		4.86

Table B.10 Tooth impact marks from case #17, measurements (in mm)

Element	Pit	Puncture
Tibia, Right Proximal	3.02	
Tibia, Left Distal		3.61
		3.21
		4.78
Femur, Right Proximal		4.5
		3.78
		2.59
		4.15
		7.26
Innominate, Left	2.00	
Skull		4.81
		3.60

Table B.11 Tooth impact marks from case #19, measurements (in mm)

Element	Pit	Puncture
Talus, Left		4.36
Tibia, Left Proximal	2.85	4.50
		3.65
Tibia, Right Distal	2.43	3.56
	2.38	
Proximal		4.30
Fibula, Left Proximal		2.46
Fibula, Right Proximal		3.61
Humerus, Right Proximal	3.08	4.44
	2.28	4.89
	2.62	
	2.37	
Innominate, Right	3.18	2.56
Scapula, Right		3.95
Innominate, Left	3.62	4.73
		2.9
Femur, Left Distal	1.92	4.93
	3.53	
Proximal		4.95

Table B.12 Tooth impact marks from case #20, measurements (in mm)

Element	Pit	Puncture
Distal Hand Phal.		7.28

Table B.13 Tooth impact marks from case #21, measurements (in mm)

Element	Pit	Puncture
Foot, Left	1.97	3.71
	2.37	3.69
	2.41	2.96
	2.27	1.94
	2.13	3.30
	1.83	2.21
	1.09	2.74
	0.76	1.66
Foot, Right	2.51	
	3.12	
	2.62	
	1.72	
	2.62	
	1.30	
	1.47	
	1.33	
	2.03	
	2.37	
	2.19	
Innominate, Right	1.37	4.43
	2.16	2.39
	3.26	3.37
	2.78	3.08
	3.32	3.68
	2.48	4.20
	1.03	6.27
	1.50	4.52
	1.40	6.40
		5.56
Scapula, Right	2.31	
Clavicle, Right		2.82
Fibula, Right	2.93	
Patella, Right		3.21
	2.49	
	1.89	
	0.86	
	1.02	
	1.17	
	3.27	
	1.69	
	1.99	

Table B.13 (Continued)

Element	Pit	Puncture
Femur, Right Proximal		3.89
Femur, Right Distal	1.89	2.94
	2.82	2.23
	4.34	3.42
	3.05	4.25
	1.84	3.20
	2.27	3.85
Humerus, Right Proximal	2.79	4.09
	3.31	2.33
	2.39	
Radius, Left Proximal	2.89	6.37
	2.28	5.00
	1.89	
Tibia, Left Proximal	4.76	
	2.98	
Femur, Left Proximal	3.30	3.63
	2.43	1.89
	1.55	3.52
	2.19	5.49
	0.96	
	3.76	
	2.19	
	0.90	
	2.08	
Femur, Left Distal	2.42	2.27
	5.15	3.08
	1.13	2.55
	0.78	6.78
	1.14	4.29
		4.38
		2.63
Sacrum	2.24	3.19
	2.27	2.75
	1.11	5.54
	1.89	3.72
	1.92	3.34
	3.15	4.17
	1.21	2.53
		1.57

Table B.13 (Continued)

Element	Pit	Puncture
Innominate, Left	1.84	3.21
	2.23	2.43
	1.95	3.02
	2.63	4.3
	4.71	2.31
	1.65	4.45
	1.85	8.81
	2.51	7.07
	2.22	3.73
	3.91	
	2.74	
	3.13	
	3.71	
Scapula, Left	1.61	2.63
	1.87	2.40
		2.66
		1.97
		2.29
Clavicle, Left	1.47	
	1.13	
	1.87	

APPENDIX C

Table C.1 Tooth impact mark minimum, maximum, and average listed by case and by element, all measurements (in mm)

Case	Element		Pit	Puncture
2	Sacrum	Max		1.14
		Min		0.89
		Avg		1.05
	Femur, Left Proximal	Max	2.48	5.45
		Min	1.76	3.36
		Avg	2.17	4.37
	Femur, Left Distal	Max	2.83	5.78
		Min	1.82	2.88
		Avg	1.99	4.64
	Femur, Right Proximal	Max	1.93	2.86
		Min	1.74	2.78
		Avg	1.90	2.82
	Femur, Right Distal	Max	2.11	4.10
		Min	1.78	2.95
		Avg	2.00	3.37
3	Scapula, Left	Max		2.35
	Femur, Right Distal	Max	2.24	7.08
		Min	0.71	2.87
		Avg	1.66	4.26
4	Scapula, Right	Max		1.45
	Clavicle, Right	Max		2.23
	Vertebrae	Max	2.58	4.50
		Min	1.58	3.59
		Avg	2.08	4.05
	Innominate, Left	Max		2.43
5	Innominate, Right	Max		5.75
		Min		5.34
		Avg		5.31
	Innominate, Left	Max		4.11
		Min		3.46
		Avg		3.80
	Femur, Right Proxmal	Max		3.73
		Min		1.87
		Avg		2.59

Table C.1 (Continued)

Case	Element		Pit	Puncture
8	Humerus, Left Proximal	Max		6.44
	Femur, Left Distal	Max	3.63	
		Min	1.24	
		Avg	2.34	
	Femur, Right Distal	Max	2.51	2.46
		Min	0.99	1.48
		Avg	1.96	1.97
	Skull	Max		2.31
9	Humerus, Right Proximal	Max	2.32	
	Radius, Right Proximal	Max	2.10	
		Min	0.82	
	Femur, Left Proximal	Max		2.77
11	Innominate, Left	Max		4.30
	Innominate, Right	Max	3.66	3.33
	Scapula, Right	Max		6.99
	Femur, Left Proximal	Max		3.42
		Min		2.78
	Talus	Max		8.95
	Tibia, Right Distal	Max	2.98	5.45
		Min	2.72	2.52
		Avg	2.85	4.28
	Mandible, Right	Max		2.55
		Min		2.54
14	Humerus, Right Distal	Max	1.11	1.76
	Innominate, Right	Max	3.10	4.70
15	Scapula, Right	Max		2.78
	Sacrum	Max	2.82	4.10
		Min	1.91	2.85
	Humerus, Right Proximal	Max	2.68	2.59
		Min	1.64	2.09
		Avg	2.21	2.23
	Humerus, Right Distal	Max		2.59
	Innominate, Left	Max		10.01
		Min		2.46
		Avg		7.04

Table C.1 (Continued)

Case	Element		Pit	Puncture
17	Tibia, Right Proximal	Max		3.02
	Tibia, Left Distal	Max		4.78
		Min		3.21
		Avg		3.87
	Femur, Right Proximal	Max		7.26
		Min		2.59
		Avg		3.62
	Innominate, Left	Max	2.00	
	Skull	Max		4.81
		Min		3.60
19	Talus, Left	Max		4.36
	Tibia, Left Proximal	Max	2.85	4.50
		Min		3.65
	Tibia, Right Distal	Max	2.43	3.65
		Min	2.38	
	Tibia, Right Proximal	Max		4.30
	Fibula, Left Proximal	Max		2.46
	Fibula, Right Proximal	Max		3.61
	Humerus, Right Proximal	Max	3.08	4.89
		Min	2.28	4.44
		Avg	2.66	4.67
	Innominate, Right	Max	3.18	2.56
	Scapula, Right	Max		3.95
	Innominate, Left	Max	3.62	4.73
		Min		2.90
	Femur, Left Distal	Max	3.53	4.93
		Min	1.92	
	Proximal	Max		4.95
21	Foot, Left	Max	2.41	3.71
		Min	0.76	1.66
		Avg	2.25	3.45
	Foot, Right	Max	3.12	
		Min	1.30	
		Avg	2.75	
	Innominate, Right	Max	3.32	6.27
		Min	1.03	2.39
		Avg	2.26	3.40
	Scapula, Right	Max	2.31	
	Clavicle, Right	Max		2.82
	Fibula, Right	Max	2.93	

Table C.1 (Continued)

Case	Element		Pit	Puncture
	Patella, Right	Max	3.27	3.21
		Min	0.86	
		Avg	2.19	
	Femur, Right Proximal	Max		3.89
	Femur, Right Distal	Max	4.34	4.25
		Min	1.84	2.23
		Avg	3.02	2.86
	Humerus, Right Proximal	Max	3.31	4.09
		Min	2.39	2.33
		Avg	2.83	3.21
	Radius, Left Proximal	Max	2.89	6.37
		Min	1.89	5.00
		Avg	2.35	5.69
	Tibia, Left Proximal	Max	4.76	
		Min	2.98	
	Femur, Left Proximal	Max	3.76	5.49
		Min	0.90	1.89
		Avg	2.43	3.01
	Femur, Left Distal	Max	5.15	6.78
		Min	0.78	2.27
		Avg	2.90	2.63
	Sacrum	Max	3.15	4.17
		Min	1.11	1.57
		Avg	1.87	3.83
	Innominate, Left	Max	4.71	8.81
		Min	1.65	3.02
		Avg	2.01	2.89
	Scapula, Left	Max	1.87	2.63
		Min	1.61	1.97
		Avg	1.74	2.56
	Clavicle, Left	Max	1.87	
		Min	1.13	
		Avg	1.49	
20	Distal Hand Phal.	Max		7.28

APPENDIX D

Table D.1 Carnivore canine measurements listed by species and specimen number. M-D = mesiodistal, diameter, L-L = labio-lingual diameter (in mm)

Species	Specimen #		Max. dim tip	M-D	L-L
Grey Fox	312	Maxilla, R	1.80	5.22	3.18
		Maxilla, L	1.93	5.20	3.12
		Mandible, R	2.07	4.64	3.4
		Mandible, L	2.03	4.54	3.59
	108	Maxilla, R	1.95	5.43	3.59
		Maxilla, L			
		Mandible, R	1.94	4.56	3.81
		Mandible, L	1.83	4.60	3.15
	962	Maxilla, R	1.78	5.05	3.20
		Maxilla, L	1.88	4.74	3.42
		Mandible, R	1.84	4.78	3.42
		Mandible, L	1.89	4.93	3.51
	692	Maxilla, R	broken	5.32	3.45
		Maxilla, L	1.95	5.37	3.89
		Mandible, R	1.95	5.39	3.89
		Mandible, L	1.97	5.31	3.93
	1187	Maxilla, R	1.91	5.14	3.47
		Maxilla, L	1.93	5.09	3.30
		Mandible, R	2.01	5.03	3.68
		Mandible, L	1.90	4.82	3.95
Racoon	276	Maxilla, R	2.56	6.67	5.45
		Maxilla, L	2.58	6.57	5.20
		Mandible, R	2.51	5.93	6.03
		Mandible, L	2.54	6.12	5.95
	1010	Maxilla, R	2.78	6.80	5.09
		Maxilla, L	3.05	6.66	5.11
		Mandible, R	2.55	7.25	6.12
		Mandible, L	2.55	7.44	5.14
	1109	Maxilla, R	3.02	7.17	5.60
		Maxilla, L	3.02	6.98	5.55
		Mandible, R	2.81	6.98	5.24
		Mandible, L	2.92	6.98	5.63

Table D.1 (Continued)

Species	Specimen #		Max. dim tip	M-D	L-L
Bobcat	1601	Maxilla, R	2.09	5.56	4.43
		Maxilla, L	2.07	5.70	4.45
		Mandible, R	2.27	5.60	4.19
		Mandible, L	2.32	5.89	4.14
	127	Maxilla, R	Broken	5.34	4.63
		Maxilla, L	Missing	Missing	Missing
		Mandible, R	Broken	5.91	4.40
		Mandible, L	2.31	4.50	4.95
	106	Maxilla, R	2.23	5.62	4.33
		Maxilla, L	2.20	5.93	4.66
		Mandible, R	2.51	5.49	4.68
		Mandible, L	2.61	5.49	4.72
	48	Maxilla, R	Broken	7.19	5.99
		Maxilla, L	Broken	7.12	5.88
		Mandible, R	2.68	6.87	6.45
		Mandible, L	2.29	6.39	5.23
	696	Maxilla, R	2.50	7.04	5.50
		Maxilla, L	2.52	6.87	5.31
		Mandible, R	Missing	Missing	Missing
		Mandible, L	2.38	6.53	5.71
Mountain Lion	951	Maxilla, R	Broken	15.32	12.54
		Maxilla, L	5.12	14.95	12.05
		Mandible, R	4.90	14.17	10.94
		Mandible, L	4.65	14.09	10.45
	345	Maxilla, R	4.20	14.02	11.13
		Maxilla, L	Broken	Broken	Broken
		Mandible, R	5.20	12.22	9.94
		Mandible, L	4.9	13.2	10.15
	1036	Maxilla, R	Missing	Missing	Missing
		Maxilla, L	Broken	Broken	Broken
		Mandible, R	Broken	11.62	9.41
		Mandible, L	5.07	11.12	10.30
	1112	Maxilla, R	4.44	13.34	10.49
		Maxilla, L	4.35	13.53	10.92
		Mandible, R	Missing	Missing	Missing
		Mandible, L	Missing	Missing	Missing

Table D.1 (Continued)

Species	Specimen #		Max. dim tip	M-D	L-L
Coyote	827	Maxilla, R	Broken	9.89	6.04
		Maxilla, L	3.70	8.68	5.49
		Mandible, R	3.79	8.94	6.51
		Mandible, L	Broken	9.29	6.23
	62	Maxilla, R	Broken	8.15	4.74
		Maxilla, L	Missing	Missing	Missing
		Mandible, R	3.72	8.15	6.12
		Mandible, L	3.88	8.84	5.54
	82	Maxilla, R	3.69	8.78	5.16
		Maxilla, L	4.92	8.61	5.300
		Mandible, R	2.83	8.64	6.09
		Mandible, L	3.46	9.29	5.77
	126	Maxilla, R	Broken	9.51	6.01
		Maxilla, L	Broken	9.13	5.89
		Mandible, R	3.67	9.65	6.47
		Mandible, L	3.81	9.41	6.87
Bear	640	Maxilla, R	Missing	Missing	Missing
		Maxilla, L	5.44	16.37	11.81
		Mandible, R	4.91	16.86	11.58
		Mandible, L	5.02	18.54	10.95
	269	Maxilla, R	4.56	17.10	10.19
		Maxilla, L	4.78	15.28	10.31
		Mandible, R	4.86	19.27	11.74
		Mandible, L	Broken	18.14	Broken

APPENDIX E

Patella		Hind Hoof		Cervical Vert		Thoracic Vert		Lumbar Vert		Sacrum		Ribs	
Present	Scavenging	Present	Scavenging	Present	Scavenging	Present	Scavenging	Present	Scavenging	Present	Scavenging	Present	Scavenging
L/R	L/R	L/R	L/R									L/R	L/R
0/0	4/4	0/0	4/4	0	4	0	4	0	4	0	4	1/1	1/1
0/0	4/4	0/0	4/4	0	4	0	4	0	4	0	4	0/0	4/4
0/0	4/4	0/0	4/4	0	4	0	4	0	4	0	4	0/0	4/4
1/1	0/0	1/1	0/0	1	1	1	1	1	1	1	0	1/1	1/1
1/1	0/0	1/1	0/0	1	1	1	1	1	1	0	4	1/1	1/1

APPENDIX F

Table F.1 Inventory of pit and puncture marks on pig #1.

Element	Pit	Puncture
Frontal	2.21	3.24
	2.64	3.20
	2.67	3.08
	2.63	1.46
	2.10	
	1.59	
	3.05	
	2.93	
	3.20	
	2.24	
	1.42	
	1.63	
	1.19	
	1.48	
	1.75	
	1.75	
	1.77	
	1.84	
	1.79	
	2.88	
	2.95	
	3.98	
	3.20	
	2.96	
	3.4	
	2.58	
	2.55	
	1.84	
Maxilla	2.35	
Mandible	1.89	3.81
	1.60	3.36
	1.67	
	3.50	
	2.80	
	2.54	
	2.37	
	2.38	
	2.21	

Table F.1 (continued)

Element	Pit	Puncture
Left Humerus	2.02	
	2.40	
	3.08	
	2.30	
	2.31	
	3.12	
	1.83	
	1.16	
	1.22	
	1.40	
	1.49	
Right Tibia	1.33	
	1.55	
	2.24	
	1.94	
	2.06	
	2.37	
	2.59	
	1.72	
	1.66	
	2.27	
	1.64	
	1.84	
	1.81	
	1.89	
	2.21	
	2.33	

Table F.2 Inventory of pit and puncture marks on pig #3.

Element	Pit	Puncture
Mandible	2.21	2.73
	2.90	
	2.45	
	3.07	
Left Scapula		3.18
		4.02

Table F.3 Inventory of pit and puncture marks on pig #4

Element	Pit	Puncture
Metatarsal		7.39
Innominate		
Right Ischium		3.78
Left Ilium		4.53
	2.72	3.21
	2.33	
Left Ulna	3.10	
Right Ulna	2.42	
Left Humerus		2.77
Left Scapula		5.12
		3.49
Right Scapula		4.44
		2.36
Left Rib	3.37	
Right Rib		3.50
Vert Body		2.97
		4.25
		3.21
		3.44
Spinous Process		5.45