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Animal scavenging on human skeletal remains in the southwest United States: a preliminary model

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ANIMAL SCAVENGING ON HUMAN SKELETAL REMAINS IN THE
SOUTHWEST UNITED STATES: A PRELIMINARY MODEL

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Arts

in

The Department of Geography & Anthropology

by
Maximilian Hiram Cantu
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Abstract

Animal scavenging is a major taphonomic process responsible for damage to bone and alternations to postmortem interval estimates. Despite the significant implications animals can have on altering forensics cases, extensive research on animal scavenging has yet to be done. The most notable research on animal scavenging comes from Haglund . Haglund's extensive research in the Pacific Northwest led him to create a model for the sequence in which animals scavenge and disarticulate a human body after death. The major goal of my research was to apply Haglund's model to 60 southern Arizona cases in order to see if animals scavenge a body in a similar fashion cross-environmentally. Aside from the sequence in which animals scavenge a body, I was also able to comment on the types of animals that scavenge in the area, the frequency and timing of scavenging by animals, and the areas of bone most frequently scavenged. A final section of my research investigated the interdependence between postmortem interval estimations and animal scavenging. Based on the data in southern Arizona, I was able to create a preliminary model of animal scavenging in the area. The results indicated a similar model of scavenging in southern Arizona as in the Pacific Northwest. The role of mummification proved to be a major factor in scavenging patterns and the type of scavenger. The mummification of several cases also affected the interdependence of postmortem interval and stage of disarticulation for the southern Arizona cases. As the PMI increased the dependence on stage of disarticulation decreased. The large number of cases and difficulty identifying remains is a problem that will continue to challenge forensic specialists in southern Arizona. An increased discourse on taphonomic processes in the area will help forensic investigators greatly. The information I provided further contributes to a rather thin discourse on the major taphonomic

process of animal scavenging. Continued research and experiments in southern Arizona will create a clearer picture for forensic scientists in future years.

Chapter I Introduction

The Arizona-Sonora Desert is one of four major North American deserts and spans the northern Mexican state of Sonora, much of southern Arizona, and parts of California (Galloway 1997) (Figure 1). The region is characterized by high temperatures, intense droughts, and variable rainfall patterns. The harsh conditions create an environment of low density habitation and limited water supply (De León 2012; Galloway 1997; McEvoy and Wilder 2012; Wilder et al. 2010). Despite the hostile environmental conditions, thousands of migrants crossing from Mexico into the United States travel through the Arizona-Sonora Desert every year. The combination of large numbers of migrants and inhospitable conditions results in hundreds of migrant deaths yearly in areas of southern Arizona (De León 2012). Because of the remoteness of the area, bodies are undiscovered for long periods of time and undergo a variety of taphonomic processes (Galloway et al. 1989).



Figure 1: Map of the Sonoran Desert (<http://www.nps.gov>)

Animal scavenging on human remains is a major taphonomic process affecting an overwhelming number of cases in southern Arizona (Haglund 1989). Scavengers significantly alter the condition and decomposition rate of a human body as well as disarticulate the body to easily transport bones away from the original death site (Haglund 1989; Spradley et al. 2012). In addition, documentation of the presence of animal scavenging is important in a forensic context when distinguishing between postmortem scavenging and “nefarious human acts” (Rippley et al. 2012: 699).

However, the effect of animal scavenging on the decomposition process of humans is a subject that has yet to be explored in great detail (Haglund 1989; Murmann et al. 2006). While research regarding animal scavenging as a taphonomic process has been limited, Haglund (1989) provided a model for animal scavenging processes and sequences. His research in the Pacific Northwest involved an investigation of past forensic cases to formulate a hypothesis regarding the sequence in which animals scavenge a human body after death. Haglund was able to make conclusions based on the skeletal element representation as well as the amount of disarticulation for each recovered case. Haglund addressed variables that may affect animal scavenging activity, but the variables posed by Haglund in the Pacific Northwest have not been tested in southern Arizona.

Using Haglund’s methodology, I examined forensic cases from the Pima County Medical Examiner’s office in Tucson, Arizona. By using the same categorization and methodology as Haglund, I analyzed the results of my findings to those of Haglund’s to compare animal scavenging in the Pacific Northwest to southern Arizona.

Other interests of this research deal with patterns left by scavengers on human bone, assessment of scavengers in the area, and implications for postmortem interval with relation to

stages of disarticulation. By carefully documenting and photographing actual skeletal remains, I provide preliminary conclusions on scavengers present in the area, frequency of scavenging on different skeletal elements, and areas of the bone scavenged most frequently. Because of the large number of cases consisting of skeletal remains in Arizona, the data used can provide useful information with regard to taphonomic processes in southern Arizona.

Chapter II Literature Review

Motives for Scavenging

Although animal scavenging on human remains has not been extensively documented, a number of studies and experiments have been conducted on animal scavenging more generally. Reasons animals scavenge as well as the ways in which they scavenge in natural habitats are fairly well known. In terms of motive for scavenging, when food sources become scarce or ecosystems experience extreme selective pressures, animals will scavenge for nutrients as a way to maintain their strength in the ecosystem (Barton et al. 2013; Rippley et al. 2012). Carrion, or dead animal tissue, provides scavengers with a nutrient-rich food source that can be consumed to sustain strength. Meaty flesh filled with nutrients, ends of bones that contain nutrients and minerals, and bone marrow are all popular food sources animals scavenge to maintain survival (DeVault et al. 2003; DeVault et al. 2004; Wilson and Wolkovich 2011).

Although scavenging is often viewed as the lowest level in an ecosystem, consumption of carrion has proven to be both beneficial to scavengers and to the ecosystem of which they are a part (Barton et al. 2013; DeVault et al. 2003). Studies have shown that scavenging of carrion represents a stabilizing force in an ecosystem. The flow of carrion resources within an ecological system can contribute to the strength of interactions between species within a trophic food web (DeVault 2003; Wilson and Wolkovich 2011).

Relationships between scavengers and decomposers, as well as competition among scavengers, also influence carrion availability within an ecosystem (DeVault et al. 2003; DeVault et al. 2004). As a result, the amount of carrion available to scavengers varies for each ecosystem. For ecosystems where carrion is scarce, the scavengers that can detect and consume carrion rapidly will have a competitive advantage (Houston 1979). However, even in ecosystems

where carrion is plentiful, predatory species will not always scavenge carrion. The consumption of carrion is based primarily on foraging strategies, access to remains, and selective pressures within an ecosystem (DeVault et al. 2003).

Sequencing of Animal Scavenging

Aside from motive and reason for scavenging of remains, numerous experiments have been conducted on the sequence in which animals scavenge remains. Observing disarticulation patterns of remains is a key component to making inferences about animal scavenging sequencing. In terms of disarticulation, the process can occur naturally after a body has been exposed for an extended period of time. Hill (1979) addressed natural disarticulation by noting the correlation between remaining elements and synovial joints. According to Hill, natural disarticulation of bones depends on the rate in which joints holding together bones break and collapse. Hill explains that natural disarticulation varies based primarily on air moisture and other environmental conditions.

Disarticulation can also occur from the effects of animal scavenging, which Hill (1979, 1984) also addressed. Hill (1979, 1984) concluded that similar natural disarticulation patterns can be visible cross-environmentally regardless of specific species and taxa for each region. However, Hill called attention to the drastic effects animal scavenging has on altering the sequence of disarticulation. Often times, large scavengers will discover a fresh cadaver and disarticulate the body by attacking the ends of bones and tearing apart the limbs to separate the remains. Large predators, such as coyotes or wild canids, will often disarticulate portions of the body to easily transport remains away from the original death site (Hill 1984, O'Brien et al. 2010). Toots (1965) noticed natural patterns of disarticulation among species, but he also acknowledged the overwhelming frequency of disarticulation due to animal scavenging.

Disarticulation of remains transpires with a combination of the natural decay of joints and tissue holding bones together as well as environmental and ecological effects, such as animal scavenging. However, the focus of this study is geared more toward disarticulation affected by animal scavenging, and the sequence of events that occur when an animal scavenges a body. More specific studies have been done on the subject of the sequence in which animals scavenge and disarticulate a human body.

The most cited research on animal scavenging on human remains comes from Haglund's (1989) Pacific Northwest study. Haglund's sample included previously recovered remains from King County, Washington. Haglund was able to obtain a large sample of 46 partially skeletonized remains recovered between 1979 and 1988. From examination of the extent and patterns of animal scavenging on the bones, Haglund was able to develop a model on the sequence in which animals scavenge human remains. The sequence Haglund proposed begins with removal of face skin and muscles as well as neck organs. The removal of the face and neck muscles is followed by the destruction of the ventral thorax, which includes the sternum, sternal ends of ribs, and clavicles. The upper extremities and scapula are scavenged next. Finally, the lower extremities are disarticulated, which leaves the head and vertebral column the last elements to be scavenged (Haglund 1989). Haglund's Pacific Northwest study has since become a respected model in the field of forensic taphonomy. Figure 2 is a visual representation of Haglund's proposed model of animal scavenging sequencing. Kjørlién et al. (2009) presented a study focusing on disarticulation sequences as well as scattering patterns in Alberta, Canada. Their findings validated scavenging and disarticulation sequencing proposed by Haglund (1989), Hill (1979, 1984) and Toots (1965). They also discovered a pattern of non-random scattering.

According to Kjolien and colleagues, scavengers in the area predictably transport skeletal remains in the direction away from human activity.

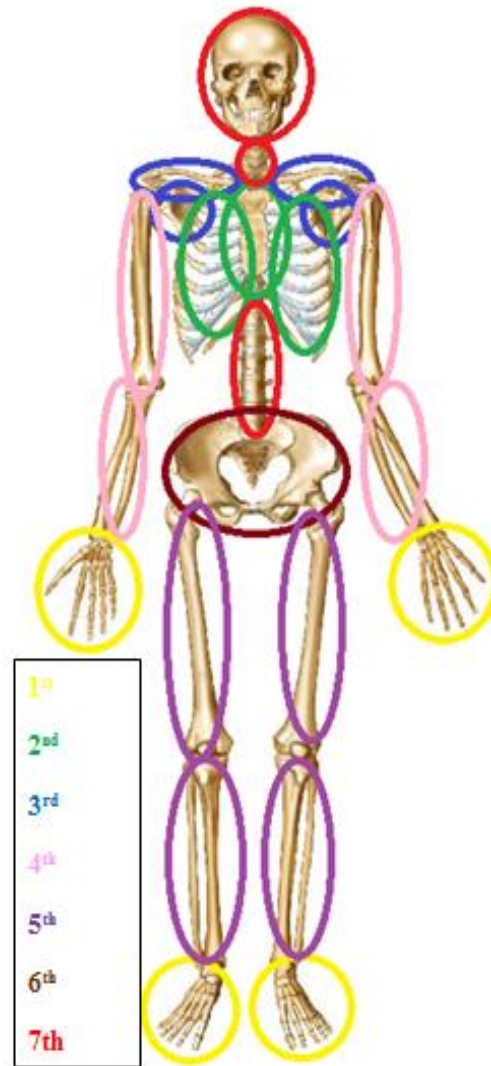


Figure 2: Visual Representation of Sequence in Which Animals Scavenge a Body, According to Haglund

However, Manhein et al. (2006) discovered different results when conducting a study on scattering patterns of human remains in Louisiana. The study was aimed at determining if geographically specific dispersal patterns of human remains could be predicted. By using GPS technology and spatial analysis, Manhein and her colleagues were able to track skeletal remains

that had been dispersed from the original dump site. Based on the results, scattering of remains did not follow a particular geographical pattern of dispersal, nor was there an indication that dispersal distance of scattered remains could help determine PMI. As the remains were scattered farther away from the original site where the body was found, predicting the direction in which animals scatter a body becomes increasingly difficult.

In Central Texas, Reeves (2009) conducted a study to document vulture scavenging patterns. Reeve was also interested in comparing Haglund's model of disarticulation and animal scavenging sequence to Central Texas. Using pig carcasses as the cadavers, the bodies were placed in the outdoor decomposition laboratory at the Forensic Anthropology Center at Texas State University in San Marcos. Reeve's results were comparable results to Haglund's model in the Pacific Northwest. However, several differences did occur in the Central Texas experiment. In terms of sequence, Reeves discovered that animals scavenged the mandible and cranium first, followed by the clavicles and scapulae, and upper limbs.

In contrast, in northern California, Bright (2011) found complications with the sequencing model proposed by Haglund (1989). Based on her decomposition study, the sequencing of animal scavenging did not support Haglund's model. Instead, in Bright's experiment, the head was the first to be disarticulated and scavenged, followed by the forelimb, hind limb, thorax, and vertebral column. Bright noted that the sequence proposed by Haglund was based primarily on canid-scavenged remains. She hypothesized that different species and taxa, such as bears, could scavenge remains differently and alter sequencing patterns.

Based on conflicting results involving sequences of animal scavenging on human remains, further research in other regions, such as Arizona, is necessary in order to confirm or deny the validity of Haglund's model cross-environmentally.

Variables Affecting Animal Scavenging

When investigating animal scavenging, understanding the variables affecting scavenger's patterns is crucial. For example, Blumenshine (1987) observed that differences in scavenging opportunities are based on differences in predator:prey ratios. The competition for scavenging animals may be reduced if predator to prey ratios are relatively even. In a scenario where predator to prey ratios are even, scavenging may be a last resort for many animals. Animals who may not usually scavenge may still eventually scavenge the remains because primary scavengers did not initially attack the body.

In terms of scattering patterns, Manhein and colleagues (2006) addressed the variables which affect the ways in which animals scavenge and scatter a body. Variables, such as climate, access to body, and geographical boundaries, all affect the way in which animals scavenge and scatter a body. In a subtropic climate region, such as Louisiana, bodies sometimes are dumped in heavily forested or wooded areas. Access to remains may be difficult for some scavengers, and the body may be left unharmed until scavengers can gain access. Once scavengers do attack the body, the pattern of scattering the remains becomes muddled based on geographical boundaries and the amount of remains the animal can physically carry and scatter. Additionally, the heavy woods may affect access to a body for avian scavengers, such as vultures.

Climate is a key variable affecting scavenging patterns (Galloway 1997). Selva et al. (2005) conducted an experiment investigating factors influencing scavenging in Europe. From their observations of animal scavenging on over 200 carcasses, they were able to conclude that scavenging patterns were not random, but instead were part of a hierarchical system of energy maximization. He explained that in highly seasonal environments and harsh winters, scavengers encounter prey scarcity, and carrion then represents a key food source. Selva and colleagues

determined that even when a carcass is easily accessible, climactic conditions may affect the carcass' rate of use. They observed that actions, such as foraging behavior, habitat use, capacity to break into carcasses, and visual and olfactory abilities can all be affected by drastic climactic conditions (Selva et al. 2005).

In another study, O'Brien et al. (2010) studied scavenging patterns in Australia to determine the effects of distinct ecological niches on scavengers. According to O'Brien and colleagues, availability of food sources, protein requirements, competition and environmental conditions all affect an animal's scavenging strategy. Furthermore, breeding was seen to be a key factor in scavenging patterns (Blumenshine 1987; DeVault et al. 2003; O'Brien et al. 2010;). Returning to O'Brien et al. (2010) for an example, in the spring months in Australia, scavenging was more abundant due to the higher protein demand of breeding season. However, in the winter and autumn months when food is not scarce, the overall amount of scavenging decreased.

With regard to disarticulation, Hill (1979) discussed the effects of moisture in relation to disarticulation. He explained that in environments with heavy moisture, bodies will become disarticulated very quickly due to joints collapsing from the moisture of their own body fluids. The rapid disarticulation leads to easy access for animals to scavenge and scatter a body. He also described the effects of aridity on disarticulation. The absence of external or internal moisture leads to mummification of the entire body, which completely restricts disarticulation and animal scavenging.

Scavengers: Canids, Rodents, and Vultures

A main focus of this study is to develop a comprehensive model of animal scavenging in the Southwest United States. In order to develop the model, an understanding of the various scavengers in the Southwest United States is necessary. In southern Arizona, scavengers can leave distinct marks, which can provide further information on taphonomic processes. The three

main groups of animals that scavenge remains are canids, rodents, and vultures. The process of scavenging and the patterns left on bone vary between species and will be discussed further.

Canid Scavenging

Canid modifications to remains can be highly disruptive to the natural sequencing process of disarticulation, alter decomposition rates, and cause major damage to the bones (Domínguez-Rodrigo and Piqueras 2003; Haglund 1989, 1997a; Haglund and Sorg 1997; Haynes 1980, 1982; Kjørliien 2009; Klippel and Synstelien 2007; Rippley et al. 2012; Wiley and Snyder 1989). The most common canid scavengers are coyotes, dogs, and wolves, but the number of each species differ regionally (Haglund 1997a; Klippel and Synstelien 2007). For example, Galloway and colleagues (1989) found that coyotes are the most common natural scavenger in Arizona. On the other hand, in east Tennessee and east Texas, wolves are often the most common scavengers (Rippley et al. 2012; Wiley and Snyder 1989).

The aggressive nature of canids as well as their prominent canines leads to extensive scavenging damage and distinct patterns (Delaney-Rivera et al. 2009; Haglund 1997a; Wiley and Snyder 1989). Canids often consume meaty parts of a decomposing body by ripping open the thoracic cavity and eating the ribs (Wiley and Snyder 1989). The limb bones are the next bones to be attacked, which causes damage to the long bones and distinctive marks.

Binford (1981) expands on canid scavenging with more detail in “Bones: Ancient Men and Modern Myths.” According to Binford, the main types of scavenging marks left by canids are pits, punctures, and furrows. The most common marks are caused from tearing off flesh from the bones, chewing on long bones to extract more meat and fat, and scooping and licking the ends of long bones to extract bone marrow (Binford 1981; Klippel and Synstelien 2007). The

most common type of animal damage, furrowing, occurs with repeated jaw action on relatively cancellous bone tissue.

Furrowing often results in a “hole” in the bone where the soft tissue has been scooped out (Figure 3). Pitting (Figure 3) is more common in chewing and gnawing of bone rather than eating and pulling meat from the skeleton. Remains with pitting marks are more likely found on bones that have been scattered and dragged away from the original position of the body. When carnivores, such as coyotes or dogs, take bones back to their home, they spend an extensive time gnawing on the bone.

Punctures (Figure 4) occur when the bone has collapsed under the tooth, leaving a clear imprint of the tooth. Punctures usually occur where bone is thin and porous, leaving distinct holes in cancellous bone. Pitting occurs with extensive gnawing on cancellous parts of bone after punctures are no longer feasible. As the animal encounters hard bone, it can no longer be punctured and, subsequently, pitting occurs. In a study involving wolf scavenging, Wiley and Snyder (1989) provide a more detailed description of damage to bone by scavengers. They noticed a pattern of complete long bone destruction based on accessibility and bone density.



Figure 3: Left: Furrowing Marks on Bone. Right: Pitting Marks on Bone

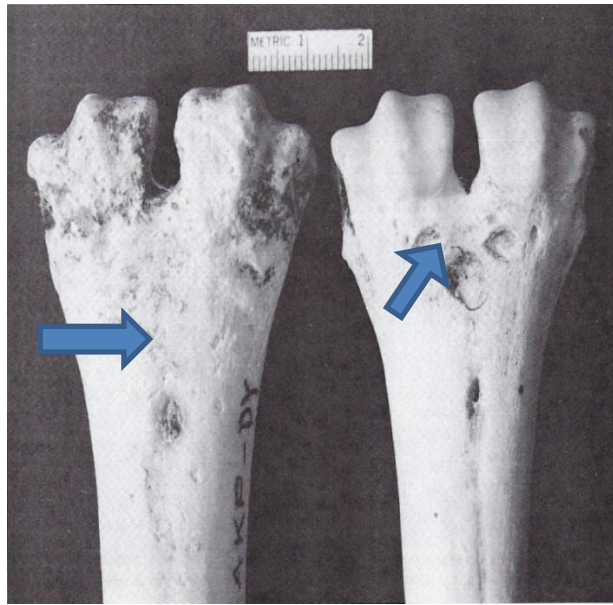


Figure 4: Puncture Marks on Bone

According to Wiley and Snyder, wolves destroy the more porous long bone ends because they can easily break through the bone cortex and eat the spongy tissue within the bone. Conversely, more compact bone ends, such as the distal tibia and distal femur, will not be fully destroyed but will have punctures. Bones taken by canids from an original kill site to their cave have also been shown to have more gnawing damage due to extensive chewing on the bone at cave sites (Haynes 1983).

Rodent Scavenging

Although rodents are not highly destructive scavengers, their presence in the taphonomic process leads to bone accumulation and modification (Haglund 1997b). Some common rodent scavengers in the United States are brown rats and gray squirrels (Klippel and Synsteliën 2007). In the southwest US, packrats and other small rodents have also been seen scavenging remains (Galloway 1997). Because of the small size of many rodents, they often cannot carry large bones with them. Instead, they are sometimes responsible for transporting small bones, such as carpal bones (Galloway 1997).

Rodents create bone modifications by the action of gnawing, which is characterized by the upper incisors being pressed against a bone, and the lower jaw moving freely in different directions across the bone (Figure 5). They tend to gnaw on skeletal remains to extract either nutrients from the bone depending on the species (Klippel and Synstelién 2007). For example, Klippel (2007) noticed that brown rats were interested in obtaining nutrients from fat-rich cancellous bone. The brown rats attacked bone ends with minimal cortical thickness to obtain desired nutrients. In contrast, gray squirrels attack more dense bone ends to obtain minerals such as calcium.

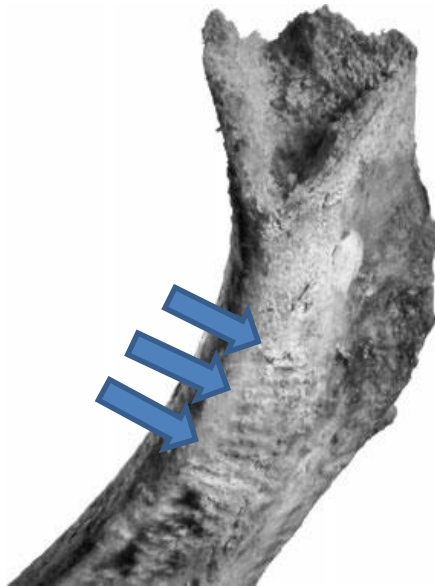


Figure 5: Striations on Bone Indicating Rodent Scavenging

The gnawing motion leaves striations or flat-bottomed grooves on bones that can be distinguished by investigators as rodent scavenging (Haglund 1997b; Klippel and Synstelién 2007). Rodent gnaw marks can usually be distinguished from canid scavenging marks because rodents do not damage soft tissue or leave claw-induced scratch marks (Haglund 1997b).

Vulture Scavenging

In more arid regions, such as the southwest United States, vultures occasionally are primary scavengers. The Turkey Vulture (*Cathartes aura*) and Black Vulture (*Coragyps atratus*)

are the most common species to the area (Kjorlien et al. 2009; Reeves 2009; Rippley et al. 2012; Spradley et al. 2012). Vultures have a difficult time capturing live animals and, therefore, are predominately scavengers (DeVault et al. 2003). They typically scavenge at all levels of decomposition and have the ability to effectively scavenge an entire body in a very short time (Reeves 2009; Rippley et al. 2012).

Vultures leave distinct marks on skeletal remains in the form of scratches or punctures, which can be distinguished by investigators as vulture scavenging (Reeves 2009, Pharr 2014) (Figure 6). Vulture punctures can be seen in areas of thin bone, such as the eye orbit, and are usually triangular in shape. Vultures can also greatly accelerate the rate of skeletonization when they are given full access to a body (Reeves 2009). However, using vulture scavenging to assess topics, such as postmortem interval (PMI), can be misleading.

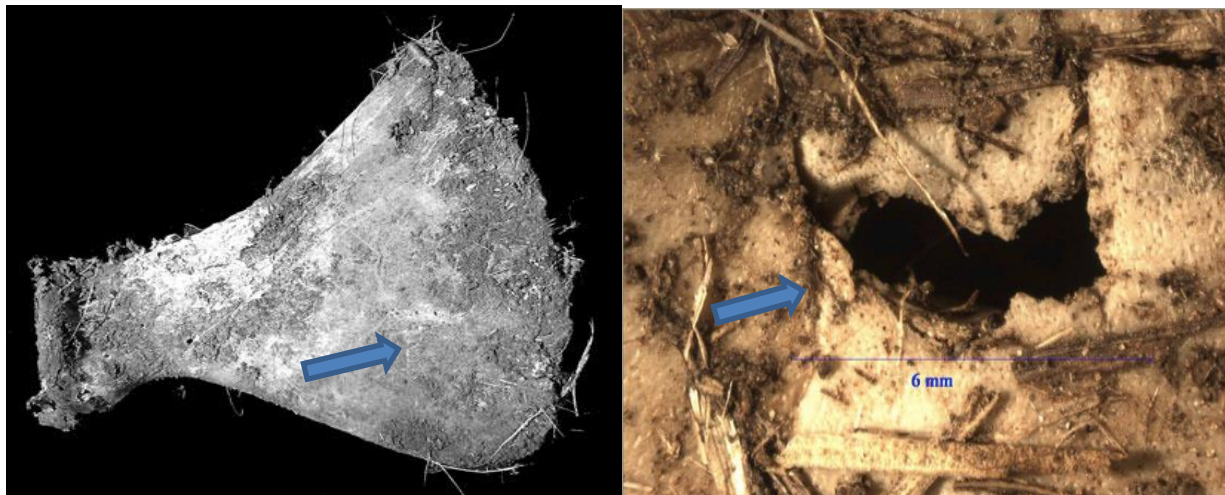


Figure 6: Scratch and Puncture Marks on Pig Scapula Indicating Vulture Scavenging

During a vulture scavenging study by Reeves (2009), vultures began scavenging remains 24 hours after the initial deposit of the bodies. Within 96 hours, the vultures left all the cadavers completely skeletonized. Based on her results, Reeves concluded that vulture scavenging patterns could effectively help estimate PMI intervals. However, a similar study done by Spradley et al. (2012) at the same site displayed drastically different results. In their vulture

scavenging experiment, 37 days passed before vulture scavenging ensued. The stark differences between Reeves (2009) and Spradley et al. (2012), led Spradley and her colleagues to reconsider the validity of using vulture scavenging patterns to estimate PMI.

Pharr (2014) also conducted an experiment to assess vulture scavenging patterns. Pharr was interested in vultures' importance to assessing PMI estimations. Based on her results, vultures were the primary scavenger in the majority of cases she investigated. Vultures scavenged fresh carrion within the first five days of exposure in many cases. In terms of PMI estimation, Pharr encouraged the use of vulture down feathers found at the scavenging site to more properly assess PMI. The condition of the feathers left at the site where scavenging occurred could help investigators narrow the PMI estimations, according to Pharr.

Studying Animal Scavenging in Southern Arizona

Since the mid-1990s, an increase in U.S.-Mexico border security has forced undocumented migration to shift to more remote areas, such as the Sonora Desert in Arizona (De León 2012). Escalating violence along the border has forced many Mexican and Central American families to migrate to America. Despite the unruly environmental conditions and heightened border security, migration through Arizona is still highly prevalent (De León 2012; Slack and Whiteford 2011). While border security may be weaker in more remote regions across Arizona, the environmental and physical conditions of the area pose the biggest challenge for migrants. In 2010, a record-breaking 252 bodies were discovered in desert regions of Arizona (Slack and Whiteford 2011). Because of the remoteness and low population density of southern Arizona, bodies remain in the desert area for long periods of time without being discovered. The extended period of exposure allows scavengers to attack and return to bodies as freely as possible.

Environment in Southern Arizona

The Southern Arizona climate is characterized by hot, arid summers and mild winters. The average high temperatures in Tucson usually exceed 100°F during the summer months and the mid-60s during the winter months. Temperatures in the nighttime usually remain high in the summer but often reach below freezing during winter nights. The humidity on average is about 30% but drops to 17 or 18% during the summer. Rainfall is heaviest during the summer monsoon season of July and August when approximately two inches of rain fall per month. Flooding often occurs during the monsoon months, but since the duration of the rainfall is limited, the flooding waters recede within one to three days (Galloway 1997; Hoffmeister 1986).

The southern area of Arizona is characterized by low desert below 5,000 feet as opposed to the northern mountainous region separated by the Mogollon Plateau. Vegetation in the region is limited because the soils are underlain with hard clay, known as caliche hardpan, which makes it difficult for plants to grow. Plants that are present are creosote brush, tarbrush, and whitethorn, as well as various species of tall columnar cacti. (Galloway 1997; Hoffmesiter 1986).

Fauna in Southern Arizona

When studying animal scavenging, becoming familiar with the local and regional wildlife in the area is critical (Ripley et al. 2012). Knowing the fauna of the region will not only give the investigator a better understanding of which animals scavenge but also the motives for scavenging on carrion. With regard to the US Southwest, the southern region of Arizona has many species not common to the northern parts of Arizona, as well as species that have crossed from Mexico. Some of the species most common to southern Arizona include the white tailed deer, peccaries or javelinas, mountain sheep, jackrabbits, a number of rodents, including various squirrel and rat species, and a large number of predatory species including coyotes, bears,

wolves, and even jaguars (Hoffmeister 1986). Avian species, such as the American Black Vulture and Turkey Vulture are also common to the area (Reeves 2009).

My main focus will be on canid species because they are the most common animals that scavenge on human remains in Arizona (Galloway et al. 1989; Galloway 1997). Small rodents and avian species have also been known to scavenge in the area and will be considered as well (Galloway 1997).

Previous Animal Scavenging Studies in Southern Arizona

Galloway (1997) found results similar to Hill's (1984) when conducting decomposition research in the extremely arid region of the Arizona-Sonora desert. Because of the intense heat and low humidity in desert areas, early decomposition is followed by dehydration of the outer surface resulting in mummification in some bodies (Galloway 1997; Haglund 1989; Hill 1984). The dehydration leads to a thick, leathery covering over the body. Access to a body is a major variable affecting scavenger's activities, and mummification due to intense heat can create a barrier for scavengers. (Blumenshine 1987; DeVault et al. 2004; Galloway 1997; Haglund 1989).

During the bloat stage of decomposition, volatile organic compounds are released from the body, which causes strong odors that attract scavengers (O'Brien et al. 2010; Galloway 1997). Conversely, when mummification occurs, strong odors are not released but are instead trapped under the thick mummified shell of the body. The lack of emitted odors prevents scavengers from detecting mummified remains. Because of the effects of mummification in desert regions, such as Arizona, Galloway (1997) observed that scavengers in Arizona often do not feed on a body until late stages of skeletonization. The scavenging pattern suggested by Galloway is unlike scavenging patterns in more temperate regions, such as the Pacific Northwest (Haglund et al. 1989).

Haglund's Model in Southern Arizona

One of the main objectives of my research is to analyze the effectiveness of Haglund's Northwest Pacific model when applied to southern Arizona. Haglund and his colleagues (1989) recognize the effects of variables on scavenging activity, such as environment, population density, habitation, animal species, seasonality and food availability (Haglund et al. 1989). Despite the variables being addressed, Haglund and his colleagues provided little insight to whether or not different variables will affect the sequence in which animals disarticulate and scavenge human remains in other regions. My research will use Haglund's model in southern Arizona to determine if comparable results occur. The results will be based on cases in Arizona, which is an area of extremely low population density, intense aridity, and minimal food availability. As Galloway's (1997) study showed, mummification is a common occurrence for bodies found in the US Southwest. The effects of mummification and low population density may alter the ways in which animals scavenge a body.

Chapter III Materials and Methods

Pima County Medical Examiner's Office

The analysis for this research was based on the skeletal remains and records provided by the Pima County Medical Examiner's Office in Tucson, Arizona. Regularly, the Medical Examiner's Office in Tucson receives any human remains discovered within the western two-thirds of the Tucson Sector (Figure 7) (Anderson 2008). Within the Pima County Medical Examiner's Office, the Forensic Science Center (FSC) investigates any deaths that require forensic analysis.



Figure 7. Map of the Southwest United States with the US Border Patrol's Tucson Sector Highlighted (courtesy of USBP).

If the body is unidentified or needs further analysis with regard to skeletal remains, it is sent to the W. H. Birkby Forensic Anthropology Laboratory for further analysis. In the Forensic Anthropology Laboratory, a team of trained forensic anthropologists assess the remains and creates a forensic anthropology report. The report includes where the remains were found, information on estimated age, sex, ancestry and stature, PMI range, trauma, pathology, and any

other information deemed vital to the case. In 2012, 161 cases were examined in the Forensic Anthropology Laboratory with 63% of those cases being skeletal remains (Figure 8) (Anderson 2012).

Some challenges forensic anthropologists must cope with in the Pima County Medical Examiner's Office are the large number of unidentifiable migrant remains, and the difficulty of locating remains quickly. A large number of Mexican and Central American immigrants are extremely difficult to identify because many individuals found in remote desert regions do not have proper identification. After an extended period of time, bodies become increasingly difficult to identify because PMI estimations become less reliable, and skeletal remains have been heavily scavenged and scattered. The Pima County Medical Examiner's Office is faced with the unruly task of an extensive number of cases and, often times, cases with minimal remains to analyze.

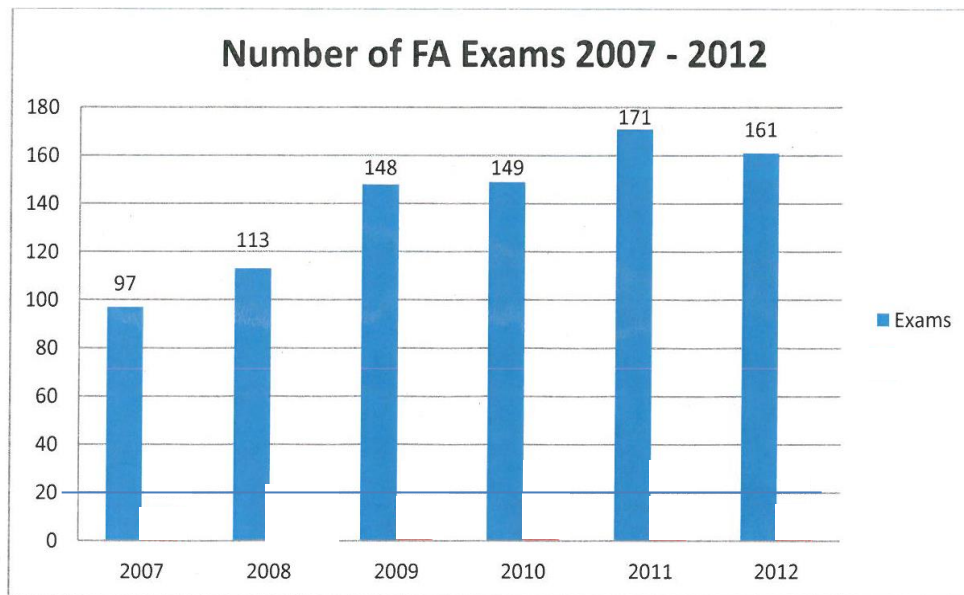


Figure 8. Number of Forensic Anthropology (FA) Cases between 2007 and 2012

My analysis began by establishing a feasible number of cases necessary for producing accurate results and conclusions. As my time to conduct research in Tucson was brief, I was able to use 60 cases to obtain results. Among the 60 cases, 33 were from 2011, seven were from 2012,

19 were from 2013 and one case was from 1992. The cases were chosen based on the cases available to me at the Pima County Medical Examiner's Office and are not a result of random sampling.

The selection of the cases was based on availability and accessibility in the Pima County office. Because of the vast number of cases, the Pima Medical Examiner's Office does not normally hold remains from previous years. Therefore, I was only able to view and photograph the actual remains of the 19 cases from 2013 and the one case from 1992. For the remaining 40 cases, I was given full access to the forensic anthropology reports. From the reports, I noted the skeletal elements present for each case as well as PMI, age, sex, ancestry, and information regarding pathology.

The forensic anthropology report also contained information regarding the location of the recovered remains. Of the 60 cases I investigated, 39 contained information of the exact location of the recovered remains. The exact coordinates of the remaining 21 cases were not disclosed in the forensic anthropology reports and were, therefore, not mapped. Figure 9 shows the known location of the 39 cases across Arizona. Of the 39 cases in which the location was known and mapped, 38 cases were discovered south of Phoenix in remote desert regions. With the exception of two cases, the remains of the individuals have yet to be formally identified by the Pima County Medical Examiner's Office. Because of the remote locations of the remains recovered, the majority of the cases have been assumed to be the remains of Mexican and Central American immigrants.

Animal Scavenging Sequence

Haglund's Northwest Pacific model was created from his analysis of 30 cases. Haglund's conclusions on animal scavenging sequencing were primarily based on the element

representation of each case. He formed conclusions on the order in which animals scavenge a body by categorizing each case according to their stage of disarticulation and their elemental representation.



Figure 9: Exact Location of 39 Pima County Cases (created courtesy of Google Maps)

The categorization was a scale between 0-4, with each increasing stage showing greater amounts of disarticulation and less elemental representation. Stage 0 is described as the removal of soft tissue with no disarticulation and full elemental representation. However, stage 0 can sometimes be associated with missing hands and feet from minor rodent scavenging. Stage 1 is the destruction of the ventral thorax characterized by absence of the sternum and damage to distal ribs, accompanied by evisceration and removal of one or both upper extremities, including scapulae and partial or complete removal of clavicles.

Stage 2 is characterized by fully or partially separated and removed lower extremities. Stage 3 is described as nearly complete disarticulation with only segments of vertebral column articulated. Stage 4 is represented by total disarticulation and scattering, with only cranium and assorted skeletal elements or fragments recovered.

Atypical scavenged remains were designated by the letter “A” (Haglund 1989). According to Haglund, cases are described as atypical if the bones recovered or damaged did not correspond with the expected sequence of animal scavenging. An example of an atypical case would be one where the skull and vertebrae were scavenged and scattered first as opposed to being the last elements to be scavenged and scattered. Another example of an atypical case would be one in which all the elements are disarticulated, but the remains are not scavenged or scattered. Of the 30 cases Haglund examined, eight cases were atypical. By comparing the stages of disarticulation to postmortem intervals, Haglund was able to create a model on the sequence in which animals scavenge a body. Haglund’s stages specific to the Northwest Pacific model created a compatible method for testing his model in other geographical regions.

The initial step in comparing Haglund’s model to Arizona was creating a bone inventory for each of the 60 Pima County cases. The bone inventory would outline the elemental representation and stage of disarticulation for each case. The inventory of each case would also allow me to duplicate Haglund’s methodology for comparison.

After the inventory was taken for each case, I assessed the remains and determined the stage of disarticulation for each case. For the 60 cases from the Pima County Medical Examiner’s Office, if a case coincided with one of the stages presented by Haglund, the case was considered as “fitting Haglund’s model.” If a case did not coincide with one of Haglund’s stages, the case was deemed atypical and therefore “not fitting Haglund’s model.”

By using the same stages as Haglund, comparable results could be made on whether or not Haglund’s model can be applied to southern Arizona. Due to the stark environmental and geographical differences between the Northwest Pacific and the US Southwest, I hypothesized a drastic difference in the sequence in which animals scavenge a human body.

To statistically compare the results, Fisher's exact probability test was conducted. Fisher's test is designed to test the independence of frequency data classified on two dichotomous variables (2×2 contingency table). This test is generally used with small samples where the chi-square test is inappropriate. Fisher's test was used to determine the statistical significance between Haglund's Northwest Pacific results and my southern Arizona results. Using the program JMP 11 for calculations, Fisher's test provided an exact P-value that represents the degree of statistical significance between two groups.

Animal Scavenging Patterns

The next phase of analysis in Arizona was a more in-depth look at skeletal remains from cases housed in the Pima County Medical Examiner's office. Because of the limited number of cases retained by the Pima County Medical Examiner's Office, I only examined, documented and photographed 20 cases of actual remains available. However, given the various conditions of each case and the characteristically different PMIs of each body, reliable conclusions could be made from the mere 20 cases. The analysis began with taking photographs of areas on the body that had been scavenged by animals. The photos were taken with a Canon EOS Rebel T3i, and the number of photos for each case depended on the amount of animal scavenging on the body.

After the photos had been taken, notes were taken on the condition of the body, the elements missing and present, the bones that had been scavenged, and any other observations considered to be vital. Once the necessary photographs and notes were acquired, I was able to access the forensic anthropology report for each case. From the case file, I noted the PMI of each case, the location of the body, and any other information that would help in the analysis.

The next step was to analyze each case individually and document the scavenging marks for each bone that had been scavenged. I noted puncture marks, pitting, and furrowing on

specific bones caused by chewing or gnawing by animals. I also documented the elemental representation of each case along with the frequency of scavenging on different skeletal elements. Upon further analysis, I recorded the specific location of animal scavenging on each skeletal element represented. The location of the scavenging on the skeletal elements speaks to the area of bone animals most frequently scavenge. Once the documentation was completed, I made a conclusion on the probable scavengers for each case, and the way in which the scavengers attacked the body. Finally, several examples of cases at different stages of decomposition were provided to provide a more in-depth look at the scavenging patterns.

Postmortem Interval and Animal Scavenging

The final section of my research dealt with postmortem (PMI) estimations and their relationship to animal scavenging. In Haglund's Northwest Pacific model, PMI estimations of the 30 scavenged cases he investigated contributed a role in assigning stage of disarticulation. In sum, PMI and stage of disarticulation were strongly correlated in the Pacific Northwest. My goal in the southern Arizona model was to determine the type of interdependence between PMI and stage of disarticulation in the area.

The analysis of PMI was taken from 42 of the 60 Pima County cases. There were 18 cases where PMI and/or stage of disarticulation were not known and, therefore, were not able to be statistically compared for interdependence. For the 42 cases used, the PMI estimations were determined by forensic anthropologists at the Pima County Medical Examiner's Office. The estimates were based on a combination of overall condition of the body, stage of decomposition, bone bleaching and weathering, and the amount of tissue remaining on the remains. Animal scavenging was not a major component of assigning PMI in southern Arizona, but the

relationship of PMI to stage of disarticulation could contribute to forensic anthropologists' assessment of PMI in future cases depending on the results of my analysis.

However, PMI ranges for the 42 cases were often too large to correlate properly. To resolve the issue, I created four PMI ranges that would encompass and accurately represent all 42 Pima County cases. The four ranges were: 1) 1 day to 1 month, 2) 1 month to 8 months, 3) 8 months to 2 years, and 4) >2 years. The four ranges were created to include all 42 cases and were independent of stage of disarticulation.

For further analysis I applied a chi-squared to statistically test the interdependence of the two variables. The chi-squared test was conducted with a .05 significance level. The null hypothesis for the test was that the two variables are independent of each other. The results of the chi-squared test were able to express the level of dependence between PMI and stage of disarticulation.

Chapter IV Results

Haglund's Stages of Disarticulation

I evaluated each case to determine the validity of using Haglund's stages of disarticulation for the Pima County cases. For each case I assigned either a stage (0-4), or I noted that Haglund's categorization could not apply to the case ("A"). The overall condition of the body as well as the elemental representation provided by the forensic anthropology report was considered when assigning a stage of disarticulation to a specific case. After evaluation of each of the 60 cases, I was able to apply a stage to 48 of the cases. A stage of disarticulation did not apply to 12 cases for various reasons. For several of the atypical cases, the elemental representation did not match the sequence of disarticulation outlined by Haglund. For other cases, the lack of scavenging, scattering, and disarticulation did not coincide with the postmortem interval. Table 1 is a summary of the stages of disarticulation for the 60 Pima County cases. Figure 10 displays the number of cases for each stage of disarticulation.

Table 1. Summary of Stages of Disarticulation for 60 Pima County Cases

Stage 0	Four cases were in stage 0 and fit Haglund's model
Stage 1	Four cases were in stage 1 and fit Haglund's model
Stage 2	Seven cases were in stage 2 and fit Haglund's model
Stage 3	12 cases were in stage 3 and fit Haglund's model
Stage 4	21 cases were in stage 4 and fit Haglund's model
Atypical cases	12 cases did not fit Haglund's model for various reasons

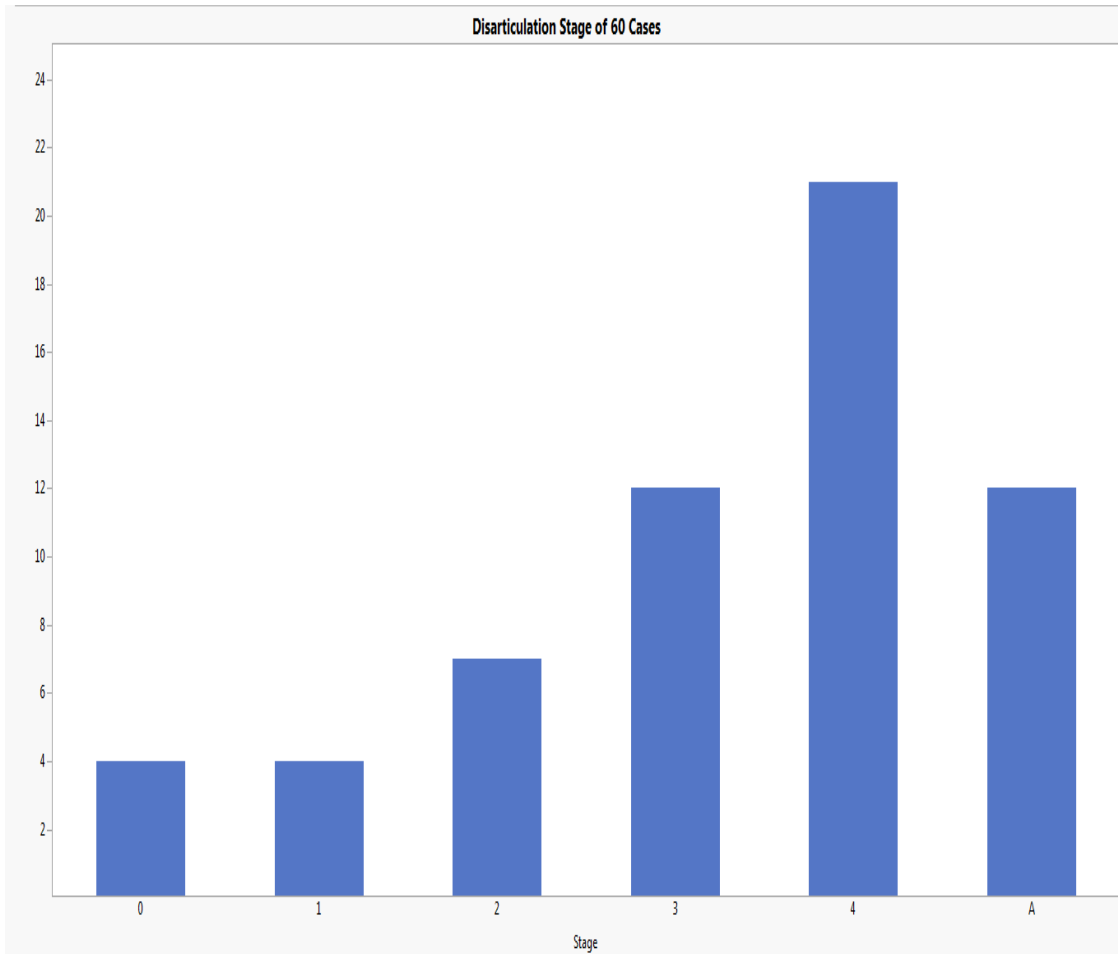


Figure 10. Distribution of Disarticulation Stages for 60 Pima County Cases

Statistical Analysis

Fisher's exact probability test was applied to 60 Pima County cases and compared to the results of Haglund's Northwest Pacific cases. For Haglund's Northwest Pacific model, he evaluated 30 cases. Of the 30 cases, 22 fit the model of scavenging sequence he created. For the 60 Pima County cases, 48 cases fit the model of scavenging sequence created by Haglund. Fisher's exact probability test was able to test the statistical significance between the two models. The P-value once the two models were compared was equal to 0.5916. The P-value for the sample indicates the Northwest Pacific model and the Southwest United States model are not statistically significant. Table 2 is a visualization of the Fisher test conducted. The table provides the P-value as well.

Table 2. Fisher’s Exact Test to Statistically Compare the Northwest Pacific and Southern Arizona

	Fits Haglund’s Model	Did not Fit Haglund’s Model	Total
Northwest Pacific	22	8	30
Southern Arizona	48	12	60
Total	70	20	90

P-value = .5916

Skeletal Element Representation

For each of the 60 Pima County cases, I conducted a complete skeletal inventory to assess element representation for each case. The element representation of Haglund’s Northwest Pacific cases was vital in the creation of his animal scavenging sequence model. By assessing the skeletal inventory of each of the Pima County cases, a model for animal scavenging can be achieved for the Southwest United States. Figure 11 represents the percentage of each element present for each case. The graph illustrates the consistent presence of the skull, vertebrae, femora and mandible and a minimal presence of smaller elements, such as the hands and feet.

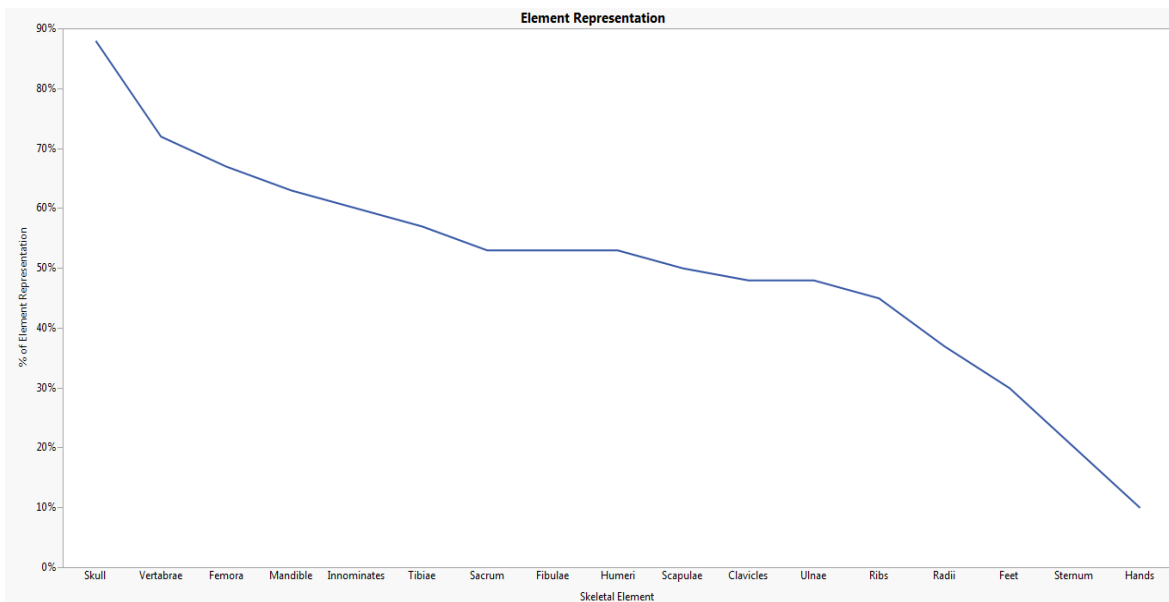


Figure 11. Skeletal Elemental Representation of 60 Pima County Case

Analysis from Remains

Twenty cases were fully documented and photographed for animal scavenging patterns. Each case provided different levels of animal scavenging and damage to different bones. Table 3 shows the stage of decomposition for each case. Of the 20 cases, 16 were completely skeletonized with eight cases having only the skull remaining. Four cases were either partially mummified or completely mummified. One case was in the bloat stage.

Table 3. Stage of Decomposition and PMI of 20 Cases

Case	Stage of decomposition
13-00545	Skeletalization
13-00639	Skeletalization
13-00750	Skeletalization
13-00974	Skeletalization
13-01132	Skeletalization
13-01154	Skeletalization
13-01239	Skeletalization
13-01288	Mummification
13-01446	Skeletalization
13-01674	Skeletalization; some mummification
13-01833	Mummification
92-013	Skeletonization
13-01612	Skeletonization
13-01613	Skeletonization
13-01724	Mummification
13-01921	Skeletonization
13-01947	Bloat
13-01436	Skeletonization
13-01498	Skeletonization
13-01532	Skeletonization

A bone inventory was conducted to report the frequency of each skeletal element in the 20 cases photographed. Each skeletal element was then investigated to determine if the bone had any signs of animal scavenging. Figure 12 is a representation of the frequency of skeletal elements and the frequency of animal scavenging on each element. The skull and mandible, vertebral column, and lower limbs are the most common bones found from the 20 cases

investigated. From the 20 cases, the ribs, vertebral column and lower limbs are the skeletal elements displaying the most amount of animal scavenging.

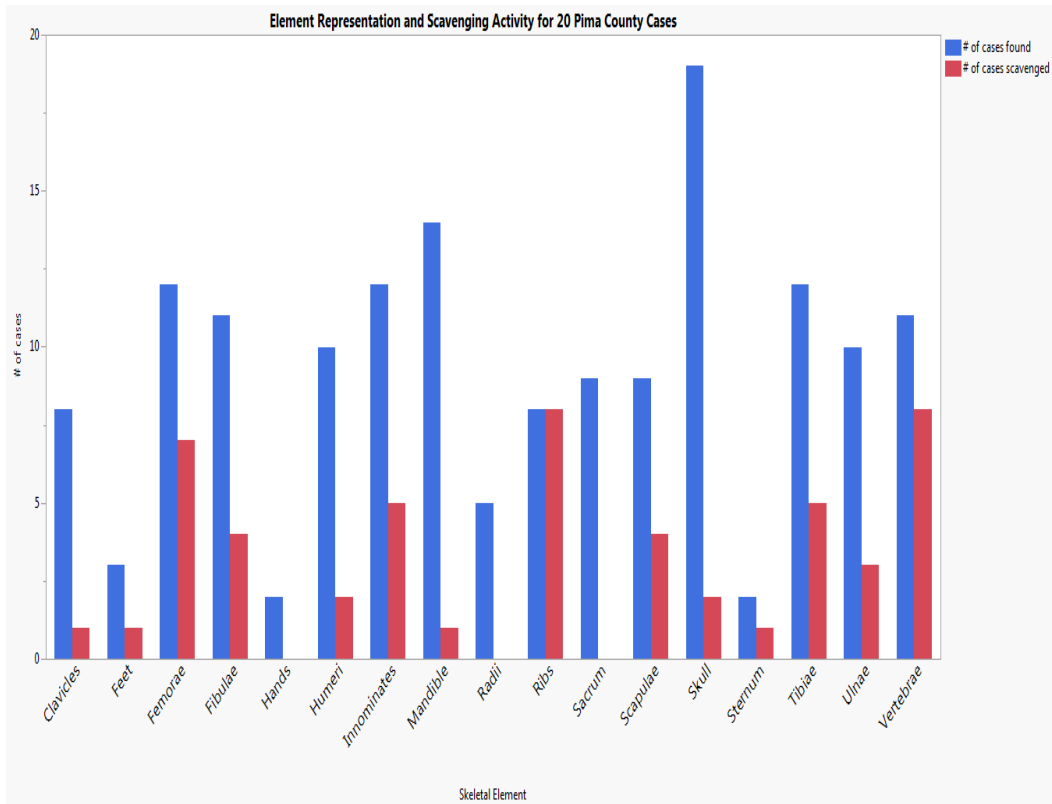


Figure 12. Element Representation and Scavenging Activity for 20 Pima County Cases

Figure 13 represents the location of scavenging on specific skeletal elements for the 20 photographed cases. For each element, only the cases where the element was represented were taken into account. For example, a tibia was found in 12 of the 20 cases and therefore the percentages in Figure 12 with regard to the tibia represent the 12 cases where the tibia was discovered. The upper and lower limbs have the most damage to the proximal and distal ends. The scapulae show furrowing marks on the acromion and coracoid process as well as the body. The vertebra display furrowing on the vertebral bodies and punctures on the transverse processes. The ribs exclusively have puncture marks on the sternal ends, and the clavicles have furrowing marks on the medial and lateral ends.

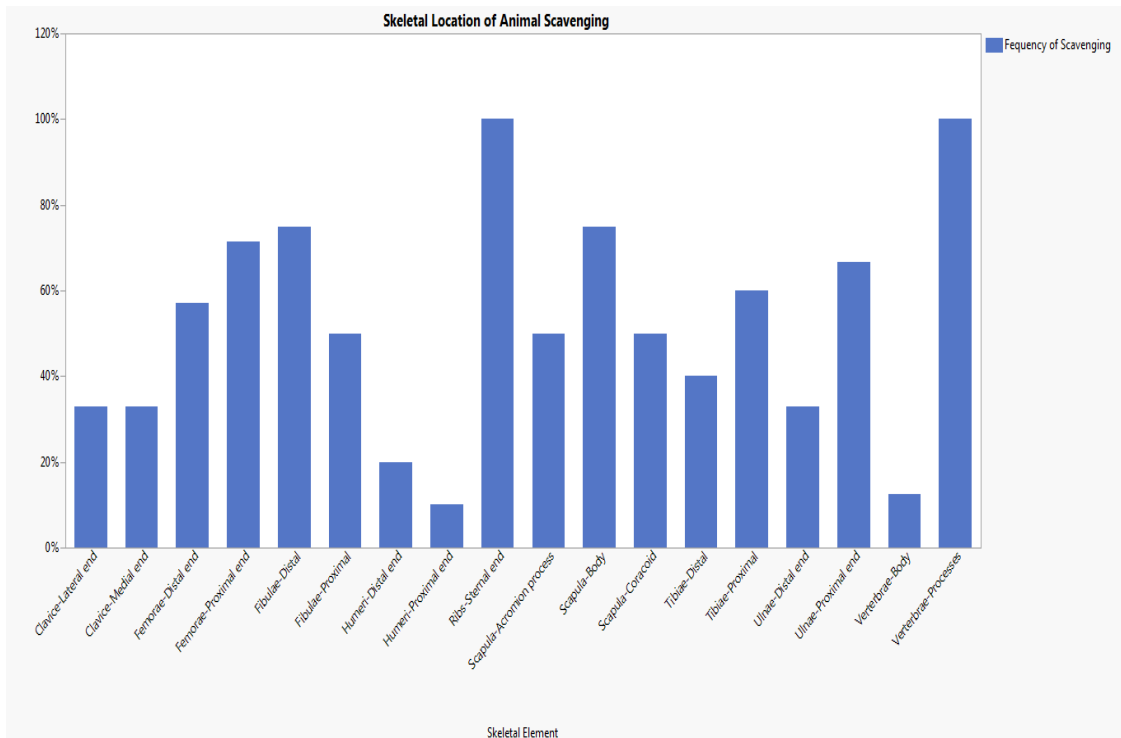


Figure 13. Skeletal Location of Animal Scavenging Marks for 20 Pima County Cases

Examples of Scavenging Patterns in Five Pima County Cases

The following examples provide a more in-depth look at several of the 20 cases. The cases chosen were based on the diverse stages of decomposition encountered in the 20 cases I was able to document and photograph.

Case 13-00639

In Case 13-00639, there was extensive scavenging by a large carnivore on most portions of the body. The ends of long bones, including the right humerus, are heavily scavenged but still remain (Figure 14). The ends of clavicles and parts of scapulae have been scavenged but also remain with the body. The presumed PMI for the case was 4-10 months, and the body was recovered completely skeletonized, almost completely disarticulated, and no signs of prior mummification. From the extensive damage, animals most likely had full access to the body. Elements missing included most ribs, sternum, hands, feet, radius, and fibula.



Figure 14. Head of the Right Humerus with Extensive Furrowing (Case 13-00639)

Case 13-01132

For this case, there is some damage due to weathering but animal scavenging marks are clearly visible on the elements. For the lower limbs, the proximal and distal ends are the most heavily scavenged areas with heavy furrowing evident. For the innominate, the ischium is the only area with furrowing and puncture marks.

The vertebral column and sternal rib ends were also subject to extensive furrowing and puncturing (Figure 15). The probable scavenger is a large carnivore such as a coyote based on the extensive chewing damage on the long bones. No signs of vulture or rodent marks on the body. The lack of many skeletal elements indicates the animals had complete access to the remains and scattered much of the body.

Case 13-01288

Case 13-01288 is a partially mummified body with the right foot and left arm still mummified (Figure 16). Small punctures are present on the lateral condyle of the left femur.



Figure 15. Rib with Puncture Marks and Vertebral Column with Furrowing (Case 13-01132)



Figure 16. Partial Mummification of Case 13-01288

The PMI for the body is 2-12 weeks and the body was found before the monsoon season began. The body was found in a remote desert region, which would indicate the conditions were characterized by extreme aridity. Mummification hindered animal's access to the body, which is why minimal scavenging is seen. The right humerus, radius, ulna, scapula and clavicle are all missing, which suggests that the right portion of the body did not undergo full mummification

and was dragged off by a large carnivore. Minor scavenging is present on most of the body but the ribs have been noticeably punctured (Figure 17).

Case 13-01724

Case 13-01724 is an example of a case that is in a state of mummification across the entire body. The photographs indicate little penetration through the mummification by carnivores or rodents. However, punctures on the arms and feet suggest the presence of vulture scavenging. The medial side of the left foot has a large puncture mark, which is indicative of vulture scavenging. The right foot and left arm remain completely mummified and therefore no scavenging marks are present on those elements.

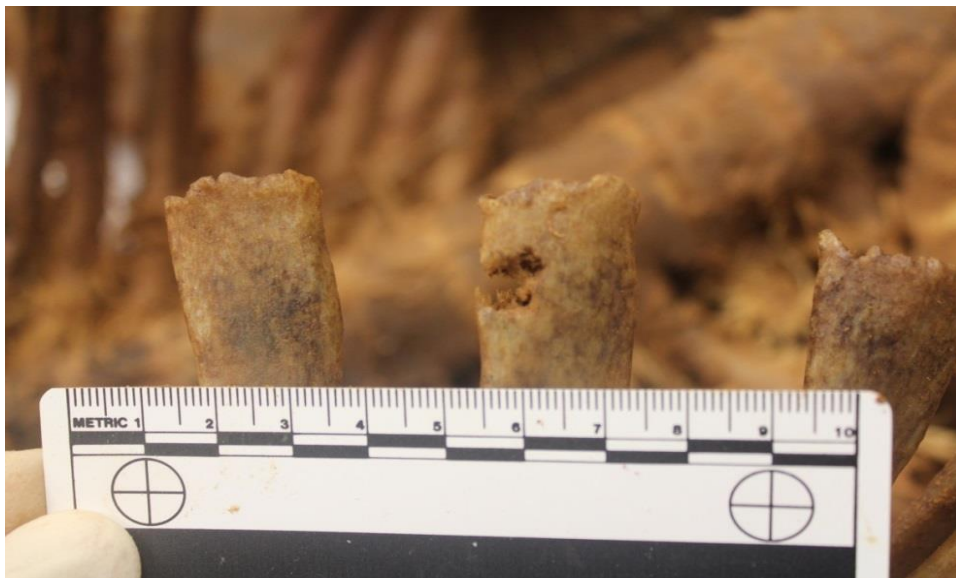


Figure 17. Puncture Mark on Left Rib of Case 13-01288

The left arm also has several breaks in the skin from scavenging (Figure 18). The scavenging is different from normal insect decomposition because the punctures do not occur at natural orifices of the body. The marks are also rough and irregular which would indicate animal puncturing. The body was also found with several black feathers which could be from vultures who scavenged the body (Figure 19). However, a proper analysis on the feathers would need to be done to confirm vulture origin.

Case 13-01947

Of the 20 Pima County cases I photographed, Case 13-01974 was the only case in a complete bloat stage. The PMI was 4-7 days, and the body showed no signs of prior mummification. Carnivore and rodent scavenging was not evident, and the ventral cavity had yet to be attacked by large predators. However, the information on the case file indicated the presence of a number of vultures attacking the face and hands when the body was recovered. The facial muscles were damaged, and both hands were missing from the body.



Figure 18. Presumed Vulture Puncture Marks on the Left Foot and Right Arm of Case 13-01724



Figure 19. Presumed Vulture Feathers Found with Case 13-01724

Postmortem Interval versus Stage of Disarticulation

Forty-two of the 60 Pima County cases were tested to determine the interdependence between PMI estimations established by forensic anthropologists and the stages of disarticulation. The results would indicate if the extent of animal scavenging on remains can be useful in the determination of PMI estimations. Table 4 displays the stage of disarticulation and the coinciding PMI for each case.

The chi-squared test applied was able to show a strong amount of interdependence between PMI estimations and stages of disarticulation. Figure 19 shows the JMP© 11 results which provided the overall chi-squared value as well as the level of statistical significance for the two independent variables.

		SoD					
Count		0	1	2	3	4	
Expected							
Deviation							
Cell Chi^2							
PMI	1	3	1	0	0	0	4
		0.38095	0.28571	0.66667	1.04762	1.61905	
		2.61905	0.71429	-0.66667	-1.0476	-1.619	
		18.0060	1.7857	0.6667	1.0476	1.6190	
2		1	2	5	2	3	13
		1.2381	0.92857	2.16667	3.40476	5.2619	
		-0.2381	1.07143	2.83333	-1.4048	-2.2619	
		0.0458	1.2363	3.7051	0.5796	0.9723	
3		0	0	2	4	7	13
		1.2381	0.92857	2.16667	3.40476	5.2619	
		-1.2381	-0.9286	-0.1667	0.59524	1.7381	
		1.2381	0.9286	0.0128	0.1041	0.5741	
4		0	0	0	5	7	12
		1.14286	0.85714	2	3.14286	4.85714	
		-1.1429	-0.8571	-2	1.85714	2.14286	
		1.1429	0.8571	2.0000	1.0974	0.9454	
		4	3	7	11	17	42

Tests			
N	DF	-LogLike	RSquare (U)
42	12	17.558379	0.2927
Test	ChiSquare	Prob> ChiSq	
Likelihood Ratio	35.117	0.0004*	
Pearson	38.565	0.0001*	

Figure 20. JMP© 11 Results of the Chi-squared Test when Comparing PMI and Stage of Disarticulation of 42 Pima County Cases

Table 4. Stage of Disarticulation and PMI of 42 Pima County Cases*

Case	Stage of Disarticulation	PMI Range	Case	Stage of Disarticulation	PMI Range
1	0	2	22	3	4
2	0	1	23	3	3
3	0	1	24	3	4
4	0	1	25	3	4
5	1	2	26	4	4
6	1	2	27	4	4
7	1	1	28	4	4
8	2	3	29	4	4
9	2	3	30	4	3
10	2	2	31	4	3
11	2	2	32	4	3
12	2	2	33	4	2
13	2	2	34	4	4
14	2	2	35	4	4
15	3	3	36	4	3
16	3	4	37	4	3
17	3	3	38	4	3
18	3	4	39	4	3
19	3	2	40	4	2
20	3	3	41	4	4
21	3	2	42	4	2

*Stages of disarticulation: 0) No disarticulation, 1) minimal disarticulation, 2) moderate disarticulation, 3)severe disarticulation, 4) Full disarticulation. PMI ranges: 1) 1 day to 1 mo., 2)1 mo. to 8 mo., 3) 8 mo. to 2 years, 4) >2 years

Chapter V Discussion

The intent of this study was to evaluate a widely cited model of animal scavenging proposed by Haglund (1989) and apply the same model to southern Arizona. The study was also an attempt to create a preliminary model of animal scavenging patterns in southern Arizona. The material obtained from the Pima County Medical Examiner's Office provided sufficient cases to be analyzed and discussed.

Animal Scavenging Model in Southern Arizona

According to Haglund (1989), animals scavenge a deceased body in a very predictable manner. Animal scavengers will first attack the ventral thorax scavenging elements, such as the sternum, ribs, clavicles, and scapula. The next skeletal elements to be scavenged are the pelvis, lower and upper limbs and the rest of the ventral thorax. This is followed by disarticulation of remaining axial elements and heavy damage to the remaining bones. The final stage is the disarticulation of the vertebrae, with all elements scattered and extensive gnawing on remaining elements. Haglund's conclusions were based on the stage of disarticulation and elemental representation of 30 cases in Washington.

The present study took Haglund's methods and applied them to southern Arizona to test the consistency of the model cross-environmentally. According to the results of 60 Pima County cases, 80% of the cases were scavenged and disarticulated in the predictable fashion Haglund (1989) outlined in his Northwest Pacific study. Statistically, Fisher's exact probability test yielded a p-value of 0.5916 when the two studies were compared. The results from Fisher's test indicate little statistical significance between Haglund's results and my results. The high percentage of cases fitting Haglund's model, in addition to Fischer's test, provide me with viable conclusions on animal scavenging sequencing. The results suggest that animals in southern

Arizona scavenge a body in a relatively similar sequence to that of animals in the Pacific Northwest.

Based on the elemental representation of the 60 Pima County cases, the feet, hands and sternum were the least represented element overall. The skull, femora, and vertebrae showed the highest frequency of representation for the 60 cases. Of the 60 cases, the skull and vertebrae were the most frequently represented skeletal elements. The skull was present in 88% of cases, and the vertebrae were present in 72% of cases; 48% of the time the vertebral column was still fused. Conversely, the sternum, hands, and feet were the least represented elements. The sternum was only represented in 20% of the cases. In addition, the hands were represented in 10% of cases, and the feet were represented in 30% of cases. In terms of elemental representation, the skeletal elements least represented can be interpreted as being the first elements to be scavenged by animals. On the other hand, the skeletal elements represented the most indicate little scavenging and scattering is being done to those elements, and the assumption can be made that those elements are normally last to be scavenged. The results of the elemental representation in southern Arizona give credence to Haglund's hypothesis that the sternum, hands, and feet are the first elements to be scavenged, while the skull and vertebral column are the last elements to be scavenged.

However, despite the overall consistency of applying Haglund's model in southern Arizona, there are still discrepancies between the results. The main difference involves the clavicle/scapula and the radius/ulna. According to Haglund's model, the clavicles and scapulae should be two of the first skeletal elements scavenged and, in turn, should not be highly represented. However, the clavicles and scapulae are present in 50% of the cases. In contrast, the radii (37%) and ulnae (48%) are represented less frequently than the clavicles and scapulae. The

results from the Pima County cases indicate that radii and ulnae are scavenged before scapulae and clavicles.

The minor disparity between the Northwest Pacific results and the southern Arizona results with regard to elemental representation, led me to create a slightly different model from Haglund on the sequence in which animals scavenge a body. I suggest that, in southern Arizona, animals first scavenge the hands and feet, followed by the ribs and sternum. The next elements to be scavenged are the ulnae and radii, followed by the clavicles and scapulae. The humeri, fibulae, tibia and femora are scavenged next, followed by the sacrum and the pelvis. The final elements to be scavenged are the vertebral column and skull, which are often times not scavenged at all.

A main reason for the slight difference in the two experiments may be the environmental differences between the Pacific Northwest and southern Arizona. As several researchers have mentioned, intense heat can often times result in mummification of a body during decomposition (Galloway 1997, Haglund 1989, Hill 1979). The mummification can occur between the tenth day and first month and can last as long as nine months (Galloway 1997). In Haglund's Northwest Pacific model, mummification was not particularly an issue, and carnivore scavenging began as early as four days. However, in southern Arizona, mummification can greatly hinder carnivore scavenging for several weeks or months.

Mummification on the body does not cease at the same time across the body. Therefore, scavenging patterns by animals, especially carnivores, can be dependent on the presence of mummification. For example, in case 13-01288, scavenging has occurred as seen by the missing skeletal elements and scavenging on the ribs. However, the left arm and right foot remain completely mummified, and no degree of scavenging is present on the two elements. The hands

and feet are primarily the first elements to be scavenged, but Case 13-01288 shows the effects mummification has on animal scavenging patterns. The extent and prevalence of mummification in different cases could account for the inconsistencies between the sequencing patterns in southern Arizona and the Pacific Northwest. However, a further study with regards to timing of mummification is needed to make more accurate conclusions.

Animal Scavenging in Southern Arizona: Patterns and Scavengers

A major part of my analysis involved a more in-depth investigation of several recorded cases. I was able to photograph and record the skeletal remains of 20 cases from the Pima County Medical Examiner's Office. The photographs and documentation of each case gave a different scenario of animal scavenging. However, the patterns of scavenging were consistent amongst the cases. As Binford (1981) claimed, furrowing and punctures are the most common marks of animal scavenging on bone. Overall, both puncturing and furrowing were highly prevalent in the 20 Pima County cases. Puncturing was more common in cases where the remains were still mummified, as in cases 13-01288 and 13-01724. Heavy furrowing was evident in cases with extended PMIs, such as Case 13-00639.

Scavenging in the long bones was primarily seen at the proximal and distal ends of the bones. Furrowing marks can be seen in many upper and lower limbs from the scooping out effect Binford (1981) mentioned. When the ribs were represented in a case, puncturing was evident 100% of the time. Scavenging marks on ribs were so predominant and common for two reasons. The first reason was because animals damage ribs when trying to obtain vital organs underneath the rib cage. The second reason is that punctures occur easily on the sternal ends of ribs because animals often chew the ends of ribs to obtain nutrient-rich cartilage. For the vertebrae, scavenging was heavy in many cases primarily because the vertebral column remained intact. In

several southern Arizona cases, the intervertebral discs between the vertebrae became hardened after extensive time exposed to the heat. For example, in Case 92-01, fusion of intervertebral discs to the vertebrae left the entire vertebral column intact, despite a PMI of 5 years. The fusion of the vertebral column in some cases leads to the inability, or unwillingness, of scavenging by scavengers. As a result, scavenging on the vertebrae to obtain nutrients is done last but often times done at the site of death. In the southern Arizona example, this led to a large representation of intact vertebral columns, and high amounts of scavenging on the vertebral body and processes.

Other areas of bone scavenged were primarily in areas where scavenging was predicted. As previous studies have shown, cancellous bone, such as the proximal ends of long bones, is sought out by scavengers because it is rich in hemopoietic tissues (Binford 1981, Hayes 1980, Moraitis and Spiliopoulou 2010). In southern Arizona, the areas of cancellous bone were, in fact, the most frequently scavenged part of the bone in the 20 cases investigated.

The 20 Pima County cases photographed and documented also provided insight to the types of animals scavenging in the area. Coyotes and dogs are presumably the most common scavengers with a large number of cases showing signs of furrowing and puncture typical of canids. However, the primary scavenger for some cases, such as Case 13-00639, could have been a larger carnivore given the high degree of furrowing to some of the bones. Vulture marks can also be seen on the mummified cases where little scavenging has occurred. Vultures seem to be the only animals that scavenge while the body is still in mummification, as seen in Case 13-01724. Vultures are primary scavengers and will swarm to attack a body (Ripley et al. 2012). In terms of rodent scavenging, visible rodent marks were not seen on any of the skeletal remains investigated. Rodents may be the primary scavengers of hands and feet for many cases, but without an acutalistic study conclusions of rodent scavenging is not possible at this time.

The Arizona case that was still in bloat phase, Case 13-01974, showed signs of vultures swarming as vultures were seen attacking the face and hands of the individual upon discovery. If vultures are able to disarticulate and scatter portions of the hands and feet by the act of puncturing, it may explain the reason hands and feet are the least represented elements for the cases I investigated. For mummified cases, vultures seem to initially scavenge the body by disarticulating the hands and feet. After vultures can no longer penetrate the mummified skin, carnivores may come and attack the ventral thorax depending on the amount and extent of mummification still prevalent.

For cases that are not mummified, it is difficult to conclude the initial scavenger for each case. However, Case 13-01974 proved that vultures were the initial scavengers in that case. The body was in a bloat stage with a PMI of approximately a week. The only signs of scavenging were vultures as seen in the face and hands. However, the results of case 13-01974 may not represent the scavenging patterns of every case in southern Arizona. Either vultures, or carnivores, could realistically reach the body first and begin scavenging. Further tests and taphonomic experiments need to be done in order to make more accurate conclusions on primary scavengers in the southern Arizona, but the 20 Pima County cases I investigated provide initial insight to the scavenging patterns in the area.

Animal Scavenging: Implications for Postmortem Interval in Southern Arizona

The results of the chi-squared test comparing PMI and stage of disarticulation show a strong dependence between the two variables. Therefore, disarticulation due to animal scavenging can be useful in estimating postmortem intervals. However, the limits of using stage of disarticulation for PMI estimations can be seen in the later stages of disarticulation. For a large number of cases postmortem intervals become increasingly difficult in southern Arizona

due to the extended period of time cases remained uncovered. The amount of disarticulation caused by animals is a reliable indicator of PMI in the early stages of disarticulation but becomes increasingly difficult once all the skeletal elements have been disarticulated, scavenged, and scattered. Despite the issues plaguing PMI estimations for cases that go undetected for several years, disarticulation caused by animal scavenging should be considered more when assessing PMI. Understanding the timing of disarticulation by animals could help narrow PMI estimations in order to positively identify more remains.

Chapter VI Conclusion

The research presented has provided vital information regarding animal scavenging in southern Arizona. The cases I investigated from the Pima County Medical Examiner's office in Tucson, Arizona, provided me with enough information to create a preliminary model of animal scavenging patterns as well as validate the compatibility of Haglund's Northwest Pacific model. Based on the results, Haglund's model proved to be relatively applicable when discussing the sequence in which animals scavenge a body in southern Arizona. I presented a slightly revised animal scavenging sequence for southern Arizona based on the elemental representation of 60 cases.

The aridity and extreme heat proved to be important for several of the cases I viewed and documented. I briefly discussed how the effects of mummification can severely alter the sequence of scavenging and disarticulation. Mummification and the effects it has on scavenging could be investigated further in the future. Research could include timing and duration of mummification as well as more specific information on the effects mummification has on animal scavenging in southern Arizona.

I provided vital information on types of scavengers in southern Arizona. However, more actualistic experiments could be done in the area to determine primary scavengers. Vultures proved to be important scavengers because they seemed to be the only animals able to penetrate mummified skin. They were also seen as primary scavengers in several cases. Further research on vulture scavenging specific to southern Arizona would also be helpful in the taphonomic discourse.

Postmortem interval and its relation to animal scavenging is another subject researchers can expound upon in the future. I showed the relatively strong interdependence between PMI and

stage of disarticulation despite the limitations in the later stages of disarticulation. Animal scavenging can be useful when assessing PMI once a better understanding of Haglund's stages of disarticulation is met in southern Arizona. From my research, forensic anthropologists in southern Arizona can begin to more closely evaluate animal scavenging and the amount of disarticulation when assessing PMI.

The southwest United States has been an area of much forensic interest since the rise of Mexican immigration and border security in the early 2000s (DeLeon 2012). The trends of increased migration show few signs of halting, and the intense heat will remain constant from year to year. Therefore, the southwest United States, and, more particularly, the Sonora desert area in south Arizona, will continue to see a large number of unidentified skeletal remains every year. Forensic anthropologists and forensic taphonomists have the increased pressure of attempting to find the identity of individuals found in remote desert regions. The task may seem insurmountable, but increased research and advanced technology in the area will help tackle the issue at hand. Animal scavenging is a major taphonomic process that modifies bone, alters PMI, and leaves patterns on the body for forensic scientists to analyze. By presenting a preliminary model of animal scavenging with an in-depth look at patterns and sequences, a more complete picture of the taphonomic processes in the southern Arizona can be seen.

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Appendices

Appendix A. PMI and Stage of Disarticulation for 52 cases

Case	Stage of Disarticulation	PMI range	Case	Stage of Disarticulation	PMI range
11-00277	A	2-5 years	11-01966	A	1-2 years
11-00297	3	1-2 years	11-01998	1	1-8 months
11-00394	4	2-20 years	11-02194	3	2-10 months
11-00529	A	2-6 months	11-02214	2	2-10 months
11-00570	4	2-20 years	11-02458	2	2-10 months
11-00573	3	2-20 years	11-02626	3	6 months to 1 year
11-00800	A	8-18 months	11-00700	A	1.5-5 years
11-00829	A	2 months - 1 year	12-00804	A	Over 2 years
11-01066	A	1-2 years	12-00847	4	1.5-5 years
11-01096	4	2-20 years	12-00848	4	8 months - 1.5 years
11-01146	0	1-3 months	12-00860	4	1-2 years
11-01293	2	1-2 years	12-00889	A	6-14 months
11-01307	0	1-2 weeks	12-00905	4	6 months to 1.5 years
11-01408	A	1-2 years	12-01485	0	1-2 weeks
11-01412	4	1.5-5 years	13-00545	4	1-3 years
11-01416	4	8-16 months	13-00639	3	4-10 months
11-01455	4	1-2 years	13-00750	4	4-10 months
11-01474	3	1-2 years	13-00974	4	>2 years
11-01535	4	1-3 years	13-01132	3	2-4 years
11-01580	2	6-18 months	13-01154	3	6 months to 1.5 years
11-01601	4	4-12 months	13-01239	4	2-10 months
11-01658	2	1-3 months	13-01288	1	2-12 weeks
11-01814	2	2-8 months	13-01446	3	1-5 years
11-01845	3	2-5 years	13-01674	2	3-12 months
11-01862	4	3-10 years	13-01833	1	5-15 days
11-01964	A	2 months - 1 year	92-013	3	1-5 years

Appendix B: Stage of Disarticulation of 60 Pima County Cases

Case	Stage of Disarticulation	Case	Stage of Disarticulation
11-00277	A	11-01862	4
11-00297	3	11-01964	A
11-00394	4	11-01966	A
11-00529	A	11-01998	1
11-00570	4	11-02194	3
11-00573	3	11-02214	A
11-00800	A	11-02458	3
11-00829	A	11-02626	3
11-01066	A	11-00700	A
11-01096	4	12-00804	A
11-01146	0	12-00847	4
11-01293	2	12-00848	4
11-01408	A	12-00889	A

11-01416	4	12-01485	0
11-01455	4	13-00545	4
11-01474	3	13-00639	3
11-01535	4	13-00750	4
11-01580	2	13-00974	4
11-01601	4	13-01132	3
11-01658	2	13-01154	3
11-01814	2	13-01239	4
11-01845	3	13-01288	1
92-013	3	13-01446	3
13-01833	1	13-01674	2
13-01612	3	13-01947	0
13-01613	4	13-01436	4
13-01724	1	13-01498	4
13-01921	4	13-01532	A
11-01412	4	12-00905	4
11-01307	0	12-00860	4

Vita

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