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THE EFFECTS WILD FIRES HAVE ON SKELETAL REMAINS

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ABSTRACT

Heat induced alterations to skeletal remains have been studied in a variety of settings; but few have investigated what kind of heat induced alterations will occur from a wildfire passing through an area where human remains are present. It is important to examine the effects of a wildfire because the heat delivered differs from the heat produced in an oven or other controlled situation. Heat exposure from a wildfire changes throughout the duration of the fire because it is affected by several variables such as fuel present, weather conditions, topography, and soil composition. This study aims to investigate the extent human remains are altered due to heat exposure from a wildfire. It is proposed that the heat exposure will affect the human remains enough that a forensic analysis will provide inaccurate results. This study also examines if leaf litter covering skeletal material is enough to prevent heat induced alterations from occurring. It is proposed that the leaf litter does not provide a thick enough layer to protect the skeletal remains. A 10 x 10 meter square area in a field was marked off and skeletal material was placed throughout the area on top of the ground and covered under leaf litter. A fire was started at one end of the grid and allowed to spread across the area at a natural pace. After the fire settled, the skeletal material were collected and analyzed to see if heat induced alterations occurred. Visual observations of color change and level of cremation were made as well as weight and dimensional measurements taken. Statistical analyses were conducted in order to examine the relationship between level of cremation and degree heat induced alterations experienced as well as the relationship between level of cremation and presence of leaf litter layer. Results showed that the skeletal material did experience heat induced changes that could complicate and provide inaccurate forensic analyses. They also showed that leaf litter did not show a significant impact on whether or not skeletal material experienced heat induced alterations. This study is important

to the anthropological community because it examines heat induced alterations to skeletal material in a setting that has not been previously studied. Wildfires are a common natural disaster and it is important to know how they affect skeletal material in a forensic or archaeological context. Further studies are needed to expand of the data collected and to back up the results found in this study.

Chapter 1: INTRODUCTION

Burned human remains can appear in many anthropological cases, whether in the forensic or archaeological context. Heat exposure can occur in a variety of manners and may be intentional or accidental. Intentional heat exposure can be seen in cases involving cremations and sometimes cannibalism. The skeletal remains may also become accidentally exposed to heat through a controlled fire used to clear land or a wildfire. It is also important to note that skeletal material may have been exposed to more than one heating event, further complicating investigations (Bennett, 1998; Binford, 1963; Eckert, 1981; Koon et al., 2003; Nicholson, 1993; Pijoan et al., 2007; Taylor et al., 1995; Wells, 1960).

Exposure to heat can result in a variety of alterations to the skeletal material. These alterations include color change, change in mechanical strength, fracturing, and shrinkage. Research needs to be conducted on heat-induced bone modification because these changes can affect current methods used for estimating sex, age at death, stature, and ancestry. The extent to which skeletal material is altered depends a great deal on the temperatures reached and duration of exposure. Ceremonial cremations, criminal cover-ups, and even cannibalism have been studied in the past (Asnussen, 2009; Bennett, 1998; Bohnert et al., 1998; DeHaan and Nurbakhsh, 2001; Fairgrieve, 2008; Mayne Correia, 1997; Richards, 1977; Warren and Maples, 1997), however little research has been conducted on how wildfires can affect skeletal remains.

Many factors must be considered when discussing fires. The heat produced from a wildfire will differ from the heat produced in an oven or kiln. An oven or kiln produces a constant heat at a set temperature while the heat produced from wildfires vary in temperature and duration throughout the stint of that fire. Wildfires themselves will differ from one another depending on certain factors such as the type and amount of fuel present, weather conditions, the temperatures reached, and duration of the fire. Wildfires not only affect the environment above ground but the environment below ground as well. Heat is transferred through the soil with intensity decreasing as depth increases. This means buried items can still be affected up to a certain depth (Bennett, 1998: Fuller, 1991; Neary et al., 2005; Pyne, 1996).

Research needs to be done on wildfires, especially in the northwestern United States, because forest fires occur frequently throughout the area. According to the National Interagency Fire Center, Montana reported a total of 1,731 wildfires in 2009 covering an area of 48,912 acres. The years preceding had even more acres covered by wildfires: 166,842 in 2008 and 778,079 in 2007.

This study sets out to accomplish a couple different things. First of all it will examine what will happen to skeletal material exposed to a wildfire by simulating a wildfire in an area containing skeletal remains. The skeletal remains will lay on the surface of the ground as well as buried under a leaf litter layer. The leaf litter layer will consist of dead leaves, wood shavings, and twigs. The layer is about ½ inch thick, which is enough to cover the remains. The skeletal material will be analyzed before and after exposure to the wildfire and will focus on alterations to coloration, weight, and dimensions. It is proposed that wildfires will in fact be able to cause heat-induced alterations to skeletal material that will affect the accuracy of applying forensic methods used in establishing age, sex, and ancestry. Secondly, does skeletal material buried under leaf litter react differently than skeletal material lying directly on the surface? The skeletal material buried beneath leaf litter will be compared to the skeletal material lying on the surface unobstructed. It is proposed that the accumulated leaf litter layer will not provide the skeletal material with enough covering to avoid heat-induced alterations. Finally, this study will examine if variations are present due to type of bone.

Chapter 2: LITERATURE REVIEW

Characteristics and Effects of Fires

Fire is described as an exothermic oxidation reaction that occurs in two basic forms: flaming and smoldering (DeHaan, 2008). In order for a fire to occur, four basic elements are needed: fuel, oxygen, heat, and chemical oxidation to keep the reaction self-sustaining. A fire's heat output is measured as the heat release rate in kilowatts. This can vary in fires due to different fuels and their availability as well as the amount of oxygen present in the environment. Many other factors influence fire behavior such as topography, weather, and soil environment. This makes predicting and studying fires a complicated task at best.

Ignition and Combustion

Combustion is the reaction of heat, fuel, and oxygen which then produces carbon dioxide, water vapor, and heat (Fuller, 1991; Neary et al., 2005; Pyne 1996). This is characterized by a flame and is classified as either smoldering, also described as glowing, or flaming. For combustion to occur a fuel is heated, known as the pre-ignition phase, to its ignition point at which point the fuel has dried out and its chemical structure breaks down producing flammable gases. It then reacts with oxygen and bursts into flame, or ignites. Ignition thus refers to the transition from pre-ignition to combustion.

Types of Fire

Fires are categorized into four types: ground, surface, transition, and crowning (Neary et al., 2005). A ground fire spreads mostly by smoldering combustion. It will do this in a creeping manner, which means that in one day it may only spread a few decimeters to a few meters.

Ground fires' main sources of fuel are the humus layers found in peat soils and organic muck. They can last anywhere from hours to weeks. Surface fires also creep but by flaming combustion instead of smoldering. If environmental conditions are favorable then the fire can spread much more quickly. Their fuels consist mainly of leaf litter, woody debris, and small plants and trees. The fire will pass over the surface usually in a few minutes, but can last up to hours around logs and other heavy woody debris. This is where extensive soil heating will occur. A crowning fire is also characterized by flaming combustion and burns fuels above the surface about five to fifteen meters off the ground. Although they may release energy at the maximum rate, they only last for a very small amount of time, usually around a minute. Transition fires occur when a fire is changing from a surface to a crown fire. Fires will usually transition from one to the next as it spreads depending on the conditions it comes into contact with.

Types of Fuels

Different fuels will combust differently because of the difference in moisture and chemical properties contained within the fuel. Fuller (1991) and Pyne (1996) classify fuels into three groups: ground fuels, surface fuels, and aerial fuels. Ground fuels refer to duff and humus as well as any buried wood or roots below the surface litter. Surface fuels refer to dead organic matter on the surface such as leaves, needles, logs, twigs, and bark as well as any plants or shrubs less than six feet tall. Aerial fuels are found about four feet or higher off the ground and include trees, shrub canopy, lichens, and mosses.

Fire Severity and Intensity

Fire severity is a term used to describe the magnitude of the disturbance caused by the fire to the surrounding environment (Neary et al., 2005). It accesses the energy or heat given off by the fire to the above ground and below ground environments. The fuels used to sustain the fire and whether the fire is flaming or smoldering will largely determine the fire severity.

Fire intensity differs from fire severity in the fact that it is concerned with the rate of fuel consumption and therefore rate of energy released from the fire (Fuller, 1991; Neary et al., 2005). Fire intensity increases with the consumption rate of the fuel present and can be measured by the length of its flames.

Heat and Heat Transfer

Heat can be transferred by several different processes: radiation, convection, conduction, vaporization, and condensation (DeHaan, 2008; Fairgrieve, 2008; Nearly et al., 2005; Pyne, 1996). Radiation is defined as the transference of heat from one object to another without direct contact. It is passed to the object by electromagnetic wave motion and will increase the molecular movement thus raising its temperature. Conduction refers to heat transferred by molecular movement from one part of an object to another or between two objects in contact. Convection occurs when heat is transferred from one position to another by mixing two fluids together. Vaporization occurs when water is heated to a threshold point, in which it changes from liquid to gas (Nearly et al., 2005). Condensation, on the other hand is when water changes from a gas to a liquid while releasing heat. Heat is released in all directions; but is mainly lost to the atmosphere with only about 5-15% transmitted downward.

Fire Effects on Soil

Soil is composed of both mineral and organic matter as well as air and water (Neary et al., 2005). The composition of these materials will vary and give soils different chemical and biological properties. Soil will also vary in thickness, arrangement, and layering of these materials, which is described as its profile. The surface litter layer will contain organic matter that has not yet been decomposed such as leaves and twigs. The duff layer refers to the layer of humus and decomposing organic matter below the surface litter. Soils are important to anthropologists because cultural artifacts and skeletal remains can become deposited within the soil and stay there for hundreds to thousands of years.

Most of the energy transmitted by a fire is not released downward and the rate at which it can be transmitted into the soil is limited due to the soil's thermal properties (Neary et al., 2005). Different types of soil will have different temperature thresholds, meaning that the heat-induced alteration of a soil will only occur once that particular threshold is reached. Therefore, the effects burning has on the soil depends on its composition as well as the fire severity and duration. The thicker the surface litter or duff that is present as well as the longer the duration, the more the heat will transfer down into the soil. This is termed depth of burn.

Although it is hard to completely separate these categories, depth of burn has been divided into five descriptive categories (Neary et al., 2005). If it is categorized as unburned than no plants have been altered and are still green. This can occur in patches throughout the affected area. If it is found scorched then heat was radiated from neighboring burning areas and caused plants and grass to turn brown or yellow. A light depth of burn leaves the plants and surface litter charred to consumed. However, the underlying duff has not been affected. Larger woody debris may be blackened, but will not have extensive charring. Moderate burn depths will have consumed plants and surface litter as well as the duff. The damage ends at the mineral soil beneath the duff and if the soil is affected it will only expand about a centimeter. If a deep burn depth is achieved than all the surface litter and plants are consumed as well as logs and other heavy woody debris. The top layer of soil will oxidize resulting in a color and texture change.

Weather Effects on Wildfires

Certain weather characteristics can affect the way a fire behaves such as temperature, humidity, air stability, and wind speed (Fuller, 1991; Pyne 1996). As humidity decreases fuels will dry out, thus they are more combustible. Air stability refers to its ability to resist vertical motion. Air can become unstable if it cools or heats faster than the surrounding air. It must become stable again by reaching a vertical level in which the temperatures are the same. Unstable air can increase fire activity. Changes in wind speeds and directions can also change a fire's direction and/or cause the fire to spread faster. For example a cold front can bring thunderstorms that can ignite fires and then spread them, due to the lightning and strong winds accompanying them.

Alteration of Bone by Fire

The effects fire will have on an object will depend upon the object itself, the temperature, the duration of contact, and the atmosphere surrounding the heated surface (Bennett, 1998; Mayne Correia, 1997; Stiner and Kuhl, 1995; Thompson, 2004). A wildfire cannot be recreated in an oven because the atmospheric conditions surrounding the heated surface are not the same as well as the duration of contact. In an oven or crematorium the object experiences a constant heat exposure while in a fire the object would more likely experience an on-and-off exposure. It has also been found that buried bone will not progress as far as exposed bone in the cremation process. The breakdown of bone during heating is a complex process and is still being studied. Heat exposure can cause the inorganic matrix to alter, organic degradation, and evaporation. Many studies have attempted to categorize heat-induced alterations to bone. Table one compares the definitions of the four stages of heat-induced alterations to bones proposed by Maybe Correia

(1997) and Thompson (1994). Different types of bones have also been found to differ in their ability to survive heat-exposure (Spence, 1967).

Table 1: A comparison of the four stages of heat-induced alterations from Mayne Correia (1997) and Thompson (2004)

Stage	**Histological Change (Mayne Correia 1997)**	**Histological Change (Thompson 2004)**	**Temperature Range (Mayne Correia 1997)°C**	**Temperature Range (Thompson 2004)**
Dehydration	Water removal (physisorbed & chemisorbed)	Fracture patterns & Weight loss	105-600	100-600
Decomposition	Removal of organic components	Color change, weight loss, reduction in mechanical strength, changes in porosity	500-800	300-800
Inversion	Removal of carbonates	Increase in crystal size	700-1100	500-1100
Fusion	Melting of crystals	Increase in mechanical strength, reduction in dimensions, increase in crystal size, changes in porosity	1600+	700+

Color Change

Various color changes have been reported to occur. The most common colors found are brown, gray-blue, black, gray, gray-white, and chalk white. All of these colors can be seen in a single cremation (Fairgrieve, 2008; Mayne Correia, 1997; Shipman et al., 1984; Walker et al., 2008). A studied performed by Dunlop (1978) reported a traffic light color scheme, this included green, yellow, pink, and red. However, these colors are found less frequently. The color of the skeletal material depends on the temperature achieved and the length of time the skeletal material is exposed to the heat source (Fairgrieve, 2008; Mayne Correia, 1997; Shipman et al., 1984; Walker et al., 2008). Organic and inorganic material associated with the skeletal material can also have an impact on bone color. A brown coloration can result from the presence of hemoglobin or soil discoloration. A black coloration can result from the carbonization of the bone in an oxygen-starved state. A gray or gray-blue coloration occurs when the organic components are pyrolised. When the complete loss of organic material and the fusion of salts within the skeletal material occurs, the final stage in calcination has been reached resulting in a white color and porcelain-like texture. The traffic-like coloration found in the Dunlop (1978) study resulted from the exposure to copper, bronze, and iron in the surrounding environment.

Symes et al. (2008) created a classification system based on color change to the bone. These categories are termed calcined, charred, border, and heat line. Remains are considered calcined when their organic material and moisture has been lost so that the bone is reduced to fragments, which are very fragile and warped. The damage can be so extensive that the bone is unidentifiable. The exception is cortical bone in which its trabeculae can withstand distortion. Charring occurs when the bone is in direct contact with the flame and causes the bone to blacken. Charred bone is still identifiable and is more durable than calcined bone. A heat altered border appears as an off-whitish area that has been protected from direct contact with the flame due to the presence of soft tissue. The heat exposure has still caused some degree of dehydration and flaking can be seen on the outer cortical layer. This may not be easily seen and will fade over time (such as in archaeological remains). A heat line appears between the border of burned and unburned bone.

Shipman et al. (1984) and Devlin et al. (2008) label color change in burned bone using munsell colors and then divided these into five different color stages. These stages are characterized by their differences in hue, value, and chroma and are composed of both dominant and secondary colors. If the dominant colors present are pale yellow and very pale brown then the skeletal material has been exposed to temperatures less than 285°C (545°F). If the dominant colors present are pink and black with secondary colors of very dark grayish brown, brown, reddish brown, neutral dark gray, and reddish yellow then the skeletal material has been exposed to temperatures of 285-525°C (545-977°F). Stage three has dominant colors of light gray and secondary colors of brown and light brownish gray and has been exposed to temperatures up to 645°C (1193°F). The next stage experiences temperatures up to 940°C (1724°F) and show neutral white and blue gray colors. The last stage represents skeletal material exposed to temperatures in excess of 940°C (1724°F) giving an appearance of neutral white and medium gray in color.

Another color classification system was developed by McCutcheon (1992). His is divided into three stages based on surface color as well as microscopic characteristics. The first stage is characterized by pale brown to black colors and has been exposed to temperatures up to 340°C (644°F). In the second stage skeletal material demonstrated light brownish gray colors and was exposed to temperatures up to 600°C (1112°F). The last stage represented skeletal material exposed to temperatures above 650°C (1202°F) and are dominantly white in color. Although a pattern can be seen between color change and temperature exposure, the lines separating these temperature ranges can be blurry.

Although using a Munsell Soil Color Chart can standardize color assessment, it has its flaws. The Munsell system uses three dimensions of color: hue, chroma, and value. Hue is how similar a color is to red, yellow, green, blue, or a combination of the two. Value represents the lightness of a color and chroma indicates its richness. The variation in lighting can affect the color interpretation and cause inter-observer error. Another method known as the CIELAB color system uses a measurement device to accurately record differences in color (Devlin et al., 2008). Devlin and Herrmann (2008) use the CIELAB color system and records colors from their skeletal sample using an X-rite CA 22 spectrophotometer. They discovered that different skeletal elements differed slightly in their color value. For example cranial elements had the whitest colors as well as a higher yellow value.

Shrinkage and Deformation

Shrinkage and deformation can also occur when heat is applied to skeletal material. The bone length and width can be reduced. This can affect various aspects of a forensic analysis such as age, sex, and stature. There have been various studies attempting to quantify this amount of change. Dokladal (1971) cremated half of five cadavers in a study. He used a gas oven exposing skeletal material to temperatures ranging from 600-1000°C. He found that the rate of shrinkage ranged from 5 to 12%. Another study by Strzalko et al. (1974) found a similar shrinkage rate of 6-13%. Studies by Hermann (1996, 1997) investigated the shrinkage rate at different temperatures. He used samples of femoral compact bone and heated them at temperatures ranging from 150-1200°C. Hermann found different shrinkage rates depending on the temperature. From 150-800°C he only reported a shrinkage rate of 1-2%. However, once temperatures reached the 1000-1200°C range the shrinkage rate increased to 14-18%. The amount of shrinkage has been linked to a few variables such as the type of bone present (compact or spongy), the temperature of exposure, the mineral content of the bone. Studies have also shown a correlation between the amount of shrinkage and the sex of the individual (Mayne

Correia, 1997). Males have been reported to have larger amounts of shrinkage due to the fact that they have a higher percentage of minerals present in their bones.

Fracture Patterns

There have also been numerous studies investigating the fracture patterns created by heat exposure. Lisowski (1968) exposed different skeletal material to heat which had the following results: cracking in teeth, compact bone splitting along straight or elliptical trajectories, twisting and bending; and the separation of internal and external tables in the crania. Studies have found that cremated dry bone can be distinguished from fresh or green bone (Binford, 1963; Buiksra et al., 1989). Binford (1963) also noted that dry bone exhibited checking and longitudinal fractures on the surface as well as no warping. However, green bone had warping and curved transverse fractures. Thurman et al. (1980) took this study one step further to investigate whether or not green bone can be distinguished from flesh bone. He concluded that green, fleshed, and dry bone can in fact be distinguished from one another. His results indicated that fleshed bone had diagonal fractures and more extensive warping while green bone displayed more parallel fractures and less warping. White (1992) set out to examine if different heating methods could be distinguished from one another in burned skeletal material in archaeological sites. His results, however, suggested that it is very difficult to determine if skeletal material had been cooked, heated, burned, or even just weathered.

Fractures can be divided up into seven classifications: longitudinal, step, transverse, patina, splintering and delamination, curved transverse, and burn line fractures (Farigrieve, 2008; Symes, 2008). Longitudinal fractures occur in a parallel pattern down the shaft of long bones. Step fractures are transverse fractures on the shaft of long bones usually extending from a longitudinal fracture. Transverse fractures transect haversion canals and can compose step fractures. Patina fractures are superficial fractures that appear in an uniform pattern similar to cracking seen on the surface of old china or paintings. Splintering can be described as the separating of the cortical bone from the cancellous bone or the outer and inner tables of cranial bone. This also describes the exposure of cancellous bone on the epiphyses. Curved transverse fractures are caused when soft tissue pulls on the surface of the heated bone as it shrinks away. Lastly, burn line fractures separate the burned and unburned bone.

Weight

Another aspect that is affected by heat exposure is the weight of the skeletal material. Bonucci and Graziani (1975) found that the weight of the skeletal material changes with the temperature of the heat exposure. This happens in three phases. Phase one occurs at 105-300°C and results in the removal of water. Phase two involves the removal of collagen and occurs at temperatures of 500-600°C. Lastly, stage three occurs between temperatures of 600-900°C and carbonates are decomposed.

Microstructure

The outer appearance is not the only thing affected by heat exposure. The microstructure can also be altered depending on the degree of exposure (Piga et al., 2009). It appears that the microstructure undergoes different changes at different temperature ranges and durations. Bradtmiller and Buikstra (1984) conducted a preliminary study investigating the effects of heat exposure to bones' microstructure. They heated skeletal material for several minutes at temperatures around 600°C and found some interesting results. Osteon size in the burned bone was larger than those in the unburned bone. This could be due to a variety of reasons. First of all, it could be attributed to a sampling problem. It could also suggest that the osteons expand in size before they shrink. If this is the case then the experiment simply concluded before shrinkage could occur. It may also mean that although bone shrinks in external dimensions the osteons themselves increase in dimension. Nelson (1992) found opposing results in his study. He noted that osteon diameter decreased in size, but he also found that canal diameter increased. Hermann (1977) found that heat exposure reaching temperatures between 700 and 800°C can cause the bone mineral crystals to fuse. This is thought to be directly linked to the shrinkage observed in heat treated bone.

Holden et. al. (1994) studied change in microstructure using scanning electron micrographs on a very large skeletal sample (527 bones). They heated them at different temperatures, ranging from 200-1600°C for various lengths of time, ranging from 2-24 hours. Results demonstrated a difference in observed characteristics and temperature ranges. While heating up to 400°C the organic material combusted. The bone mineral began recrystallization at 600°C. The crystal morphology varied in shape and included spherical, hexagonal, and rhomboidal. Crystals began to fuse at 1000°C and then melted at 1600°C. After fusion voids were occasionally detected in the bone matrix. This may be due to gas bubbles forming during heating and then become trapped during cooling. They also saw a correlation between age at death and changes seen in heated skeletal material, such as crystal morphology. They were able to separate the age at death of a victim into three broad categories: 1-22 years, 22-60 years, and above 60 years. However, these changes will not be seen unless viewing the skeletal material at higher magnifications.

Levels of Cremation

There have been two methods proposed for characterizing the amount of modification a fire causes to a body. The first method classifies remains into four categories based on the amount of tissue left (Eckert, 1988). If the internal organs survive then the body is classified as charred. If the internal organs are gone, but soft tissue is still present then the remains are classified as a partial cremation. If only skeletal fragments are present after cremation then the remains are labeled as an incomplete cremation. This is most often seen in sites. The final category, complete cremation, occurs when only ashes remain present. The last stage is seen in rare cases. The second method, known as the Crow-Glassman Scale, proposes five levels of heat exposure (Symes, 2008). If the body is still recognizable with only epidermal blistering and hair singeing then it is a level one. If the body has experienced minimal charring (extremities, ears, and genitalia) and may be recognizable then it is a level two. Level three occurs when the body is no longer recognizable due to destruction of the extremities and head. Once the skull and extremities are severely fragmented or even missing the remains are classified as level four. Level five is cremation, in which the remains are reduced to scattered and incomplete fragments.

How Heat-induced Alterations can Affect Anthropological Methods

Unfortunately, there have not been many new techniques established for gaining identification information from burned remains. Heat exposure can alter skeletal material in a variety of ways and these alterations can affect the accuracy of determining this information. Many different aspects have been used to identify sex, ranging from using the skull to the pelvis and even long bones. Many different techniques including, both metric and non-metric, have also been used to identify sex. The accuracy and ability to use these techniques depends upon the survival of certain bones and the amount of shrinkage incurred. Warren and Maples (1997) found that the weight of cremains could be correlated to the sex of the individual. Stature can still be determined if the long bones have not shrunk or been destroyed. The ability to determine ancestry will depend upon the survival of the skull. It has been suggested that using only one or two available characteristics is not a reliable method. Age determination will also depend on the degree of fragmentation and tooth survival. Microscopic analysis can also be used, but further studies need to be conducted to find the accuracy of this technique (Grevin et al., 1998; Mayne Correia, 1997; Thompson, 2005; Ubelaker, 2009). The table below illustrates the different techniques that are affected by heat-induced alterations and why they are affected.

Table 2: The influence of heat-induced change on anthropological techniques

Heat-induced Change	Technique Affected	Cause of Effect
Color Change	Metric	Indirectly: color change implies loss of organics, which causes shrinkage
Weight Loss	Metric	Indirectly: weight loss implies loss of organics, which causes shrinkage
Fracture Formation	Metric & Morphological	Directly: increased fragmentation reduces likelihood of technique application
Changes in Strength	Metric & Morphological	Indirectly: weaker bone increases fragmentation, which reduces likelihood of technique application
Recrystallization	Metric & Morphological	Directly: changes in microstructure may affect shape and will affect dimensions
Porosity Change	Metric	Indirectly: implies loss of organics and reorganization of microstructure
Dimensional Change	Metric & Morphological	Directly: differential size changes may affect shape and will affect dimensions

T.J.U. Thompson. 2004. Recent Advances in the Study of Burned Bone and their Implications for Forensic Anthropology. Forensic Science International. 1465: S203-S205.

Distinguishing Trauma

Means have been established for identification of certain trauma afflictions made to bones. This information also aids in establishing manner of death: accidental, homicide, suicide, or natural. It has been determined that ballistics, sharp force trauma, and blunt force trauma can survive heat-exposure. However, extinguishing methods or even the recovery process can still damage or alter these patterns. Entrance wounds can retain their circular shape as well as the internal beveling. Careful observation showed that blunt force trauma characteristics can still be seen such as inward crushing of skeletal material. Sharp force trauma could still be distinguished as either a scalpel incision, a deep knife wound, saw marks, or chop marks. Sharp force trauma patterns remained the most intact in contrast to ballistics, which were found to survive the least (Gruchy and Rogers, 2002; Herrmann and Bennett, 1999; Marciniak, 2009; Pope and Smith, 2004).

This study will help expand the ever growing field of taphonomy by providing a comprehensive analysis of skeletal remains that have been exposed to a wildfire. In Montana, wild fires occur every year sweeping across miles upon miles of forested areas. If skeletal remains were present in an area where a wild fire past through, how have they been affected? If skeletal remains are covered by leaf litter, will that provide a protective cover from the wildfire? If skeletal remains are affected than a forensic analysis of the remains could provide inaccurate results if these alterations are not taken into account. I proposed that shrinkage will occur affecting the skeletal materials' weight and dimensions and these changes will occur whether or not they are covered by leaf litter.

Chapter 3: MATERIALS AND METHODS

To study the effects of wildfires on skeletal remains, a surface fire was simulated in a designated area containing skeletal elements from two pigs. The area chosen was a square section of field measuring 10x10 meters. The area was marked off into a 4-unit grid with skeletal samples distributed throughout each 5x5 meter square. A detailed map was created of the study area before burning. Weight, coloration, dryness, and dimensional measurements were recorded as well as photographs were taken of the skeletal sample before and after exposure to the surface fire. Also degree of cremation and any fracturing were noted post-burning. Temperature readings were taken using a non-contact infrared laser thermometer throughout the duration of the fire in order to record the maximum temperature reached. The fire was initiated in the afternoon on 23 October 2010 and went out on the morning of 25 October 2010. Tables 1, 2, and 3 contain weather data for each date from the weather station at Johnson-Bell Field located in Missoula, Montana.

Table 3: Weather data collected from Johnson-Bell Field station located in Missoula, Mt for October 23rd, 2010

ITEM	DATA
Mean temperature	46.5°F
Max. temperature	61.0°F
Min. temperature	33.1°F
Visibility	9.7 miles
Precipitation	0.02 inches
Mean wind speed	1.4 knots
Max. sustained wind	7.0 knots
Max. wind gust	No data
Mean dew point	38.0°F
Sea level pressure	1011.1 mb

Table 4: Weather data collected from Johnson-Bell Field station located in Missoula, Mt for October 24rd, 2010

ITEM	DATA
Mean temperature	46.1°F
Max. temperature	52.0°F
Min. temperature	37.0°F
Visibility	10.0 miles
Precipitation	0.06 inches
Mean wind speed	6.1 knots
Max. sustained wind	12.0 knots
Max. wind gust	No data
Mean dew point	40.8°F
Sea level pressure	1003.3 mb

Table 5: Weather data collected from Johnson-Bell Field station located in Missoula, Mt for October 25rd, 2010

ITEM	DATA
Mean temperature	42.7°F
Max. temperature	51.1°F
Min. temperature	39.0°F
Visibility	10.0 miles
Precipitation	0.03 inches
Mean wind speed	5.1 knots
Max. sustained wind	12.0 knots
Max. wind gust	No data
Mean dew point	34.1°F
Sea level pressure	1001.3 mb

Study Area

The study site was located in an unused pasture (Figure 1) in Saint Ignatius, Lake County, Montana approximately 41 miles north of Missoula, Montana. The geographic area is in western central Montana at an elevation of 2939 feet. To the east is the Mission Mountain range and to the west is the National Bison Refuge.

The study area consisted of a 10 m X 10 m unit divided into four 5 m X 5 m units. The area already contained dead grass as well as living grass underneath. The area was then filled with debris to mimic the forest floor. This included fallen tree branches, bark, twigs, logs, dead leaves, and wood shavings. The dead leaves, small twigs, and wood shavings were used to simulate a surface litter layer. This layer was spread over the entire 10 m X 10 m plot equally about ½ inch in thickness. This was the main source of fuel for the fire. The bigger pieces of branches and logs were scattered throughout the plot randomly. There are no trees or structures to allow for a transitional or crowning fire, therefore only ground and surface fires will be demonstrated in this study. Skeletal elements from a pig were divided into four equal allotments and then scattered throughout each unit with an equal number placed on top of the surface and covered underneath leaf litter (Figure 2).

Figure 1: Northwest view of unused pasture

Figure 2: Northwest view of study area after skeletal sample has been distributed

Test Samples

The skeletal samples consisted of dry bones collected from two subadult pigs (*Sus scrofa*) used in a decomposition study located in Gold Creek, Montana. They were exposed to the elements for about a year prior to this study. A variety of bones were used in this study (Figure 3 and Table 6) including vertebrae (cervical, thoracic, and lumbar), ribs, metacarpals, tarsals, scapulae, os coxae, and long bones (humerii, radii, ulnas, femurs, tibias, and fibulas).

Figure 3: Skeletal sample sorted by type of bone

Table 6: Skeletal sample breakdown

Type of Bone	Number Present
Long bones: humerii, ulnae, radii, femurs, tibias, fibulas, and femurs distal heads	20
Vertebrae: cervical, thoracic, and lumbar	44
Ribs	42
Pelvis: ischium and ilium	5
Phalanges: tarsals and metacarpals	8
Scapulae	4

Data Collection Protocol

Dimensional Measurements, Weight, and Coloration

Before the skeletal sample was scattered throughout the study area various elements were recorded as well as each bone photographed. First each bone was identified to element and measurements were taken depending on the type of bone using a sliding caliper. Diameters were taken in the middle of long bones as well as the diameters of each end. Length was determined by measuring from the longest points on each bone. Breadths were taken for each scapula and ilium. The height of each vertebrae body was also recorded. Weight was recorded in grams using a digital scale for each bone. The general color of each bone was noted using a Munsell Color Chart. Since the bones had been exposed to the elements while in decomposition, the amount of weathering present was recorded using a table from the Buikstra and Ubelaker's (1994) Standards recording manual. Lastly, photographs were taken.

Weathering Stages

Before the skeletal sample was subjected to the fire simulation, each bone was scored based on the degree of weathering. The scoring method utilized contains six stages ranging from stage zero to stage five as described by Haas (1994). Haas modified Behrensmeyer's (1978) bone weathering stages for collections context. A bone is categorized according to the most advanced stage that covers more than 1 cm^2 of the bone's surface. Also the surface used for categorization should be located on the shaft of the long bones or the flat surfaces of other bones, not the edges or areas that have signs of physical damage (Behrensmeyer, 1978).

Stage 0

In this stage there is no sign of flaking or cracking on the bone surface due to weathering (Behrensmeyer, 1978; Haas, 1994). The bone may still be greasy and there may still be tissue present over the surface of the bone (Behrensmeyer, 1978).

Stage 1

In stage one cracking can be seen on the bone's surface. Cracking will usually run parallel to the fiber structure. For example, cracking will run longitudinal in long bones. Mosaic cracking, however, may be seen on the articular surfaces (Behrensmeyer, 1978; Haas, 1994). Again, tissue may or may not be present (Behrensmeyer, 1978).

Stage 2

Stage two is where flaking begins to occur on the outermost concentric thin layers of the bone, usually in the areas where cracking has already occurred. A common occurrence seen with flaking in the beginnings of this stage is that one or more sides are still connected to the bone and the flakes appear long and thin. Deeper flaking will follow until the majority of the outermost bone is gone. The edges of the cracks are usually angular in cross-section. Tissue remnants may be present (Behrensmeyer, 1978; Haas, 1994).

Stage 3

In stage three, the bone surface will have patches of compact bone that has been homogeneously weathered into a rough texture. Where these patches occur, the outermost concentric bone layers have been removed. These patches will eventually cover the entire bone surface; however, the weathering extends only 1.0-1.5 mm deep into the bone at this point. Crack edges will now appear more rounded in cross-section and tissue is rarely still seen on the bone in this stage (Behrensmeyer, 1978; Haas, 1994).

Stage 4

Stage four weathering results in a coarsely fibrous and rough bone surface. Small to large splinters will occur and may even fall away from the bone if moved. Weathering extends to the inner cavities and cracks are open and are characterized by either splintered or rounded edges (Behrensmeyer, 1978; Haas, 1994).

Stage 5

In this final stage, bone is fragile and deteriorating in situ. Large splinters will separate from whole and fall around it. This may make determining the original bone shape difficult. If cancellous bone is present it is usually exposed in this stage and may outlast all traces of compact bone (Behrensmeyer, 1978; Haas, 1994).

Degree of Cremation

Eckert et al. (1988) established four categories to classify cremated or severely burned remains. Group four is classified as charred, in which internal organs still remain. Skeletal remains are classified in group three, partial, if soft tissues remain. Group two contains remains that have undergone an incomplete cremation, therefore, bone fragments remain. Lastly, remains are categorized as completely cremated when only ashes remain.

In this study, however, I created my own classification system due to the fact that all of my samples fell into category two, incomplete cremation. The remains are broken down into smaller, more specific categories in order to identify any burning patterns. Five categories were established ranging from stage zero to stage four.

Stage 0

In this stage there is no visible burning present. The bone appears to have gone unaffected. This is based on visual assessment alone and does not mean the bone has not changed in weight or other measurements.

Stage 1

In stage one, blackening has occurred from the burning; but no flaking is present. The color change can range from having a slight browning on one edge to a dark blackening over the majority of the bone.

Stage 2

Bones will demonstrate both blackening and flaking in stage two. Flaking means that pieces of burnt bone are separating from the rest of the bone. This does not have to cover the entire bone. In order to be classified as stage three, there only has to be one section of blackened bone in which the bone structure has been damaged to the point of fragmenting or crumbling away from the rest of the bone.

Stage 3

In stage three, the majority of the bone have deteriorated into fragments. The fragments may range from large to small, but the entire or at least 90% of the bone has been exposed to fire and demonstrates some kind of charring or blackening. If only a small portion of the bone is fragmenting, but the rest is white and appears unaffected by the fire, then it is categorized as stage two not three.

Stage 4

In stage four, only ashes remain.

The bones were then scattered throughout the study area. Photographs were taken of each skeletal sample *in situ*. A detailed map was then created of the site (Figure 4). Each bone was assigned a symbol based on the category of bone it fell within and mapped according to its location in each unit. The skeletal material was color coded according to whether or not it was buried. After burning was initiated fire temperatures were periodically taken from the perimeter of the site on each unit's side in order to gain a maximum temperature. The thermometer used was cen-tech brand with a temperature range of -20°C to 520°C and a distance to spot ratio of 8:1 m. After the fire went out each skeletal element was photographed in situ and then collected and labeled in ziplock bags.

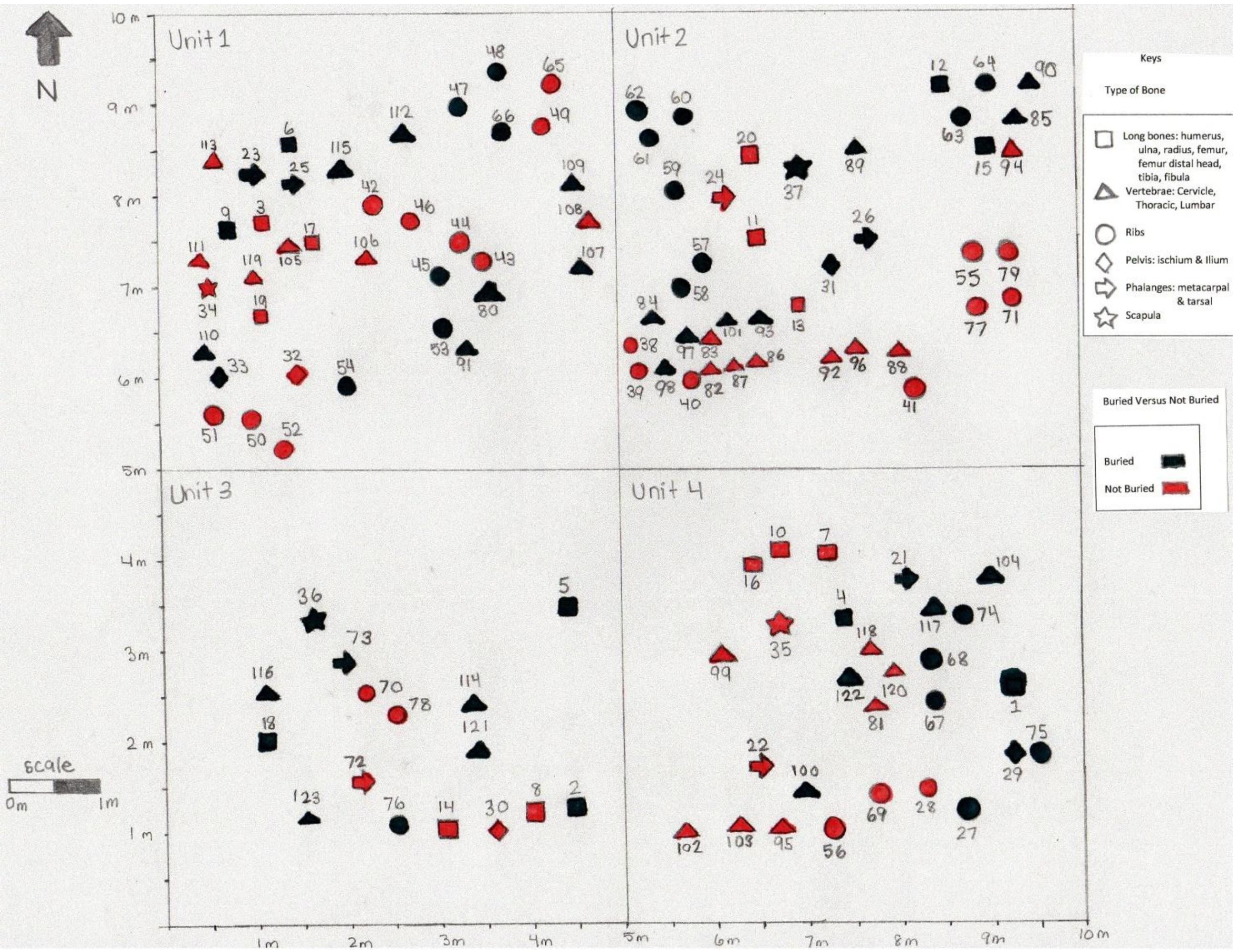


Figure 4: Map depicting location of skeletal material and whether or not each one each one was buried

Post-burning data was later collected from the skeletal sample. Weight and dimensional measurements (lengths, diameters, heights, and breadths) were recorded again as well as the primary and minor Munsell Colors. If any fracturing occurred it was noted and described. The degree of cremation was also recorded and if fragmenting occurred then no measurements aside from weight were taken.

Fire Simulation

The fire was started by lighting the north perimeter using a propane tank with an attached torch (Figure 5). The fire was then allowed to spread at its own pace and direction as a wildfire occurring on its own would (Figure 6 and Figure 7). No further help was given to the fire and it was allowed to continue until expiring on its own. The fire spread slowly over the unit and stayed within the designated area due to the lack of fuel in the surrounding pasture. For the majority of the fire small flames, characteristic of a surface fire, (Figure 8) were seen; however there was also smoldering seen in some areas, especially near the larger woody debris. The duration of the fire lasted for over forty hours even through periodic raining.

Figure 5: Lighting the north perimeter of the study area

Figure 6: The perimeter smoldering and slowly spreading after ignition

Figure 7: The fire spreading across the unit

Figure 8: Leaf litter and debris on fire

Statistical Analysis

The observed variables were placed into a database and were analyzed in SPSS. First the percentages of skeletal material by degree of cremation and level of dryness were calculated to examine how much of the skeletal material had undergone heat induced alterations. Then descriptive statistics were used to find the range for weight changes and all three dimensional measurement changes viewed in the skeletal material. These ranges were then broken down and listed by degree of cremation. Therefore, the amount of weight change and dimensional measurement change could be compared by each degree of cremation. The percentage of skeletal material exhibiting fracturing was also calculated for each degree of cremation. This information will provide insight on what type of heat induced alterations are experienced in each degree of cremation.

A discriminant function analysis was used to detect any significant relationships between degree of cremation and three other variables: the unit the skeletal material was placed, weight change, and whether or not it was buried. Skeletal dimensions were not used because several items did not have any post-burning measurements due to fragmenting. Spearman rank order correlation tests were conducted in order to determine if there were any relationships between the degree of cremation reached, the unit the bone was placed in, and whether or not it was buried with change in weight and change in dimensional measurements. Also paired samples T-tests were also carried out in order to determine if there were any significant differences between weight before and after burning as well as the dimensional measurements taken before and after burning.

Mapping of Post-burning Data

A post-burning map (Figure 9) was also created in order to examine any burning patterns seen. Each bone was mapped according to its location during the fire simulation using its symbol assigned for skeletal category. These symbols were color coordinated according to the level of cremation reached. This map was compared to post burning pictures of each unit to establish a pattern between degree of cremation and fire intensity.

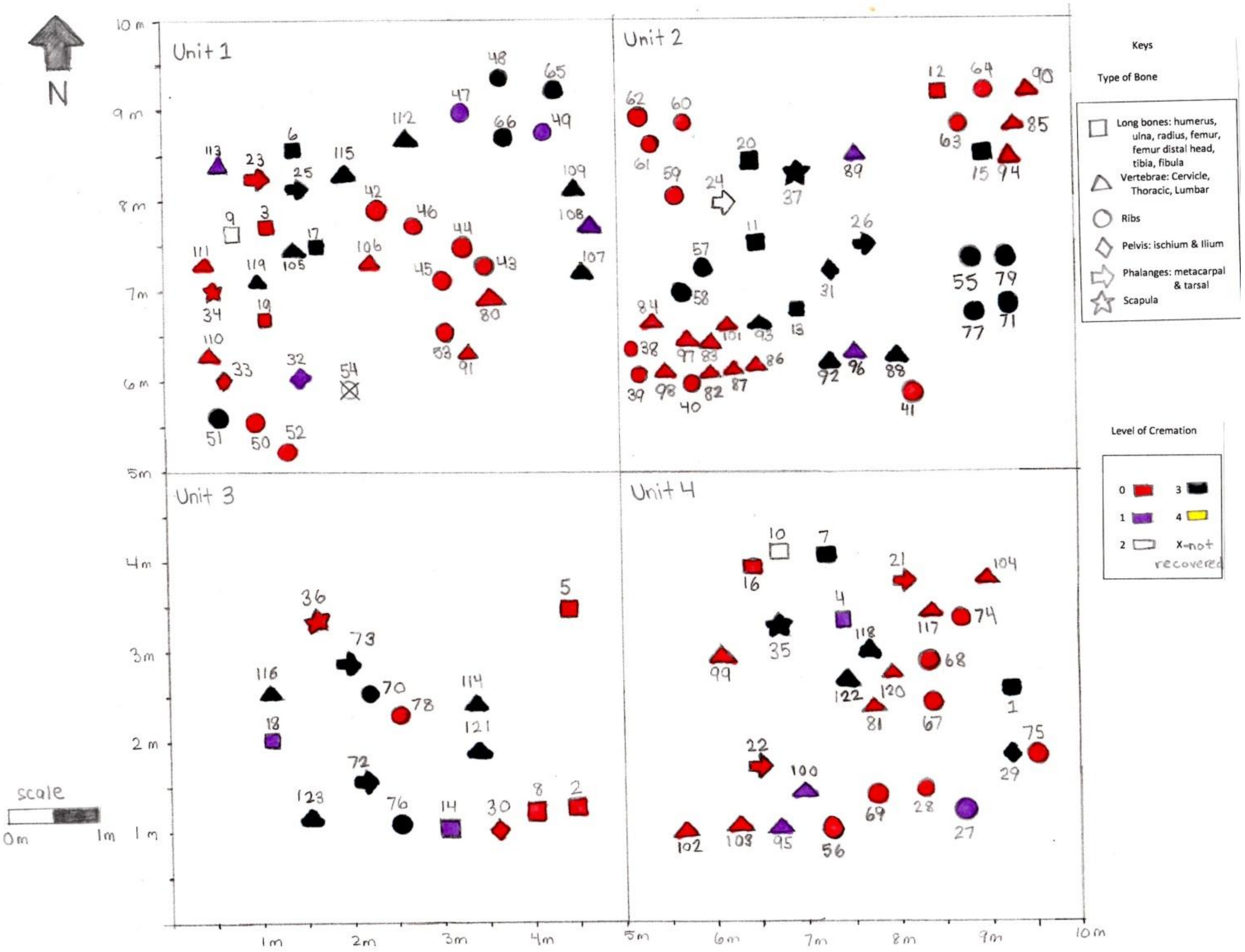


Figure 9: Map depicting location of skeletal material and post-burning effects

Chapter 4: RESULTS

The results presented are a compilation of visual observations as well as dimensional measurements taken before and after the skeletal material was subjected to heat exposure from a wildfire. The visual observations were used to determine the amount of heat exposure each skeletal element was exposed to by noting color change and assigning a level of cremation to each element. The degree of weathering was also noted as well as any fracturing. The location of the skeletal material (whether the skeletal element was buried under leaf litter or placed on top of the ground) was observed in relation to the level of cremation and color change. These also served to assess visual changes formed from heat exposure that could complicate forensic analyses. Weight and dimensional measurements were taken for each skeletal element. Statistical analyses were used to examine the relationship between level of cremation achieved and location of the skeletal element. This will shed light on the matter of whether or not leaf litter covering skeletal material will prevent heat induced alterations from occurring.

The fire lasted for approximately forty-two hours and although some areas were thoroughly burned, a lot of the area was not directly exposed to the fire. The maximum temperature range recorded was 450°C-500°C and occurred approximately twenty-five minutes after ignition. About an hour after ignition the temperature range dropped to 200°C-225°C and did not increase again. Many heat-induced transformations were seen in the skeletal material such as change in weight, change in dimensional measurements, fracturing, and color change. The following figures show before and after images of the units and help illustrate the damages caused by the fire simulation.

Figure 10: Unit 1 pre-burning taken facing south

Figure 11: Unit 1 post-burning northwest corner

Figure 12: Unit 2 pre-burning taken facing south

Figure 13: Unit 2 post-burning east side

Figure 14: Unit 3 pre-burning taken facing north

Figure 15: Unit 3 post-burning southeast corner

Figure 16: Unit 3 post-burning northeast corner

Figure 17: Unit 4 pre-burning taken facing north

Figure 18: Unit 4 post-burning southeast corner

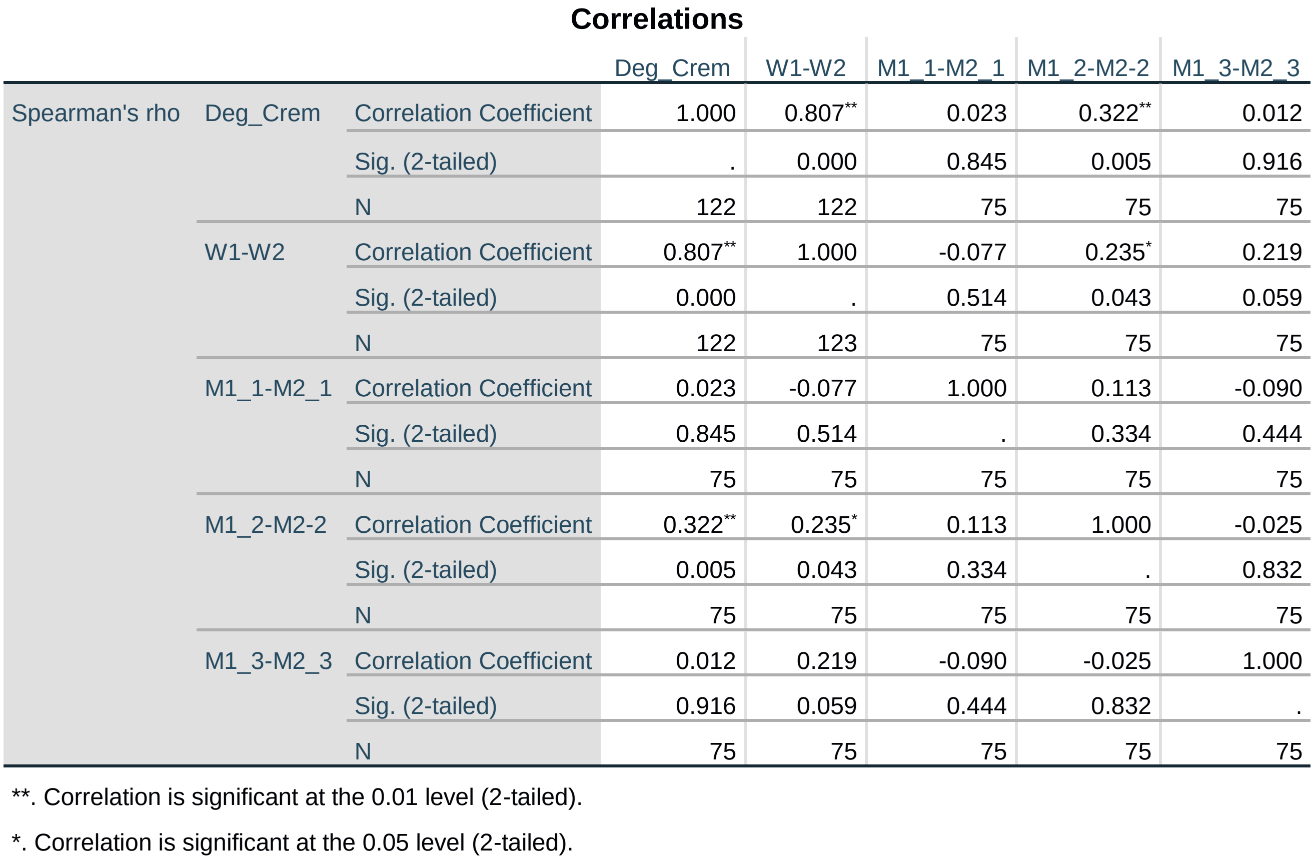
Figure 19: Unit 4 post-burning northeast corner

Degree of Cremation & Dryness

Various degrees of cremation occurred from no visible signs, degree zero, to mostly fragmented material which at least 90% exhibits charring, degree three. About half of the skeletal material remained in stage zero while about 35% reached level three. Thirteen percent of the skeletal material reached stage one and the other 2% reached stage two. None of the skeletal material reached stage four cremation, in which only ashes remain. Skeletal remains in stage three were seen clustered together on the map with stages one and two spanning out from them into the level zero skeletal material (Figure 9). When compared to photographs of the units the level of cremation appear to follow a pattern in correlation with fire intensity. The areas in the units where the ground was charred are where skeletal material from the level three group can be seen and areas where the ground was relatively left untouched are where skeletal material from the level zero group can be found. Thus, it can be concluded that the more intense the fire the higher the degree of cremation achieved. Dryness only changed from level one to level five in skeletal material having reached stages two and three. These were at least partly fragmented.

Discriminant function analyses were used to examine the significance of the relationship between degree of cremation and various thermal alterations. A significant relationship does exist between degree of cremation and weight change. However, a significant relationship was not found between change in measurement and degree of cremation reached. An analysis was also conducted using degree of cremation and whether or not the bone was buried and there was not a significant relationship there either. Spearman rank order correlation tests were conducted in order to determine if there were any relationships between the degree of cremation and the change in weight as well as the change in dimensional measurements (Table 7). A two-tailed test of significance indicated that there is a significant positive relationship between the degree of cremation achieved and the change in weight (r(122)=0.807, p<0.05). The two-tailed test of significance indicated a significant positive relationship between the degree of cremation achieved and the change in the second dimensional measurement taken (r(75)=0.322, p<0.05); but not in the first (r(75)=0.023, p>0.05) or third dimensional measurement taken (r(75)=0.012, p>0.05). This indicates that the higher the degree of cremation experienced by the bone then the more of a weight change experienced. It is hard to say for dimensional measurements taken because the three different measurements taken had different results. The change in the second dimensional measurement due to fire exposure increased as the degree of cremation reached increased. However, there was not a significant relationship seen between the first and third dimensional measurement changes and the degree of cremation reached.

Table 7: Spearman Correlation Table for Degree of Cremation from SPSS



Correlations

			Deg_Crem	W1-W2	M1_1-M2_1	M1_2-M2-2	M1_3-M2_3
Spearman's rho	Deg_Crem	Correlation Coefficient	1.000	0.807**	0.023	0.322**	0.012
		Sig. (2-tailed)	.	0.000	0.845	0.005	0.916
		N	122	122	75	75	75
	W1-W2	Correlation Coefficient	0.807**	1.000	-0.077	0.235*	0.219
		Sig. (2-tailed)	0.000	.	0.514	0.043	0.059
		N	122	123	75	75	75
	M1_1-M2_1	Correlation Coefficient	0.023	-0.077	1.000	0.113	-0.090
		Sig. (2-tailed)	0.845	0.514	.	0.334	0.444
		N	75	75	75	75	75
	M1_2-M2-2	Correlation Coefficient	0.322**	0.235*	0.113	1.000	-0.025
		Sig. (2-tailed)	0.005	0.043	0.334	.	0.832
		N	75	75	75	75	75
	M1_3-M2_3	Correlation Coefficient	0.012	0.219	-0.090	-0.025	1.000
		Sig. (2-tailed)	0.916	0.059	0.444	0.832	.
		N	75	75	75	75	75

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Color Change

Color changes were scored using a Munsell Color Chart. Although most color changes resulted in colors from the GLEY1 category (light gray to black), there were also some from 7.5YR (blacks and dark browns). The bones that were labeled level zero for degree of cremation did not demonstrate a color change. Skeletal material categorized as a level three cremation displayed colors from white to gray to black as well as brown. The amount of color change seen on a particular bone ranged from slight browning on one end to the entire bone blackened. There does not appear to be any differentiation in color scheme based on type of bone.

A clustering effect of the skeletal material was observed, according to Munsell Color. There appear to be two main color schemes in small clusters following a path throughout the units. Looking at units one and two a curved path from west to east composed of colors from the GLEY1 hue chart with values of 2.5, 3, and 4 (black and dark gray) are seen. In units three and four the same color scheme can be seen clustered towards the center of each unit. The other color scheme shown is composed of colors found in the 2.5Y hue chart with a value of 8 (white). These are seen surrounding the other clusters. When compared to photographs of the units the color schemes appear to follow a pattern in correlation with fire intensity. The areas in the units where the ground was charred are where skeletal material from the GLEY1 group can be seen and areas where the ground was relatively left untouched are where skeletal material from the 2.5Y group can be found. Thus, it can be concluded that the more intense the fire the darker the color hue with be.

Weight Change

All skeletal material exhibited a change in weight post-burning. A decrease in weight was observed in many of the specimens. An unexpected result was also observed in which some of the skeletal material showed an increase in weight. This skeletal material did not show any visible signs of heat-induced transformation, but displayed an increase in weight as well as changes in measurements. The total weight change ranged from gaining 6 grams to losing 20 grams (Table 8).

Table 8: Descriptive statistics for weight change in all skeletal material

	N	Range	Minimum	Maximum	Mean	Std. Deviation
W1-W2	123	26	-6	20	1.84	3.989
Valid N (listwise)	123					

A paired samples T-test was conducted in order to examine the difference in weight of each bone before and after exposure to the fire. The results of the test showed that the weight before burning and the weight after burning are strongly and positively correlated ($r=0.967$, $p<0.05$). There is a significant average difference between the weight before and after exposure to the fire ($t_{121}=4.973$, $p<0.001$). On average, the weight of the bone was 1.77 grams higher before exposure to the fire (95% CI (1.071, 2.487)). Therefore, we can conclude that heat exposure does have a significant impact on the weight of a bone.

Table 9: Paired Samples T-test Results from SPSS Comparing Weight

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Weight1 & Weight2	122	0.967	0.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Weight1 - Weight2	1.77860655	3.95010248	0.3576254	1.070592601	2.48662051	4.973	121	0.000

Descriptive statistics were conducted to test relationship between degree of cremation and weight change (Table 10). About half of the skeletal material remained in stage zero for degree of cremation. Change in weight ranged anywhere from gaining five grams to losing three grams. About a third of the skeletal material reached stage three cremation and had a weight change anywhere from losing one gram to twenty grams. Since the median weight change was a loss of 3.25 grams, half of the skeletal material only lost one to 3.25 grams. Stage one cremation affected 13% of the skeletal material and shows a wide range in weight change from a gain of six grams to a loss of four grams. Only three specimens remained in the stage two of cremation; but they all showed a loss in weight.

Table 10: Descriptive statistics for change in weight according to degree of cremation

W1-W2

Deg_Crem	Mean	N	Std. Deviation	Median	Minimum	Maximum	Range
0	-.49	59	.932	-.44	-5	3	8
1	.24	16	2.120	.06	-6	4	10
2	9.43	3	5.858	7.07	5	16	11
3	4.86	44	4.225	3.25	1	20	19
Total	1.78	122	3.950	.06	-6	20	26

Change in Dimensional Measurements

Almost all measurements changed after exposure to heat no matter what level of cremation was achieved. Again, both trends were seen here in which some measurements increased in size and some decreased. About 40% of the skeletal material was fragmented and accurate measurements could no longer be obtained. The measurement changes ranged from a gain of 24 mm to a loss of 13 mm (Table 11).

Table 11: Descriptive statistics for change in measurements

	N	Range	Minimum	Maximum	Mean	Std. Deviation
M1_1-M2_1	75	13.2000	-1.8800	11.3200	.730800	1.9569852
M1_2-M2-2	71	29.7200	-18.1700	11.5500	.306338	3.0894282
M1_3-M2_3	75	37.9200	-24.2800	13.6400	-.306267	3.8528518
Valid N (listwise)	71					

Descriptive statistics were calculated for each change in measurement in relationship to the degree of cremation achieved (shown below in Tables 12-14). Skeletal material that reached a stage three degree of cremation were not present in these statistics because they were all fragmented and did not have any post-burning measurements taken. The other stages of cremation showed shrinkage as well as expansion with ranges varying among the different measurements. A distinct pattern cannot be seen as with the weight change.

Table 12: descriptive statistics for change in measurement one according to degree of cremation

M1_1-M2_1

Deg_Crem	Mean	N	Std. Deviation	Median	Minimum	Maximum	Range
0	.625088	57	1.6591092	.210000	-1.8800	8.7900	10.6700
1	1.325333	15	2.9225279	.650000	-.6600	11.3200	11.9800
2	-.233333	3	.6900966	.150000	-1.0300	.1800	1.2100
Total	.730800	75	1.9569852	.210000	-1.8800	11.3200	13.2000

Table 13: descriptive statistics for change in measurement two according to degree of cremation

M1_2-M2-2

Deg_Crem	Mean	N	Std. Deviation	Median	Minimum	Maximum	Range
0	-.017170	53	2.7809976	.010000	-18.1700	6.8200	24.9900
1	.850667	15	3.5949537	.760000	-7.0500	11.5500	18.6000
2	3.300000	3	4.9063938	1.110000	-.1300	8.9200	9.0500
Total	.306338	71	3.0894282	.090000	-18.1700	11.5500	29.7200

Table 14: descriptive statistics for change in measurement three according to degree of cremation

M1_3-M2_3

Deg_Crem	Mean	N	Std. Deviation	Median	Minimum	Maximum	Range
0	-.249825	57	4.0800133	.070000	-24.2800	13.6400	37.9200
1	-.223333	15	3.1198596	.340000	-9.3200	4.8100	14.1300
2	-1.793333	3	3.3983722	-.160000	-5.7000	.4800	6.1800
Total	-.306267	75	3.8528518	.070000	-24.2800	13.6400	37.9200

Paired samples T-tests were performed in order to examine the difference between the dimensional measurements of each bone before and after exposure to the fire (Tables 15-16). The results of the test showed that the first dimensional measurements taken before and after exposure to the fire are strongly and positively correlated ($r=0.999$, $p<0.001$). There is a significant average difference between the first dimensional measurements taken before and after burning ($t_{74}=3.234$, $p<0.05$). On average, each bone lost 0.73mm from the first dimensional measurement taken after exposure to the fire (95%CI (0.281, 1.181)). The results from the second and third dimensional measurements taken contrasted with the results from the first dimensional measurements taken. The calculations showed that the second dimensional measurements taken before and after exposure to the fire are strongly and positively correlated ($r=0.902$, $p<0.001$) as well as the third dimensional measurements ($r=0.990$, $p<0.001$). However, there is not a significant average difference between the second dimensional measurements taken before and after heat exposure ($t_{72}=-1.111$, $p>0.05$) and there is also not a significant average difference between the third dimensional measurements taken before and after heat exposure ($t_{74}=-0.688$, $p>0.05$). There is conflicting conclusions seen here. Based on the first dimensional measurement, there is a significant difference in the measurement taken before and after heat exposure. However, based on the second and third measurement taken there is not a significant difference in these measurements taken before and after heat exposure.

Table 15: Paired Samples T-test Results Comparing Dimensional Measurement 1

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Measure1_1 & Measure2_1	75	0.999	0.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Measure1_1 - Measure2_1	0.73080000	1.9569852	0.2259731	0.2805385	1.1810614	3.234	74	0.002

Table 16: Paired Samples T-test Results Comparing Dimensional Measurements 2 and 3

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Measure1_2 & Measure2_2	73	0.902	0.000
Pair 2	Measure1_3 & Measure2_3	75	0.990	0.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Measure1_2 - Measure2_2	-1.35698630	10.4357416	1.22141118	-3.79182498	1.07785238	-1.111	72	0.270
Pair 2	Measure1_3 - Measure2_3	-0.30626666	3.85285179	0.44488900	-1.19272735	0.58019402	-0.688	74	0.493

Fracturing

Longitudinal fractures were seen more often than transverse fractures. Sometimes only three or less were seen on the bone whereas other times many were visible including transverse fractures. The fractures also ranged from appearing deep to small, hairline fractures. Long bones mostly exhibited fracturing on the shaft and the other types of skeletal material varied. The following figures (Figures 20-22) demonstrate some of the variation seen in fracturing and fragmenting.

Descriptive statistics were calculated in order to see if the degree of cremation reached affected the type and degree of fracturing. Although the skeletal material classified as degree zero changed in measurement, most did not show any signs of fracturing. Degree one skeletal material ranged from having no fracturing at all to displaying both longitudinal and transverse fractures. All skeletal material in degrees two and three displayed both longitudinal and transverse fractures and had flaking. About 37% of the total skeletal elements were found fragmented into large and small pieces. Some of the larger fragments could still be identified, while the smaller fragments were typically unrecognizable.

Figure 20: Bone #3 only has small longitudinal fractures

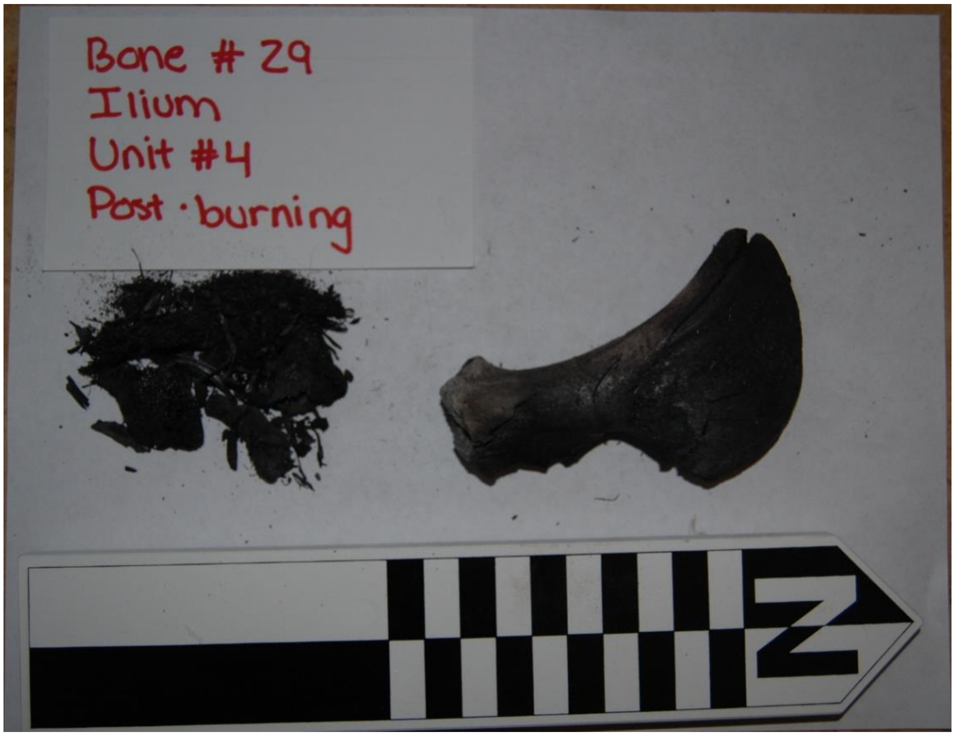


Figure 21: Many fractures can be seen as well as flaking

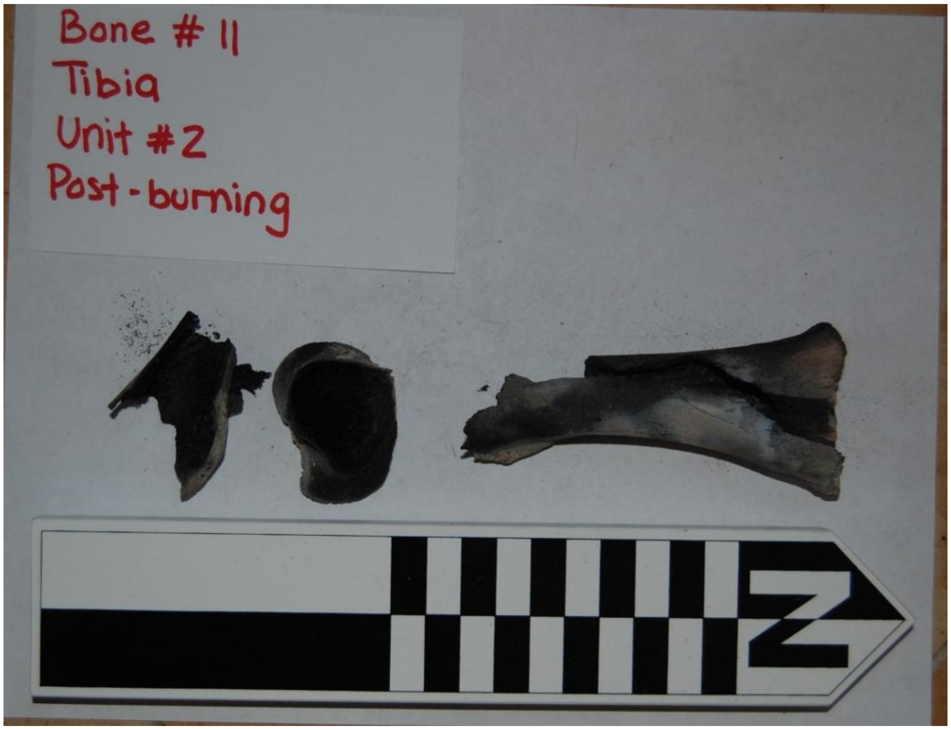


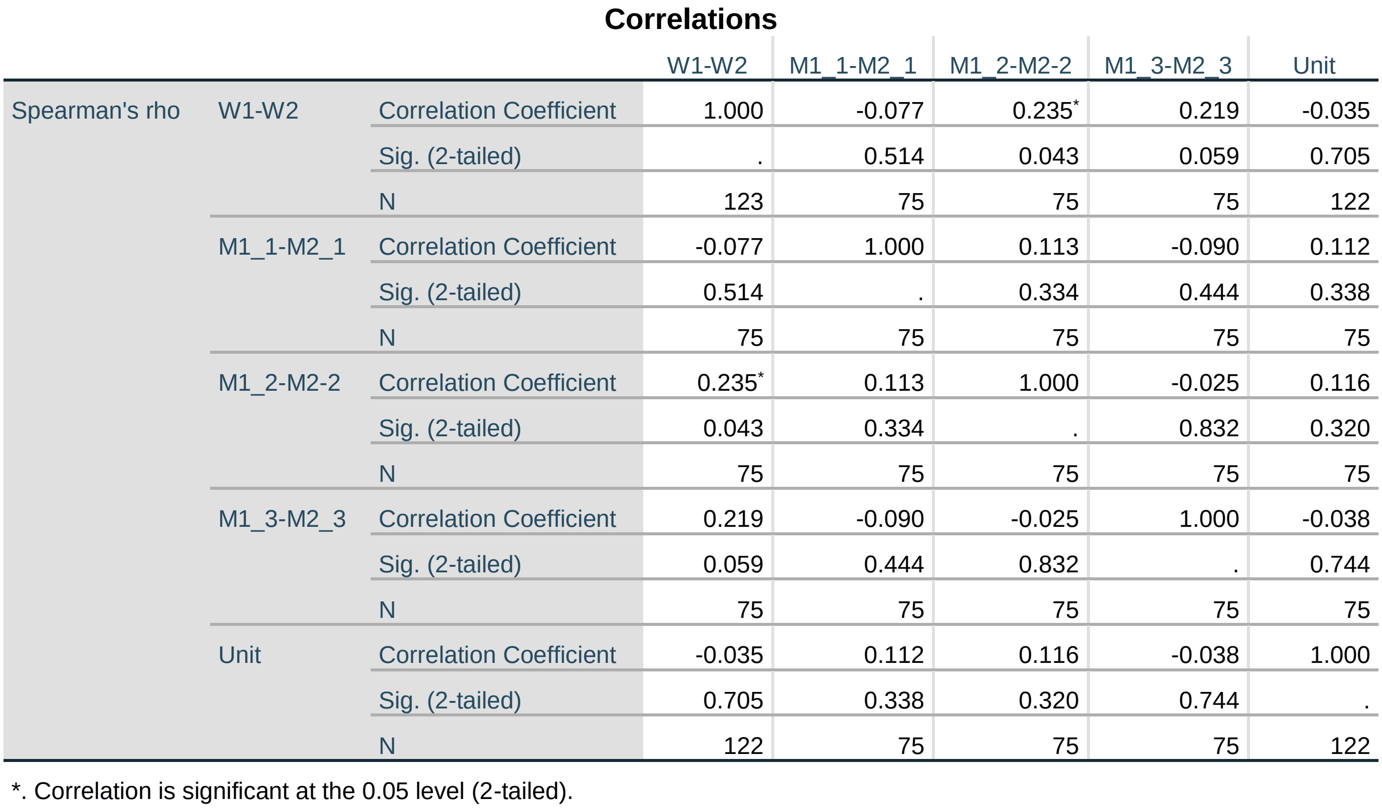
Figure 22: This bone is fragmented into three large pieces

Unit by Unit

Within each unit there was a cluster of level three cremations. On the map (Figure 9) a winding path can be seen expanding laterally or from west to east across units one and two. Units three and four appear to have its own cluster towards the center of the unit surrounded by level zero cremations closer to the perimeter. Each unit demonstrates the same spectrum of munsell colors.

A discriminant function test did not show a significant relationship between weight change and the unit it was placed in. The accuracy of classifying a bone by unit based upon weight change is about the same as random guessing, 28.7%. Degree of cremation also did not have a significant relationship with the unit it was placed in and had a similar classification accuracy of 27.9%. Spearman rank order correlation tests were conducted in order to determine if there were any relationships between the unit the bone was placed in and the change in weight as well as the change in dimensional measurements (Table 17). A two-tailed test of significance indicated that there is not a significant relationship between the unit the bone was placed in and the change in weight (r(122)=-0.035, p>0.05). The two-tailed test of significance also indicated that there are not any significant relationships between the unit the bone was placed in and the change in any of the three dimensional measurements taken. Based on these results it can be concluded that the unit the bone was placed in does not have a significant relationship with the changes in weight or dimensional measurements undergone die to heat exposure.

Table 17: Spearman Correlation Table for Unit Bone was Placed in from SPSS



Correlations

			W1-W2	M1_1-M2_1	M1_2-M2-2	M1_3-M2_3	Unit
Spearman's rho	W1-W2	Correlation Coefficient	1.000	-0.077	0.235^{*}	0.219	-0.035
		Sig. (2-tailed)	.	0.514	0.043	0.059	0.705
		N	123	75	75	75	122
	M1_1-M2_1	Correlation Coefficient	-0.077	1.000	0.113	-0.090	0.112
		Sig. (2-tailed)	0.514	.	0.334	0.444	0.338
		N	75	75	75	75	75
	M1_2-M2-2	Correlation Coefficient	0.235^{*}	0.113	1.000	-0.025	0.116
		Sig. (2-tailed)	0.043	0.334	.	0.832	0.320
		N	75	75	75	75	75
	M1_3-M2_3	Correlation Coefficient	0.219	-0.090	-0.025	1.000	-0.038
		Sig. (2-tailed)	0.059	0.444	0.832	.	0.744
		N	75	75	75	75	75
	Unit	Correlation Coefficient	-0.035	0.112	0.116	-0.038	1.000
		Sig. (2-tailed)	0.705	0.338	0.320	0.744	.
		N	122	75	75	75	122

*. Correlation is significant at the 0.05 level (2-tailed).

Type of Bone

Each category of bone (long bones, vertebrae, ribs, pelvis, phalanges, and scapula) appeared to follow the same pattern in color change and appeared in various stages of cremation ranging from stage zero to stage three. Although, ribs and vertebrae seemed to fall more in stage zero than any other bone. This could be due to placement or the fact that there was a considerable amount more of those bones than the other types. When observing the pattern of scorched earth seen in the pictures taken after the fire went out (Figures 10-18) to the pattern of level of cremation achieved (Figure 9), one can observe that these patterns do line up. The following figures show the same degree of color change and degree of cremation among two different types of skeletal material.

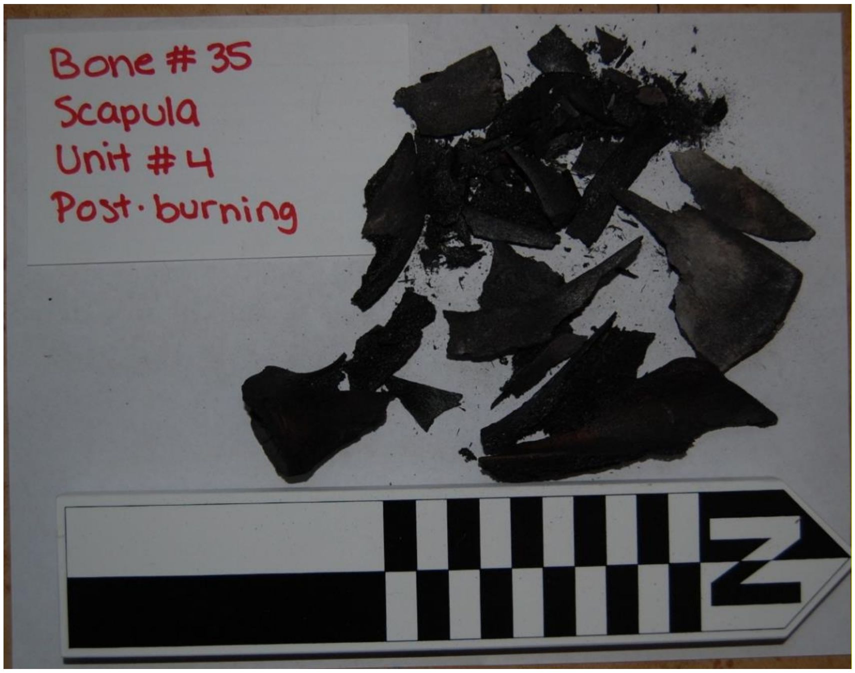


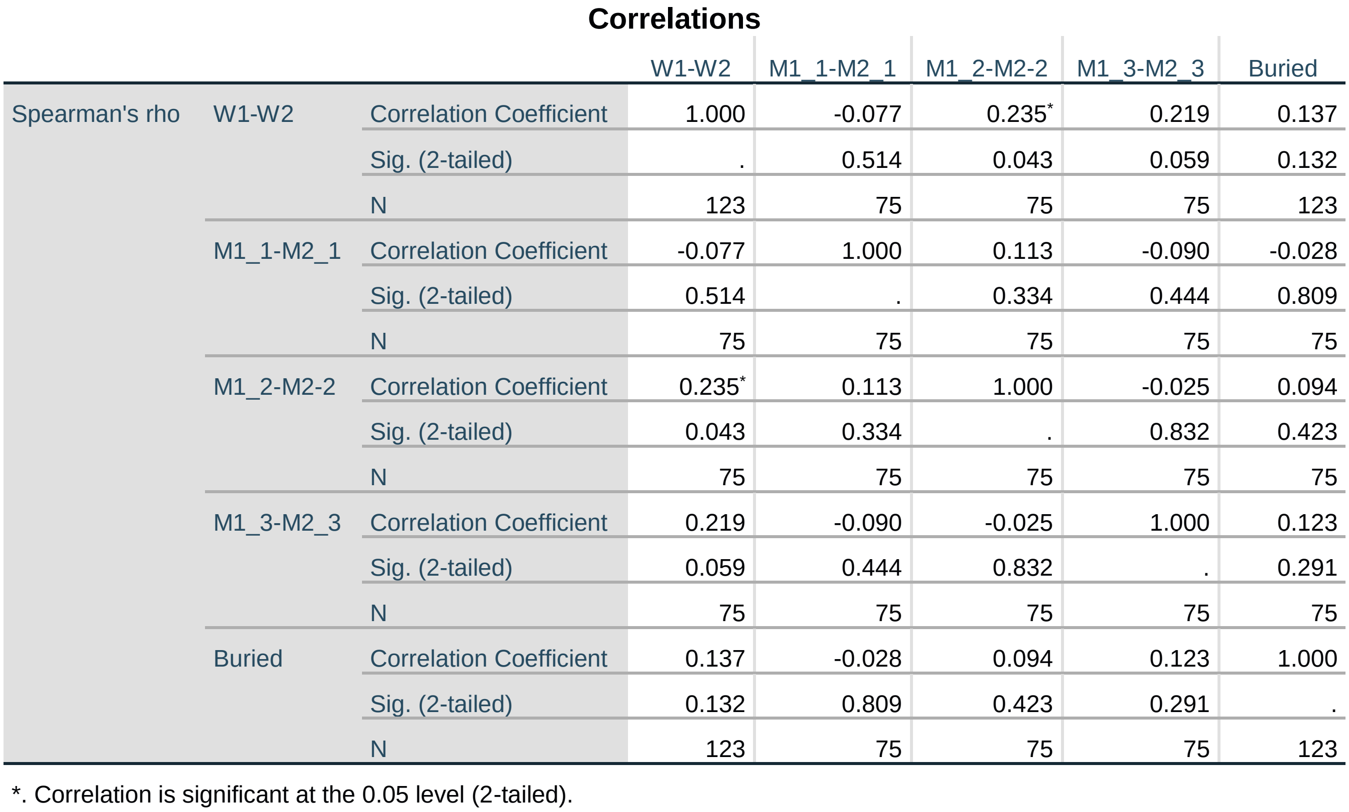
Figure 23: Post-burning alterations to a scapula

Figure 24: Post-burning alterations to a vertebra

Effects of Surface Litter Layer

Bones on top of the surface as well as bones underneath the surface litter layer were affected similarly and displayed the same pattern in color change and levels in cremation. Results from the discriminant function tests did not show a significant relationship between change in weight and whether or not the bone was covered by leaf litter. The accuracy of predicting whether or not a bone was on the surface or underneath leaf litter is about the same as guessing (57.7%). Degree of cremation was also tested to see if a significant relationship existed, however it was not the case and classification accuracy was only 54.1%. Spearman rank order correlation tests were conducted in order to determine if there were any relationships between the bone being on top of or below the surface litter layer and the change in weight as well as the change in dimensional measurements (Table 18). A two-tailed test of significance indicated that there is not a significant relationship between whether or not the bone was covered by leaf litter and the weight change that occurred (r(123)=0.137, p>0.05). A two-tailed test of significance also indicated that there is not a significant relationship between whether or not the bone was underneath leaf litter and the change in any of the three dimensional measurements taken. Based on these results it can be concluded that there is not a significant relationship seen between changes in weight or dimensional measurements after fire exposure and whether or not the bone was underneath the surface litter layer. The figures 25 and 26 show how skeletal material above and below the surface litter layer did not differ in heat-induced alterations.

Table 18: Spearman Correlation Table for Covered versus Uncovered in from SPSS



Correlations

			W1-W2	M1_1-M2_1	M1_2-M2-2	M1_3-M2_3	Buried
Spearman's rho	W1-W2	Correlation Coefficient	1.000	-0.077	0.235*	0.219	0.137
		Sig. (2-tailed)	.	0.514	0.043	0.059	0.132
		N	123	75	75	75	123
	M1_1-M2_1	Correlation Coefficient	-0.077	1.000	0.113	-0.090	-0.028
		Sig. (2-tailed)	0.514	.	0.334	0.444	0.809
		N	75	75	75	75	75
	M1_2-M2-2	Correlation Coefficient	0.235*	0.113	1.000	-0.025	0.094
		Sig. (2-tailed)	0.043	0.334	.	0.832	0.423
		N	75	75	75	75	75
	M1_3-M2_3	Correlation Coefficient	0.219	-0.090	-0.025	1.000	0.123
		Sig. (2-tailed)	0.059	0.444	0.832	.	0.291
		N	75	75	75	75	75
	Buried	Correlation Coefficient	0.137	-0.028	0.094	0.123	1.000
		Sig. (2-tailed)	0.132	0.809	0.423	0.291	.
		N	123	75	75	75	123

*. Correlation is significant at the 0.05 level (2-tailed).

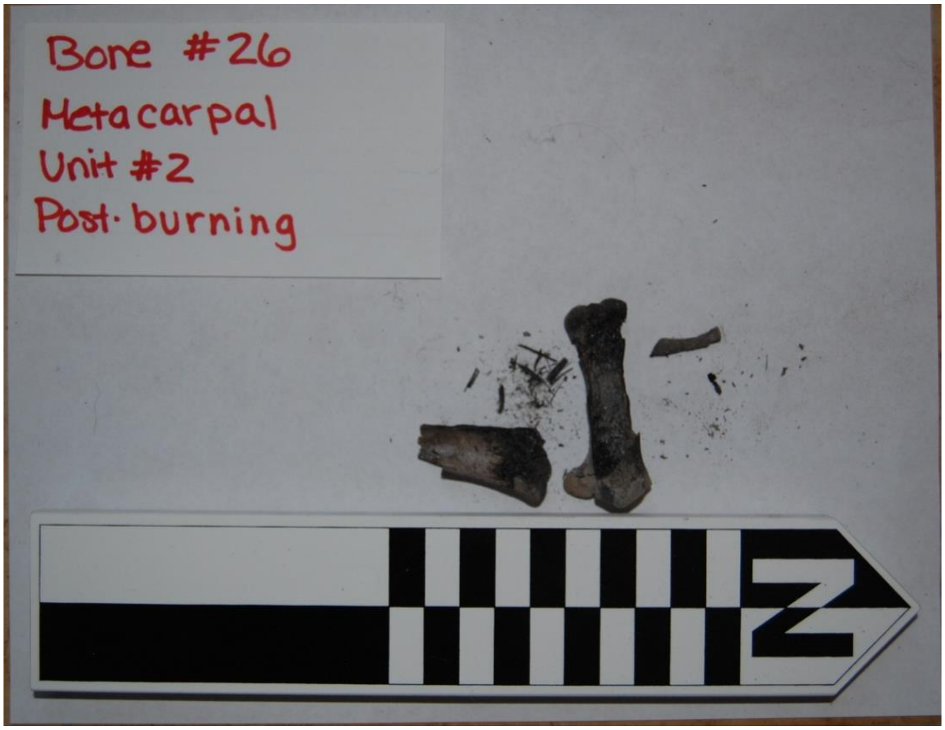


Figure 25: Post-burning alterations to a bone underneath the surface litter layer

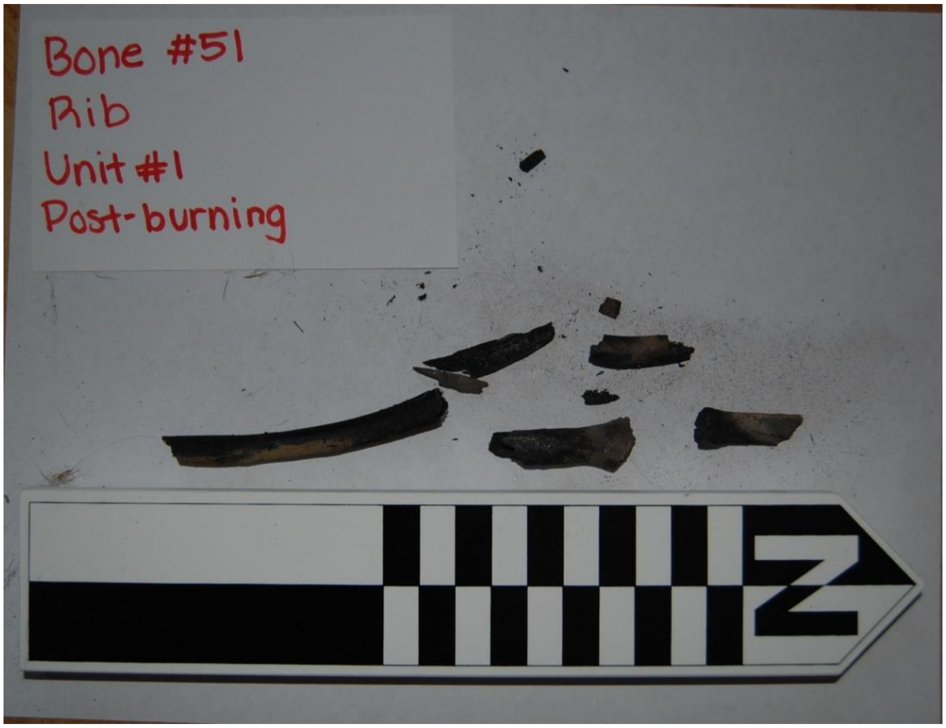


Figure 26: Post-burning alterations to bone above the surface litter layer

Some overall trends were seen in from the results. Level of cremation and color change both seem to follow the path of fire intensity. Also fracturing was observed in higher percentages as the degree of cremation increased. The more intense the fire the higher the degree of cremation, the darker the color of the bone changed, and the more likely fracturing will occur. Dimensional measurements changed in all the skeletal material not just those that were closest to the scorched earth. The category of bone each skeletal element fell into did not appear to affect the outcome of heat induced alterations nor did the unit each one was placed in. Leaf litter also did not provide enough coverage to protect the skeletal elements from the fire and prevent heat induced alterations.

Chapter 5: DISCUSSION

The purpose of this study was to examine alterations of skeletal material caused by wildfires. In order to achieve this skeletal material was placed in a 10X10 meter square marked off area in a field and then exposed to a simulated surface and ground fire. Heat-induced alterations were recorded and analyzed including change in coloration, weight, and metric dimensions. It also looked for any significance between these alterations and whether or not the bone was covered by leaf litter. Two hypotheses were proposed. The first is that wildfires will in fact be able to cause heat-induced alterations to skeletal material that will affect the accuracy of applying forensic methods used in establishing age, sex, and ancestry. The second hypothesis is that accumulated leaf litter will not cover the skeletal material deep enough to avoid heat-induced alterations.

Color change was consistent with other results found in previous studies. Skeletal material changed in color following color schemes of browns, blacks, grays, and whites. Temperature ranges could not be assessed for this study since temperature varied throughout the fire. However, a color pattern did emerge showing that bones exposed to heat in areas for a long period of time progressed further in cremation processes and therefore, color change. Examination of color change in this study is not as accurate as some studies, which employed the use of a spectrophotometer. The light present in a location will vary and affect the color identification, causing an inter-observer error (Fairgrieve, 2008; Mayne Correia, 1997; Shipman et al., 1984; Walker et al., 2008). Although color changes can provide insight on the heat intensity endured as well as length of time to the skeletal material, it does not damage the skeletal material enough to affect forensic analyses of said material.

Weight loss was observed in the skeletal material. This is due to the loss of organic material in the bone, which then causes shrinkage. An error in recorded post-burning weight may be present due to the fact that some remains were fragmented and may have been left behind during the collection process. Even through a thorough recovery process, it is impossible to collect all of the tiny fragments. Some are so small they may blend in with the soil and debris surrounding it. Fragmenting was not just seen in big pieces, but very small ones as well. An unexpected result of weight gain was also observed in some samples. The skeletal material was exposed to rain and therefore added moisture and water to the skeletal material, which could account for the increases observed. Also post measurements were taken in a different area (Ocala, Florida), which has higher humidity than Montana. This humidity change could also account for the increase in weight seen. Dimensional measurements also decreased in some skeletal material. This is also due to loss of organic material and therefore, shrinkage. Past studies have observed an increase in osteon size before a decrease. This may account for the increases seen in some skeletal material. Especially, since this material was not exposed directly to the fire, just the radiating heat from it. This means that the heat exposure was enough to begin modifications in the bone, but did not reach temperatures extreme enough to cause further changes such as color or shrinkage (Bradtmiller and Buikstra, 1984; Thompson, 2004). The changes in dimensional measurements seen in the skeletal material are large enough to affect the accuracy of forensic analyses.

The fire did not seem to reach temperatures hot enough or long enough for stage four cremation to occur, which follows past research indicating that stage four or complete cremations are less common (Eckert, 1988; Mayne Correia, 1997). Since the fire did not consume the surface of the entire test area, only patches, many skeletal samples were still in stage zero of the cremation process. This suggests that wildfires may not destroy all skeletal remains in the affected area and that there is a chance for remains to go unharmed with minimal change. Thus, it may still be possible to find skeletal material, even after a wildfire has passed over the area it was found, that will provide accurate information from forensic analyses.

One contradiction found to previous research is the effect of heat-exposure to different types of bones. Unlike past studies, this study did not see any difference in the type of bone and the amount of alteration incurred (Delvin and Herrmann, 2008; Mayne Correia, 1997). This could be due to a sampling problem because the fire spread in patches and did not drastically affect many areas with skeletal material present. It has instead been noted that the extent the skeletal material was modified is related to length of exposure. There also was not a difference observed in heat-induced alterations between units. This may mean that the fuel was distributed evenly over the units. This was not expected because the fire did not distribute itself evenly over each unit or for the same duration. It instead followed a winding path through each unit with smoldering remains left in its tracks.

Weather in this study more than likely impacted the fire sustainability. It rained, beginning Saturday night and lasting on and off throughout the remaining duration of the surface fire. With rain comes wind, which will increase the intensity of the fire as well as change its direction and spreading rate (Fuller, 1991; Pyre, 1996).

Few studies have investigated the effects of fire on remains covered by the surface litter layer. Stiner and Kuhn (1995) performed a study investigating the effects fire would have on skeletal material buried beneath the fire at various depths. They found that buried bone did experience heat-induced changes; but only up to 5 cm below the surface. After 5 cm the effects diminished greatly. They also noted that buried samples were not as advanced in the cremation process as bones on the surface. Neary et al. (2005) also observed that temperatures begin to diminish as depth increases in soil. This study, examined the effects of a wildfire on skeletal material covered by leaf litter. The leaf litter did not provide a thick enough layer to protect the skeletal material from heat-induced alterations. These alterations were seen in both the skeletal material above and below the surface litter layer.

This study does have its limitations. First, the skeletal material used came from a pig instead of a human. Even though, past studies have shown similarities between pig and human bones; they are not identical in all properties. If human bones would have been used, then forensic methods could have been tested out to see how much impact the post-burning measurements would have on them. Also estimating age is an important forensic method used, but was not looked at in this study. The epiphyseal structures located at the ends of long bones are used in estimation of age. Therefore, any damage or change to these could render an age assessment inaccurate. Second of all, there were no fresh bones used in this study. All of the bones had been exposed to weathering processes for about a year. Fresh bones differ from weathered bones and these differences could cause a different reaction. One example would be the fat content of fresh bones is higher than that of weathered bone. Fat can be used as a fuel in fires. Therefore, one would wonder if the higher fat content of fresh bone would affect the way it burned in a wildfire.

Another weakness of the study is that it takes place in October, when wild fires are less likely to occur in Montana. This only investigates one kind of fire with its own specific variants. The two main variants are temperatures reached and the duration of heat exposure, which determine the extent of heat-induced modifications. These also happen to be two main variants of wildfires. This leaves the question, if wildfires can be studied to find a pattern between them and heat-induced bone modifications or if they vary too much from one another, meaning results cannot be predicted? Also temperatures taken in this study may not be accurate because the thermometer used takes the average temperature of the entire area in its point of view. This view expands eight meters in diameter which will include surrounding air temperatures as well as the fire itself. Also since the fire moved around the units the temperatures varied throughout the units and at different times.

Chapter 6: CONCLUSION

It is important to perform studies researching the effects of heat exposure on skeletal material; because heat-exposure can alter skeletal material and affect one's investigation. It is hard to determine if heat-altered remains are a product of burial, natural forces, cooking, or criminal intent. Alterations can also affect the accuracy of current methods used to determine identification features such as sex, age, stature, ancestry, and age at death. Fires will also alter a crime scene and destroy other physical evidence that may aid in the investigation. Further research needs to be conducted to see how much the accuracy of these techniques have been affected as well as developing new techniques to gain information from skeletal material. It is clear they will be affected since metric dimensions are altered and some skeletal material is altered beyond recognition for qualitative assessments. Even if only broad categories can be established, such as in age groups, it is better than nothing.

Current studies are difficult to compare to one another because they differ greatly from one another in a variety of ways. Skeletal remains used differs in each study ranging from human to non-human, fresh to dry, and even regions of bone included. These studies also differ from one another in the heating method applied. Some used ovens and either tested material at different temperatures or the same temperature for different lengths of time. Others simulated outdoor fires in a variety of settings. Past studies have also focused on different heat-induced alterations to skeletal material. Some studies examined multiple alterations while some focused on only one aspect. There has also been an inconsistency of terminology used in studies performed on wild fires as well as cremations of skeletal material. Further research needs to be done in order to attempt to standardize these studies and examine all of the variables present.

Heat exposure from wildfires differs greatly from that of ovens. First of all, heat exposure is on and off in a wildfire instead of a constant source as seen in an oven. Temperatures reached will also vary throughout the duration of a wildfire, while an oven can apply a constant temperature for a constant amount of time. Also atmospheric conditions in a wild fire will vary amongst themselves and cannot be recreated in an oven. Further research needs to be done investigating variations in fires. This needs to include different fire types in addition to surface and ground fires such as crown fires. Fires should be simulated under different weather conditions as well as different fuels should be used.

More research could also open up the possibility to identify whether or not bones retrieved from an area affected by wildfires were fresh or weathered, based upon how they reacted to the fire. If weathered bones react differently from fresh bones in a fire than these differences can be studied and used to identify what kind of context the bones were retrieved from. This is very important in the anthropological world as it can help determine if the case is archaeological or forensic in nature.

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