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Fragmentation of calcined bone: Aspects relating to improving recovery of calcined bone from fatal fire scenes

by

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Abstract

Burning has a significant effect on the human body. Soft tissue is burnt and bone is significantly altered as water and organic content is lost. These changes cause bone to become brittle, fragile and prone to fragmentation, complicating recovery of remains. In an effort to maximize remains recovery, reduce unnecessary destruction and enhance anthropological evaluation, this research aims to increase our understanding of some factors that affect burnt bone fragmentation.

Key elements affecting burnt bone fragmentation were identified by conducting a review of fatal fire deaths in Alberta over a ten year period. The effect of decedent age on remains fragmentation was investigated with results showing that younger bone typically fragments less than older bone burnt in similar burn environments. Investigations into the effect of delayed recovery on bone fragmentation outlined the time line of remains destruction and highlighted the need for rapid recovery whenever possible. Finally, the effects of temperature and rainfall on remains fragmentation were assessed and results identify the destructive effects of freezing conditions, temperature fluctuations and damp conditions. All investigations were conducted using *Sus scrofa* (domestic pig) limbs burnt in wood fires and altering the variables decedent age; time until recovery; and season of burn event.

Data presented in this thesis will enable scene investigators and scene managers to reduce post-burning remains destruction, ensure efficient, maximum value recovery protocols are employed and appropriately prioritise remains recovery within the context of the scene. These improvements are vital to maximise anthropological assessment of burnt bone and to ensure legal and moral obligations to recover all human remains from a fatal fire scene are met.

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Table of Contents

List of Tables

List of Figures

Chapter One: Introduction

1.1. Introduction

The goal of this dissertation is to provide new insight into and a better understanding of factors relevant to calcined bone fragmentation within fatal fire scenes and assess the impact this knowledge can have on improving and strengthening recovery methods. Fire scenes that include human remains always present a complex challenge for investigators. Invariably, numerous agencies are involved, with police, fire investigators, medical examiners/coroners and insurance agents frequently on scene. Coupled with this, the scene is often highly disturbed, with the effects of the fire and fire suppression efforts and the physical environment having an impact on the human remains (Symes *et al.*, 2008, Olson 2009, Dirkmaat *et al.*, 2012). Despite these challenges human remains recovery needs to be completed expediently and efficiently with minimal information loss. Regardless of the forensic nature of the scene the remains must be recovered for identification and legal disposal, and in some circumstances they may need to be analysed as evidence in the investigation into the nature of the fire event (Olson, 2009, Dirkmaat *et al.*, 2012). Remains recovery is therefore a key component of fatal fire scene processing and should be designed to maximise recovery and minimise real and potential post-burning destruction of remains. Remains recovery also needs to be considered within the context of the greater scene investigation to ensure the appropriate timeliness of recovery and maximum benefit to all investigators involved. Finally, remains recovery processes must be efficient, balancing resource investment with valuable and justifiable outcomes.

Current remains recovery protocols (Dirkmaat, 2002, Fairgrieve, 2008, Dirkmaat *et al.*, 2012), while adequate, can be improved upon by increasing our understanding of the nature and characteristics of burnt bone material (Olson, 2009). One aspect of this relates to the reality that fragmentation of calcined bone occurs during and after the burn event. Calcined bone is formed when bone is burnt and all water and organic material is lost. Calcined bone is white in colour, brittle and often highly fragmented making recovery from the scene especially challenging (Dirkmaat *et al.*, 2012). Calcined bone can be difficult to differentiate from surrounding fire debris and the fragments are often small and not recognisable as human bone to the untrained eye (Dirkmaat *et al.*, 2012). Knowledge of how calcined bone fragmentation alters in different circumstances will give investigators better insight into the material they are attempting to recover and will enable scene specific protocols for maximal recovery value.

1.2. Background

Fires involving human remains are encountered in many different situations. In the United States in 2011 there were 3005 civilian fire deaths, 2520 occurring in house fires, 300 in highway vehicle fires and 90 in non-residential building fires (Karter, 2012). In Canada the 2002 Fire Loss report indicated 304 fire deaths, with 250 occurring in residential properties, 20 in highway fires and 10 in outdoor properties (Council of Canadian Fire Marshals and Fire Commissioners, 2007). While not all criminal in nature, these fire deaths would all have required investigation and recovery of human remains.

This recovery process may be relatively straightforward when the remains have undergone little heat-induced change but in some circumstances human remains can be significantly burnt, making recovery difficult. There is little published data on the number of fatal fires resulting in bone calcination and fragmentation, but published case studies show the complexity of these scenes and the need for scene specific recovery methods. Dirkmaat (2002) outlines six cases of highly fragmented burnt remains in residential properties and vehicles and in one case highlights how poor recovery methods resulted in the destruction of remains and loss of material. Fairgrieve and Molto (1994) describe another case where juvenile remains were burned and most of the soft tissue was totally destroyed leaving burnt bone fragments. The need for scene specific recovery methods are the focus of Mayne Correia and Beattie's (2002) presentation of a further three Canadian cases of highly fragmented burnt human remains. It is important to note that in many of these and other case studies remains recovery was not completed immediately after the fire and often occurred over a number of days (Brickley, 2007, Baker Bontrager and Nawrocki, 2008, Olson, 2009).

When human remains are burnt they are significantly altered by the burn environment. As bone is exposed to increasing burn intensity, either through increased temperature or increased burn duration, it is gradually transformed from its natural state losing water and organic components to become calcined bone (Devlin and Herrman, 2008). This transformation from unburned to calcined bone occurs as a continuous process with bone passing through a number of intermediary stages which have been outlined by Mayne Correia (1997) and further adapted by Thompson (2004) (Table 1.1). As the bone progresses through each of these stages, various physical and chemical alterations occur, resulting in a number of microscopic and macroscopic heat-induced changes.

At the microscopic level the surface morphology of heated bone is typically unaffected by temperatures below ~200°C and remains intact and continuous (Shipman *et al.,* 1984). As the heat load increases the surface becomes rough, and between ~200 and ~300°C small granular asperities separated by voids and cracks can be observed (Shipman *et al.,* 1984, Nicholson, 1993). With increasing temperatures the surface layer continues to transform and at ~300°C a carbon-rich char may develop which then disappears by ~400°C when the surface can be described as irregular and 'frothy' (Nicholson, 1993). As heating continues to ~600-800°C the bone surface becomes more irregular with extensive cracking and particle formation (Shipman *et al.,* 1984, Nicholson, 1993). Above ~800°C these particles coalesce resulting in a more globular appearance of the bone surface (Shipman *et al.,* 1984).

Bone crystal structure is also altered by heat exposure. Crystal structure change does not begin until bone temperature reaches ~600°C when the organic bone components undergo pyrolysis (Shipman *et al.,* 1984, Holden *et al.,* 1995b, Thompson, 2004). At this point the chemical composition of the bone material is changing and recrystallisation can be observed as small spherical crystal structures on the bone surface (Holden *et al.,* 1995b). As the temperature increases, these crystals combine with neighbouring crystals, increasing in size until they form a hexagonal crystal (Shipman *et al.,* 1984, Holden *et al.,* 1995a). These hexagonal crystals exhibit variable forms depending upon the degree of mineralisation of the bone material and bone age (Holden *et al.,* 1995b, Hiller, 2003). When temperatures reach over ~1000°C the hexagonal crystals begin to fuse with fusion continuing until 1400°C when hexagonal crystal size can no longer be determined (Holden *et al.,* 1995b). Burning at 1400°C can also result in the formation of new crystals with rhomboidal morphology as well as other rarer crystal shapes (Holden *et al.,* 1995b). With further heating, bone crystal structure continues to change until around 1600°C when all structural features are destroyed (Holden *et al.,* 1995b). These crystal structure changes are the focus of much recent work on identifying burnt bone and outlining the burn process (Munro *et al.,* 2007, Piga *et al.*, 2009, 2013, Thompson *et al.,* 2009, 2011, 2013).

As bone is heated, the colour and hue of its surface change as organic components are lost (Shipman *et al.,* 1984). In the initial stages of burning, the bone surface is stained brown or black by the breakdown of haemoglobin before the bone turns fully black as the organic components are burnt and the bone becomes charred. With continued heating and loss of organic components the bone colour lightens progressing through a series of grey and grey-blue colours before turning white or bluish white when the bone is completely calcined (Shipman *et al.,* 1984, Ubelaker, 1989, Mayne Correia, 1997, Walker *et al.,* 2008). Other colours, such as red, yellow and green, have also been noted on burnt remains although these tend to be observed in archaeological material and are thought to result from food, soil or artefact staining (Gejvall, 1969, Dunlop, 1978, Mayne Correia, 1997).

Bone colour has been used in attempts to determine specific temperatures attained during the burning event (Shipman *et al.,* 1984, Holden *et al.,* 1995a,b). However, this is unreliable due to the numerous factors, such as oxygen availability, fat content, bone morphology and the rate of heating, all of which affect bone colour (Heglar, 1984, Nicholson, 1993, Brickley, 2007, Walker *et al.,* 2008). Furthermore, several different colours are often observed on a single bone fragment, complicating the colour-temperature analysis (Mayne Correia, 1997). In addition to determining fire temperature, bone colour has also been used to suggest body position and possible dismemberment prior to burning (Baby, 1954, Mayne Correia, 1997). These conclusions have been derived from observed variations in colour between skeletal elements, with increased calcination and white colouration correlating with more intense burning at the centre of the fire, or with the burning of exposed skeletal elements (Brickley, 2007). Although applicable in a general sense, these conclusions seldom consider all of the factors which may influence the burning intensity and resultant bone colour (Nicholson, 1993, Brickley, 2007).

Other macroscopic heat-induced changes include dimensional change resulting from changes in crystal structure. Little bone shrinkage occurs at temperatures below ~800°C (Mayne Correia, 1997) which correlates with microscopic investigations that report no change in crystal structure when bone is burnt at these low temperatures (Bradtmiller and Buikstra, 1984, Shipman *et al.,* 1984). When bone is burnt at higher temperatures, typically once the bone has entered the 'fusion' stage of transformation, bone shrinkage becomes more significant and can result in major dimensional alteration (Thompson, 2005). These changes are complex and dependent on numerous factors affecting the heat-induced recrystallisation process such as the heat intensity of the fire, bone composition and bone age (Shipman *et al.,* 1984, McKinley and Bond, 2001, Thompson, 2005). There is debate surrounding the effect of compact versus spongy bone on observed shrinkage, although differences in experimental results may result from differing methodologies measuring absolute or relative dimensional change (Thompson, 2005). Taking this into consideration Thompson (2005) has argued that overall dimensional change is more strongly influenced by spongy bone because the irregular collagen orientation reduces structural strength increasing absolute shrinkage. Bone age affects shrinkage in a similar manner as younger bone contains less collagen cross linking, thus reducing structural strength and allowing more shrinkage to occur (Holden *et al.,* 1995a, Thompson, 2005).

Heat-induced fracturing and fragmentation of bone occurs as the physical properties are altered when water and organic components are lost (Brickley, 2007). Heat-induced bone fractures arise from the altered stresses and strains experienced within the bone and may be produced prior to total incineration or calcination of the remains (McKinley, 1994, Mayne Correia, 1997). Extensive fragmentation of the bone material arises because of the fragility and friability of completely calcined material. If undisturbed, calcined bone may appear as complete bones in anatomical position; however, they are difficult to recover whole as only a small amount of pressure is required for the bone to collapse (Heglar, 1984). Although these bone changes have negative effects on the anthropological evaluation of burnt remains, the investigation of the patterning of heat-induced bone fractures may provide additional information pertaining to the circumstances surrounding the burning event. Fracture production in burnt remains is not random but a direct response to the forces applied to the bone. These forces are in turn dependent upon heat-induced alterations occurring within the bone itself, and thus fracture types can be linked to burning types (Wells, 1960, Gejvall, 1969). This rationale of linking fracture types and burning types has led to the investigation of methods to distinguish fleshed from de-fleshed cremations and heat-induced from pre-burning fractures.

The differentiation of fleshed and de-fleshed burning is complex and highly nuanced. Research into distinguishing the burning of dry bone and fresh bone has been relatively successful (Webb and Snow, 1974, Baby, 1954, Binford, 1973). In contrast, it has proven difficult to differentiate burning of fleshed and recently de-fleshed bone. While Thurman and Willmore (1981) argue that diagnostic fractures and warping can be indicative of fleshed or recently de-fleshed burning, other researchers have not reached this conclusion (Buikstra and Swegle, 1989, Whyte, 2001). The differentiation of heat-induced from pre-burning fractures has also been contentious. Standard heat-induced alterations of the skull and long bones have been outlined through experimental work, however the numerous variables affecting burning limit their use in case work (Mayne, 1990, Herrmann and Bennett, 1999, Pope and Smith, 2004). The degree of fire agitation, the fat and mineral content, the age of the bone material, and the method of bone cooling have all been shown to modify the patterns of heat-induced fractures (Costamagno *et al.,* 2005, Brickley, 2007). Furthermore, increasing the heat load experienced, whether by increasing the temperature or the duration of burning, increases the degree of fragmentation and fracturing (Stiner *et al.,* 1995).

Heat-induced bone changes have a significant impact on the complexity of fatal fire scenes and the recovery process. Bone colour changes often make bone material difficult to distinguish from surrounding fire debris, and fragmentation and distortion can make bone pieces difficult to identify (Dirkmaat *et al.*, 2012). Despite these challenges, protocols need to aim for complete recovery with no further destruction to the remains. Universally, various forms of legislation require that in any fatal fire scene remains be collected and available for assessment of cause and manner of death, and investigators have a moral obligation to the friends and family of the deceased to recover the remains (Canada: Fatal Inquiries Act RSA 200 cF-9, United Kingdom: Coroners and Justice Act 2009). Considering this, many recovery protocols employ archaeological techniques to maximise discovery, contextual information gathering and remains recovery (Fairgrieve 2008, Symes *et al.*, 2008, Dirkmaat *et al.*, 2012).

Scene processing usually begins with a scene search, typically using a grid system that ensures that no area is disturbed prior to searching. The success of the scene search is limited by the searchers ability to locate and identify the burnt bone fragments (Fairgrieve, 2008). Once remains have been located they are documented *in situ* with photographs and written notes before being ‘lifted’. The details of this process are determined by the condition of the remains. Surrounding debris may be removed by hand and bone material picked up and placed in storage bags. Some circumstances may warrant the use of consolidants to strengthen the remains, although this is not common as it may influence later trace or chemical analyses (Schmidt, 2008). A block system of recovery may also be used where an entire section of burn debris is removed *en masse* without disturbing the remains to be transported to the laboratory.

Once lifted, remains are often stored in plastic or paper evidence bags that may be filled with supporting paper or other material. Bags are often slightly air filled to increase protection of the delicate remains (Mayne Corriea and Beattie 2002, Fairgrieve, 2008). It should be noted that while these guidelines are often followed, all fatal fire scenes are unique and many factors affect how the scene may be processed. Scenes vary in size, location, degree of burning, number of deceased, local weather conditions, scene safety, personnel skill levels and other factors which will all impact the recovery process. Additionally the criminal/accidental nature of the scene usually dictates the approach to processing. Depending on the resources available, manpower, time pressures and investigation priorities, different systems of excavation will need to be employed (Mayne Correia and Beattie, 2002).

1.3. Thesis Outline

The research presented in the following chapters was formulated and carried out in response to the challenges posed above. Chapter Two examines the occurrence and circumstances of fatal fires in Alberta and provides essential background for further work into aspects of calcined bone fragmentation in this province. Data presented here show that 274 fatal fire deaths occured in the province over the ten year period between 1999 and 2008. Within these fatal fire deaths the full range of burn injuries was observed with some remains consisting of calcined bone. Fatal fires occurred in all seasons and included individuals of all ages, with proportionally more deaths of younger and older individuals.

Chapter Three assesses the influence of decedent age on calcined bone fragmentation. Younger bone is thought to be more fragile and delicate than older material and thus suffers more degradation in a fatal fire scene (Pevytoe, 2012). Results presented here show that while young bone often consists of smaller pieces that may be difficult to locate, younger bone is in fact typically less fragmented than older bone. This discovery has significant implications for remains recovery, as it highlights the importance of using searchers trained in juvenile osteology to facilitate remains discovery. It also emphasises the value of involving anthropologists and archaeologists at the scene to ensure appropriate documentation and contextualisation of the remains to facilitate a more thorough and detailed investigation.

Chapter Four investigates how delayed recovery impacts calcined bone fragmentation. Recovery of remains from fatal fire scenes can be delayed for a number of reasons, such as ensuring site safety or difficulties finding remains, and it is important to recognise the effect these delays have on the quality of the material recovered. Results show that delays of up to 24 hrs can have a marked impact on remains fragmentation, but between 24 and 56 hrs delay, the fragmentation rate decelerates. Between 56 and 168 hrs (1 week), remains fragmentation again increases. Understanding the timeline of remains fragmentation allows investigators to prioritise their recovery more effectively within the context of the larger scene. Data on the effect of delayed recovery also enables investigators to form reliable estimations of remains condition and instruct searchers on the expected appearance of the material to be discovered. This should aid in increasing bone fragment recovery and aid later analysis of the remains.

The penultimate chapter, Chapter Five, assesses the effect of Alberta weather conditions on calcined bone fragmentation. Fatal fires occur throughout the year and in Alberta burnt remains are exposed to a large range of ambient conditions by season. The effect of freezing temperatures, temperatures fluctuating around freezing and rainfall were investigated. The effect of the conditions varies with decedent age and time of exposure, underlining the specificity of the bone response. The results highlight the importance of keeping remains dry and in temperatures above freezing until recovery can be completed. If this is not possible, knowledge of remains fragmentation ensures investigators have a better appreciation of the material to be recovered and can instruct searchers accordingly and implement recovery protocols to maximise recovery.

Chapter Six provides a summary of the research results and the value of these outcomes. Potential future research and areas of investigation are also discussed.

Stage of Transformation	Description	Evidence	Temperature Range °C
Dehydration	Hydroxyl bonds break and loosely bound and bonded water is lost	Fracture patterns, weight loss	100-600
Decomposition	Organic bone components lost through pyrolysis	Colour change, weight loss, reduction in mechanical strength, changes in porosity	300-800
Inversion	Loss of carbonates	Increase in mineral crystal size	500-1100
Fusion	Melting and coalescence of the crystal matrix	Increase in mechanical strength, reduction in dimensions, increase in crystal size, changes in porosity	700+

Table 1.1: Primary level stages of heat induced bone changes. Modified from Thompson, 2004; Thompson, 2005.

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Chapter Two: A review of fire-related deaths in Alberta[1]

2.1. Introduction

Fire-related deaths and burnt human remains represent a significant part of forensic anthropological casework. As a result, there has been a developing interest in fire-related research focusing on how remains are affected by the burn environment (Thompson, 2003, Fairgrieve, 2008, Schmidt and Symes, 2008). To be valuable to death investigations, this research must be comparable with real death circumstances. To ensure this relevance, an understanding of the circumstances associated with fire-related deaths and how these correlate with decedent data is required. The research reported on here provides an overview and analysis of fire related deaths occurring in Alberta over a 10-year period.

Reports on fires and fire-related deaths are commonly produced by fire investigation departments for different regions and time periods (Ahrens, 2008, Flynn, 2008, Council of Canadian Fire Marshals and Fire Commissioners). These reports, however, seldom offer enough detail and specifics on the effect of fire on human remains to aid in research design. The reports are commonly annual review publications, which present statistical data on the number and types of fires and fire deaths but seldom identify trends or characteristics of fire-related deaths. These reports also do not detail the degree of burning of human remains commonly observed in different fire types and circumstances, knowledge which is vital for forensic anthropological research assessing

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[1] A version of this chapter has been published. Waterhouse, 2010. The Canadian Society of Forensic Science Journal, 43:4, 171-180.

realistic scenarios. The research reported on here evaluates this type of information for the Alberta region, aiding in the development of valuable and applicable forensic anthropological approaches in fire scene recovery, as well as providing direction for future research.

2.2. Methods and Materials

Fire-related deaths occurring in Alberta between January 1999 and December 2008 were analysed by reviewing Medical Examiner records. The selection of the ten-year period is somewhat arbitrary, but also relates to the greater degree of accessibility for records dating from 1999. Relevant case files were selected by searching the Office of the Chief Medical Examiner's electronic database (MEDIC) using a series of search filters outlined in Table 2.1. These files were then manually reviewed and data collected on the age and sex of the deceased, the cause of death, the month of death, the degree of burning of the remains, and the fire type and location. The criminal or accidental nature of the fire deaths was not recorded as this information was not consistently available. Information was obtained from autopsy reports and case files, with the degree of burning determined and recorded on a scale of burn damage (see Table 2.2). This is a scale of increasing severity with remains coded according to the most severe burn injuries observed. Although other classification systems (e.g., the Crow-Glassman Scale) exist for the assessment of burn injury, these were not used in an effort to maximise observed differences in burn injuries.

Autopsy recording forms are standardised across the province, although the amount of detail provided on burn damage is quite variable; however, this was assessed as having minimal impact on the assessment of burn injury severity, as the majority of case files had sufficient detail, making it possible to corroborate or expand on the autopsy notes by consulting police and pathology reports. Researcher-determined assessment of burn injury severity likely introduced some degree of subjectivity, which was mitigated by using the presence/absence of descriptors of burn injury (Table 2.2) to determine burn injury severity.

2.3. Results and Analysis

Two-hundred-and-seventy-four fire-related deaths occurred in Alberta between January 1999 and December 2008. These deaths resulted from 231 fire incidents in residential properties, vehicles, and outdoor locations. Sixty-five percent of fire deaths (N = 179) occurred in residential fires, which is lower than the proportion of residential fire deaths recorded across Canada between 1993 and 2002 (76%) (Council of Canadian Fire Marshals and Fire Commissioners). Vehicle fires following vehicle collisions was the second most frequent type of fire death in Alberta with 56 decedents (20%). This is higher than the national average of 6% recorded between 1993 and 2002 (Council of Canadian Fire Marshals and Fire Commissioners). Stationary vehicle fires accounted for 8% (N = 21) of fire-related deaths in Alberta. The remaining 18 (7%) fire deaths resulted from explosions (N = 7), self-immolation (N = 5), accidental burn injuries (N = 4), aeroplane crashes (N = 1), and dumpster fires (N = 1).

2.3.1. Residential Fires

One-hundred-and-seventy-nine fire-related deaths occurred in 153 residential fires in Alberta in the 10-year period under review. Of these 118 (66%) were male and 61 (34%) were female. This pattern of higher incidence in males has been seen in other studies although the reasons for it remain unclear at this time (Flynn, 2008). Decedents ranged in age from one to 92 years with the full age at death profile shown in Figure 2.1. Although not the most frequent, child deaths (age 0-10 years) are relatively common, showing the third highest frequency (20%). This trend has been noticed in past research and has been attributed to a reduced ability to escape the fire due to a dependence on older individuals. A high frequency of child deaths has also been associated with accidental fire-setting by children (Squires and Busuttil, 1995, Barillo and Goode, 1996, Elder *et al.*, 1996, McGwin *et al.*, 2000, Istre *et al.*, 2002, Shai and Lupinacci, 2003, Mulvaney *et al.*, 2008).

In early to mid-adulthood the age at death profile exhibits an increase in the number of deaths with age until 50 years, above which the frequency of deaths decreases with increasing age. Although this pattern has been noted by other researchers (Thompson, 2003), the reasons for it are not easy to discern. Population differences between age categories may be an influencing factor and the strong correlation between fire deaths and smoking and/or alcohol consumption in the home may also suggest that these social habits are influencing death rates in some age groups (Chernicko *et al.*, 1993, Squires and Busuttil, 1995, Marhsall *et al.*, 1998, McGwin *et al.*, 2000, Holborn *et al.*, 2003, Shai and Lupinacci, 2003, Mulvaney *et al.*, 2008).

When comparing deaths of the elderly (> 65 years) with those of younger individuals, a lower rate of occurrence in fire-related deaths in the older individuals is observed (Figure 2.1), although when the ratio of fire deaths to total population is considered, these data show an elevated risk of residential fire deaths in the elderly. The 2001 population census determined that individuals aged over 65 years comprise only 10% of Alberta's population (Statistics Canada) but the collected data show these individuals account for 18.5% of residential fire deaths. This patterning of elevated risk in the elderly has been observed in other studies and the reasons for it have been attributed to the elderly having a higher risk of starting a fire as well as decreased mobility and ability to detect and escape the fire (Barillo and Goode, 1996, Elder *et al.*, 1996, Rodge and Olving, 1996, Holborn *et al.*, 2003). Elderly individuals are also at a greater risk of dying in residential fires due to a higher susceptibility to the effects of smoke inhalation (Yoshida *et al.*, 1991).

Smoke inhalation was the primary cause of death in residential fires, with 96% (N = 172) of decedents dying in this manner. The remaining deaths occurred prior to the fire (N = 3), resulted from burn wounds (N = 2) or from undetermined causes (N = 2). In one case of undetermined cause of death, the decedent was suspected to have died from a cardiac arrest prior to the fire, and in a second case, cause of death could not be determined due to the fragmentary nature of the remains.

Fatal residential fires resulted in the full range of burn injuries (Table 2.3). Burn injury levels *one* and *seven* are low in frequency with only 15 and nine cases, respectively. In contrast, burn injury levels *two* and *three* are high in frequency (N = 38 and N = 44, respectively) and form nearly half of all residential fire-related deaths (45%). The remaining burn injury levels, levels *four*, *five* and *six*, form an intermediate frequency grouping and exhibit relatively equal frequencies (N = 25, N = 24 and N = 24, respectively). This pattern indicates that no burn injury or very severe burn injuries (levels *one* and *seven*) are less common in fatal residential fires, while burn injuries such as skin slippage and heat-induced ruptures are observed most frequently (levels *two* and *three*). More severe burn injuries, ranging from skin charring and skin incineration to heat-induced amputation, are also observed with regularity, and these injuries form a noteworthy portion of all residential fire deaths.

Burn injury severity also differs between residence types. Decedents who died in cabin/trailer fires tend to exhibit more severe burn injuries than those who died in house fires (Figure 2.2). Burn injury severity is associated with burning intensity suggesting that cabin/trailer fires burn more intensely than house fires. This may result from increased flammability of building materials and/or a smaller and more concentrated area of burning (McGwin *et al.*, 2000). It is also possible that cabin/trailer fires develop into stronger, more intense fires as a consequence of often being more remotely located, increasing the time of burning prior to attempts of fire suppression.

The final component of residential fires assessed here was the seasonality of fatal fire incidents (Figure 2.3). Fatal residential fires occurred more commonly in the winter and spring months (N = 45 and N = 47, respectively), with notably fewer deaths in the summer and fall (N = 28 and N = 33, respectively). This pattern of fatal fire incidence is expected, as the winter and spring seasons are associated with an increase in the use of heating appliances and indoor activities (Yoshida *et al.*, 1991, Runyan *et al.*, 1992, Shai and Lupinacci, 2003, Holborn *et al.*, 2003).

2.3.2. Highway Fires

Fifty-six fire-related deaths occurred in vehicle fires following vehicle collisions in the 10-year period under review. Forty-seven decedents of these fires (84%) were male, while nine (16%) were female. The age at death profile (Figure 2.1) fits that which was anticipated for individuals over the legal driving age (16 years), with deaths of younger individuals more common than older individuals. This pattern likely reflects an age-associated change in risk of involvement in vehicle collisions, which has been shown to decrease with increasing age and driving experience (Jonah, 1986, Jonah, 1990, Williams and Shananova, 2003, Clarke *et al.*, 2006, Ahrens, 2008, United States Fire Association, 2008).

For individuals under the legal driving age the results were surprising, with only one decedent. While those under 16 years of age cannot legally drive, they may still be passengers in vehicles and, therefore, some child deaths were expected. The reasons for this result are unclear, although it does indicate that children are infrequently victims of highway fires. It is possible that children are better able to escape the vehicle following an accident, sustain less serious injuries, or a combination of these factors (perhaps due to more consistent use of seatbelts and child restraints and seating children in rear seats).

The majority of individuals killed in highway fires died as a result of blunt force trauma sustained during the vehicle accident (N = 37, 66%). The remaining decedents died from the effects of smoke inhalation (N = 16, 29%) or burn wounds (N = 3, 5 %). In no case could the cause of death not be determined.

While no individual dying in a highway fire exhibited level *seven* burn injuries (calcined fragments) there is a clear trend for significant burn injuries in these fires (Table 2.3). Over three-quarters (77%) of decedents exhibited injury levels *five* or *six*, with a further 11% of individuals sustaining level *four* injuries. This burn injury pattern suggests that highway vehicle fires are intense and individuals are usually unable to distance themselves from the focal area of burning. Considering this, it is surprising that no level *seven* burn injuries were recorded.

The seasonal distribution of fatal highway fire incidents (Figure 2.3) indicates that spring is a lower risk period for fatal highway fires with only four fatal incidents. Winter and summer are higher risk seasons with 10 fatal incidents each; however, the highest risk period is the fall with 16 incidents. This frequency peak in the fall may be associated with the onset of winter and the introduction of winter driving conditions increasing the number of roadway vehicle collisions (United States Fire Association, 2008). As drivers adjust to these conditions the number of fatal incidents decreases over the winter months.

2.3.3. Stationary Vehicle Fires

Stationary vehicle fires resulted in 21 fire deaths in Alberta between January 1999 and December 2008. The vast majority of the decedents were male (N = 18, 86%) with only three (14%) female deaths. Decedents' age at death varied from 19 to 78-years-old with no discernible distribution pattern. The primary cause of death resulted from the effects of smoke inhalation, with only two individuals dying from other causes (gunshot wounds and thermal injuries).

The degree of burn injuries sustained in stationary vehicle fires is similar to that seen in highway fires (Table 2.3). Few individuals exhibited minor burn injuries, with only four individuals with burn injury levels of *three* or below. The majority of individuals showed higher degrees of burning with 16 individuals exhibiting burn injury levels *five*, *six* or *seven*.

The seasonality of stationary vehicle fire incidents follows a pattern similar to that seen in residential fires (Figure 2.3). Few fatal fires occurred in the summer and fall months (N = 3 in each) and frequencies are higher in the winter and spring periods (N = 6 and N = 8, respectively). This likely results from the same causes as seen in residential fires of increased use of heating appliances and inside activities, as many stationary vehicle fires occurred in vehicles which were lived in.

2.4. Conclusion

These data demonstrate that residential fires form a considerable proportion of fire-related deaths. Within this category, children and the elderly are at a high risk; however, deaths occur at all ages. The degree of burn injury is varied within residential fires and individuals may be significantly burnt with remains reduced to calcined fragments. This is more likely to occur in trailer or cabin fires than house fires. Fatal residential fires are most common in the winter and spring.

Highway fires, although less common than residential fires, are also an important factor in fire deaths in Alberta. Fatal highway fires typically involve individuals in early to mid-adulthood with few children and individuals over 50 years of age recorded in the data collected. Most highway fire deaths result from blunt force trauma experienced during the vehicle accident. Individuals dying in highway fires seldom exhibit very minor burn injuries, nor are the remains reduced to calcined bone fragments. Instead, the majority of highway fire decedents show burn injuries such as skin incineration, muscle and organ charring, and thermal amputation. Fatal highway fires occur throughout the year with slightly fewer deaths occurring in the spring.

Stationary vehicle fire deaths exhibit patterns similar to both residential fires and highway fires. As in residential fires, the primary cause of death results from the effects of smoke inhalation, and the high risk periods for dying in stationary vehicle fires is in the colder winter and spring months. The degree of burn injuries observed in decedents of stationary vehicle fires is more like highway fires with individuals typically showing high levels of burn injury.

This review of fire related deaths in Alberta over a 10-year period has enabled the profiling of fire decedents and fatal fire situations, offering guidance for researchers in the design of field experiments replicating true fatal fire situations, whether criminal or accidental in nature. The ultimate goal is to provide fire death investigators with appropriate and relevant information and guidelines that will assist them in making decisions on how to approach different fire scenarios involving the recovery of the decedent remains.

Inclusion Criteria
STATS_CIRCUMSTANCE_ID field contained either 3418 (Burns) or 3438 (Fire) CME_REGION_ID was either 769 (Edmonton) or 771 (North Rural) CME_FILE_TYPE was either 372 (Medical Examiner Case) or 371 (Acceded Case) DATE_FOUND_DEAD was between January 1st,1999 and December 31st, 2008
Exclusion Criteria
DATE was not equal to the DATE_FOUND_DEAD CAUSE_A was recorded as Sepsis or other infection Additional Notes If PLACE_FOUND_DEAD was recorded as hospital the file summary was reviewed. If this summary stated the decedent was pronounced dead at the Emergency Department the file was included, if there was any indication that the decedent received any medical treatment for the burns they were excluded from the sample.

Table 2.1 Search parameters for the selection of relevant case files.

Burn Level	Degree of Burn Damage
1	No burn damage noted
2	Superficial skin damage including reddening, soot deposition and minor blistering
3	Skin slippage and/or heat-induced ruptures
4	Skin charring
5	Skin incineration and muscle exposure. Exposure of internal organs and/or bone. Heat fractures in bone may be present
6	Heat-induced amputation of distal elements
7	Remains consist of fragmented bone elements

Table 2.2 Burn injury severity scale.

Burn Level	Degree of Burn Damage	Residential fires %	Highway fires %	Stationary vehicle fires %
1	No burn damage noted	8	7	9
2	Superficial skin damage	21	3	0
3	Skin slippage and/or heat-induced ruptures	25	2	9
4	Skin charring	14	11	5
5	Skin incineration, heat fractures	14	34	29
6	Heat-induced amputation	13	43	38
7	Calcined bone fragments	5	0	10

Table 2.3 Degree of burn injuries.

Figure 2.1 Age at death profiles.

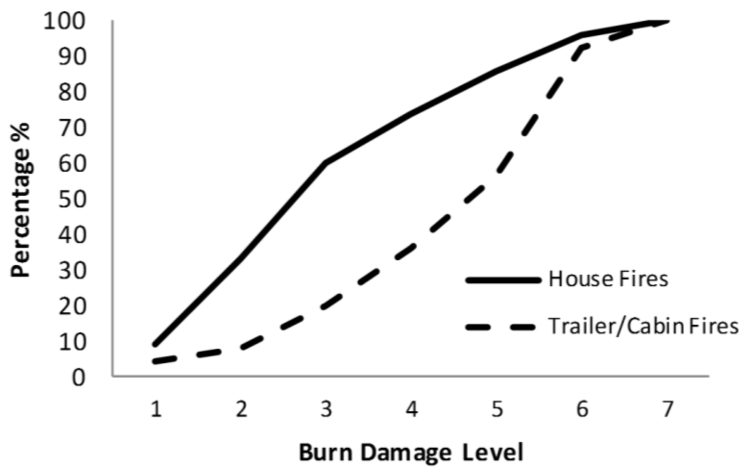

Figure 2.2 Distribution of burn injury levels for house and trailer/cabin fire decedents.

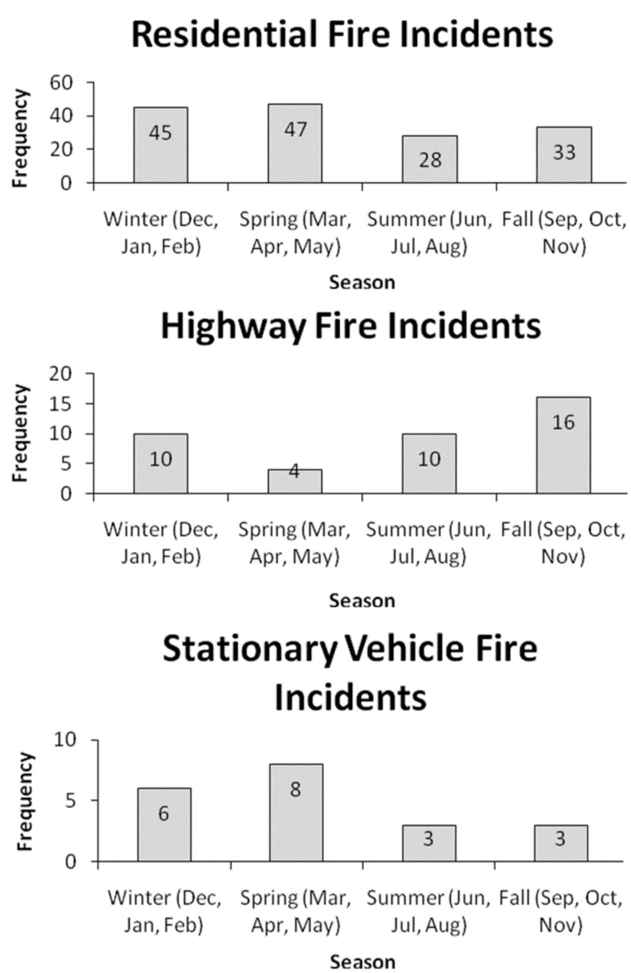

Figure 2.3 Seasonal distribution of fatal residential fire incidents.

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Chapter Three: The effect of decedent age on calcined bone fragmentation: Implications for remains recovery[2]

3.1. Introduction

Fire scenes involving human remains are typically highly complex with a multitude of factors influencing the processes of remains discovery and recovery. In addition to elements of scene safety, such as ensuring structural stability, investigators are often faced with large amounts of fire debris that needs to be searched and documented in a systematic manner that limits cumulative damage to any human remains within the scene (Dirkmaat *et al.*, 2012). Remains recovery is further complicated when some or all of the human remains consist of bone from which all organic and water components have been removed (referred to as calcined bone). Calcined bone is very brittle and fragile and commonly found in a highly fragmented state, making it challenging to identify and recover. Furthermore, calcined bone can be very difficult to locate within a scene as it is white/white grey in colour and often looks very similar to surrounding fire debris (Symes *et al.*, 2008, Dirkmaat *et al.*, 2012). Recovery of human remains is essential for a thorough, competent investigation and for meeting the needs and expectations of family and friends of the decedent(s). Ensuring maximal recovery, both in terms of quantity and quality of remains, is therefore a central part of scene processing, and by understanding remains fragmentation it may be possible to adjust search and recovery protocols to meet this demand (Olson, 2009). Knowledge of factors that may influence fragmentation, such as decedent age, will allow investigators to form

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more confident and valid predictions of the condition of material and thus implement protocols specific to the scene in question. Knowledge of expected bone fragment size and shape will allow searchers to better locate and identify calcined bone, and investigators to select appropriate tools and systems for maximal recovery.

Knowledge of the effect of decedent age on remains fragmentation is an important element of improving remains recovery. Fatal fire scenes involve individuals of all ages, with children often succumbing to the fire in part because of their reduced ability to escape (Shia and Lupinacci, 2003). As such, it is important to focus research on the fragmentation of juvenile bone to differentiate its response from that of more mature bone. Juvenile bone is smaller, has more unfused epiphyses and a higher organic content than more mature bone (Scheuer and Black, 2000). These factors have the potential to alter bone response to the burn environment, and thus the quality and degree of fragmentation. Studies by Holck (1997) showed that neonate remains were harder to destroy in the burn environment than older remains, but once burnt and placed in a burial context the younger material broke down more easily. It is logical to assume that knowledge of how decedent age affects bone fragmentation in a fatal fire context can give investigators greater insight into the nature of the material and better equip them in the difficult task of remains recovery.

3.2. Background

When human remains are exposed to extensive and intense fire situations soft tissue is destroyed and bone burns. As burning progresses bone passes through a number of intermediary stages as it loses moisture and collagen, becoming calcined when no water or organic material remains (Mayne Correia, 1997, Thompson, 2004). This process alters the bone colour with bone initially blackening as it chars before turning grey and then white as it becomes calcined. Bone microstructure alters with hydroxyapatite crystals increasing in size with increased exposure to the burn environment. Perhaps the most influential heat–induced change is fragmentation. As the bone is heated, alterations in the crystal matrix structure cause size and shape changes (Mayne Correia, 1997, Thompson, 2005, Symes *et al.*, 2008). Dimensional change leads to shape change as different bone parts are affected at different rates and to varying degrees. These size and shape changes alter the stress-strain relationship within the bone and introduce new forces that may result in mechanical failure and fracturing. Bone fragility is affected by the loss of collagen during calcination as this reduces bone elasticity, lessening the ability of the bone to withstand dynamic shifts in size and shape. Previous research has outlined seven different heat-induced fracture types: longitudinal fractures, step fractures (occurring at right angles to longitudinal fractures, often linking them), transverse fractures, patina, splintering and delamination, burn line fractures (occurring along the burn borderline), and curved transverse fractures (Symes *et al.*, 2008). Calcined bone is vulnerable to traumatic forces experienced during the burn and post-burn environment, such as shifting and falling debris, high pressures from fire extinguishing equipment, and the physical disturbance of the burn environment by the movement of the firefighters and searchers through the scene.

As bone fragmentation is so closely linked to bone size, shape and collagen content, it is important to recognise how pre-burning differences in bone may affect heat-induced changes and bone fracturing. Juvenile bone differs from mature bone by having higher levels of collagen, although with less cross-linking (Holden *et al.*, 1995). Higher collagen levels likely provide more tolerance to varying degrees of elastic and plastic deformation that can occur prior to failure, resulting in better resistance to fragmentation during the early stages of burning when the organic material has not yet been destroyed. However, the lack of collagen fibril cross-linking leads to higher levels of bone shrinkage in younger bone that may *increase* fragmentation levels (Thompson, 2005). The smaller size of juvenile bone elements may also affect fragmentation. Fire environments are not uniform and a single bone may be exposed to different heat loads and temperature time profiles across its surface. When this occurs heat-induced changes are not synchronised across the bone and unequal changes to the structural dynamics can result in mechanical failure. This is less likely to occur with smaller bones as there is a lesser chance that different bone parts will experience drastically different burn microenvironments.

3.3. Methods and Materials

To investigate the effect of decedent age on bone fragmentation, fleshed *Sus scrofa* (domestic pig) limbs were burnt in three outdoor wood fires, as outlined in Table 3.1. Limbs from post-weaning (fattening pig stage) *Sus scrofa* were sourced from a local butcher and their exact age at death was unknown, but their similar sizes and patterns of unfused epiphyses suggest they were all of a similar age, between eight and 10 months based on standard slaughtering ages (Knupp, 2012, Bull and Payne, 1982). Piglet limbs used were aged at six weeks and obtained through the Swine Research Facility at the University of Alberta where they had been euthanized for other research projects. Fattening pig limbs were approximately twice the overall size of the corresponding piglet limbs.

For each burn event *Sus scrofa* limbs were placed in a single fire with piglet and fattening pig material separated by iron rods (1.25cm diameter by 0.5m long rebar). In the first burn event limbs were placed directly on the ground, and in latter burn events limbs were placed on a wood base to promote burning of inferior surfaces to ensure full calcination. Wood and newspaper were used to build stable, burnable structures that were lit and left undisturbed except for periodical additions of wood fuel. Wood fuel was added by hand, avoiding direct contact with the bone. Fires burnt for four to five hours until full calcination was observed, at which point fires were left to burn out and cool overnight. Wood used consisted of a spruce/pine mix of 2″x4″ and 2″x6″ lumber, commonly found in the Alberta region and regularly used in home construction (Dufour, 2002). Similar time and temperature profiles for the piglet and fattening pig material were confirmed by temperature data collected from type J thermocouples placed in each limb group (piglet and fattening pig limbs) in all fires, with temperatures recorded at one-minute intervals using a DaqPRO 5300 data logger.

Bone recovery was completed the day after burning when the remains had cooled sufficiently to allow handling. No evidence for animal disturbance to the remains was observed in any of the experiments. All remains were collected by the author by hand, using tweezers for smaller fragments with care taken to ensure no additional damage to any bone fragments. Bone fragments were stored in sealable polyethylene bags and supported by toilet tissue for immediate transport to the laboratory where they were removed from the bags, evaluated for any signs of transportation damage, and stored on soft-surfaced paper trays. Any recovery or transportation damage that did occur was considered unavoidable and no reconstruction was completed. Although every effort was made to recover as much bone material as possible from the burn site, some fragments were too small to be collected consistently and were thus necessarily excluded from data analysis. The exclusion threshold was developed from a number of preliminary test/practice burn events and was defined as fragments with two dimensions less than 5 mm and one dimension less than 10 mm. In the laboratory the bone material was sorted into one of 12 defined categories within three series based on size and shape (See Figure 3.1). The *Small series* consists of three categories, numbered 1 through 3, where the shortest fragment dimension is less than 5 mm. The second series, the *Longitudinal series*, consists of four categories, numbered 4 through 7, and in this series the longest dimension is greater than twice the second longest dimension. In the third series, the *Non-longitudinal series*, the longest dimension must be less than twice the second longest dimension and there are five categories within this series, numbered 8 through 12. As with the exclusion threshold, these categories were developed from preliminary test/practice burn events where material was sorted into perceived naturally occurring clusters.

Sieves were not used to separate material for two primary reasons. First, they can cause considerable mechanical damage to fragile materials and induce further fragmentation; and second, they do not allow for shape differences as fragments are sorted by only two dimensions. By measuring three dimensions fragments could be separated into three distinct shape series (Small, Longitudinal and Non-longitudinal) and fragmentation characteristics could be assessed within each series. The number of categories used was based on preliminary test/practice burns to ensure that size categorisations reflected the material at hand and did not arbitrarily divide clear size groupings and thus obscure any trends in the data. The size categories selected reflect clear clusters observed in the preliminary test/practice burns. Following sorting, categories were weighed and the proportional mass was calculated for each category as a percentage of total mass within each limb group (piglet and fattening pig).

3.4. Results

To assess the effect of decedent age on fragmentation the difference in proportional mass between piglet and fattening pig remains was calculated for each size category and burn event (see Table 3.2). Using the difference in proportional mass allows all burn events to be compared directly as it controls for any dissimilarity between burn events, such as ambient temperature during cooling period. The proportional mass of the piglet remains was subtracted from the proportional mass of the fattening pig remains, with positive differences indicating higher proportional masses in fattening pig remains and negative differences indicate higher proportional masses in piglet remains. For each category, data from the three burn events was used to calculate the mean difference in proportional mass at 68%, 80% and 95% confidence intervals.

In the Small series, (Figure 3.2a) piglet and fattening pig limbs showed different levels of fragmentation in the different categories. In Category 1 there was little difference in fragmentation, whereas in Category 2 higher proportional masses were seen in the piglet remains and in Category 3 the fattening pig remains showed the highest proportional masses. The spread of data in Categories 2 and 3 indicate a confidence in the difference from zero at approximately 68% and when looking at the data (Table 3.2) it appears that a single data point from burn 3 likely inflated the difference from zero in Category 3. Category 2 showed one data point that differed from the trend, with a positive difference recorded in burn 3. The general pattern of higher proportional masses in the piglet remains for Category 2 is clearly evident in burns 1 and 2. The higher proportional masses in piglet remains compared to fattening pig remains occurs as Category 2 material consists of a large number of complete or almost complete bone epiphyses and bone elements not present in fattening pig, Category 2 material (Figure 3.3). This observation indicates that although showing higher levels of the Series 1 fragments this is not necessarily due to increased fragmentation of the piglet remains, but rather the smaller initial size of bone elements.

In the Longitudinal Series, Categories 4, 5, 6 and 7, the results show similar patterns of difference to those seen in the Small series. No difference in proportional mass between piglet and fattening pig remains are observed in the smaller groupings, Categories 4 and 5. In Category 6 proportional masses are higher in the piglet remains, with confidence levels over 95%. In Category 7, the fattening pig remains show higher proportional masses, although the difference from zero is only confirmed at the 68% confidence limit. In only one case, burn 3, were Category 3 piglet remains recovered and this consisted of only two humeri whose dimensions were close to the boundary between Categories 6 and 7. Similar fragments were found in Category 6 in burns 1 and 2. The higher proportional masses in Category 7 for fattening pig remains are therefore a result of larger initial sizes of the older material and not an indication of higher levels of fragmentation in the younger remains. These differences in initial size are the likely cause of higher proportional masses in Category 6 in the piglet remains. Fattening pig Category 6 material typically consists of fragments that have broken off larger bone elements whereas the piglet Category 6 material has these broken fragments as well as relatively complete, clearly identifiable bone elements (Figure 3.4). As was noted in the Small series this highlights that, although consisting of more smaller bone pieces, the piglet material is not more fragmented than the fattening pig material. This observation is further supported by the lack of difference in proportional mass between fattening pig and piglet remains in Categories 4 and 5.

In the Non-longitudinal series the pattern of difference between piglet and fattening pig remains differs from that seen in the Small and Longitudinal Series (Figure 3.2c). Categories 8 though 11 all show lower proportional masses in the fattening pig remains with confidence limits of least at 68%. In Category 8 all burns showed a negative difference in proportional mass with this confirmed at the 80% confidence limit. In Category 9 burns 1 and 2 showed a negative difference in proportional mass but burn 3 showed a positive difference, contributing to the lower confidence of difference at 68%. Category 10 showed clear higher proportional masses in the piglet remains with confidence limits at 95%. In Category 11 all burns showed a negative difference in proportional mass but the magnitude of this difference varied, explaining the 68% confidence in a difference from zero. In Category 12 a different pattern is observed, as no material was recovered for the piglet remains in this category. The higher proportional masses in Categories 8 through 11 in the piglet remains appears to result from higher levels of complete or almost complete bone fragments within these categories. The fattening pig material consists of more broken, unrecognisable fragments without the more complete bone epiphyses or bone elements seen in the piglet material. The broken, fragmented pieces are still present in the piglet remains but do not constitute the entire collection (Figure 3.5). In Category 12 there was no piglet material in any of the burn events, likely due to the smaller initial size of the material. The fattening pig material in this category consists of the larger, more recognisable pieces often observed in Category 11 in the piglet material. The data from the Non-longitudinal series continues to support the observation that piglet remains show higher levels in smaller categories, and is interpreted as a reflection of the initial size differences of the material and not to increased fragmentation.

3.5. Discussion

A clear pattern observed in the Small, Longitudinal and Non-longitudinal Series is the lower levels of fragmentation in piglet remains compared to fattening pig remains. The younger material consistently shows lower proportional masses in the largest categories, but this is not due to increased fragmentation but rather smaller initial element sizes. The second largest categories show higher proportional masses in the piglet remains and these categories contain many complete or almost complete bone elements. The younger bone may fragment less than the older bone because of its ability to withstand greater deformational forces before reaching a fracturing point threshold. This idea is supported by work that suggests that post-cremation bone mass is lower in females due to higher levels of osteoporotic bone (McKinley, 1993) and that sex-based differences in heat-induced bone warping result from differences in bone mineralisation with lower collagen levels resulting in more brittle material (Goncalves *et al.*, 2011). How this mechanism operates in the burn environment with the loss of organic material is unclear and future work focusing on the mechanics of burnt bone fragmentation is required to elucidate this process. The calcined piglet remains may also have more structural integrity because of their initial size and shape. Smaller sizes would reduce inconsistent heat-induced changes within one bone and the roughly spherical shape of the small bone epiphyses would offer greater structural strength than the more irregular bone shapes in older material.

In addition to these clear differences between piglet and fattening pig remains there are also some similarities. Both the Small and Longitudinal series show no difference in proportional mass between piglet and fattening pig remains in the smallest categories, which seems to indicate that these fragments arise from similar processes occurring in both sets of remains. Fragments may flake or smaller pieces may break off larger fragments such that the fracture determining factor is the size of the resulting broken off part and not the size or composition of the initial fragment. This effect is not seen in the Non-longitudinal series, perhaps because of fragment shape. In the Categories 1, 4 and 5 the fragments are generally long, narrow fragments. These could easily flake off other fragment edges or form when two heat-induced longitudinal fractures occur parallel to each other and are linked by step fractures, allowing the fragment to 'pop out' of the bone element.

These results have clear implications for the recovery of younger material from fatal fire scenes. The common perception in fire investigation fields is that juvenile remains are less developed than adult remains and are therefore less likely to be identifiable post-burning (Pevytoe, 2012). However, this research clearly shows that, while younger remains generally consist of smaller bone pieces, the remains are typically less fragmented when compared to older remains in comparable burn environments. This observation highlights the value of ensuring maximal recovery with minimal destruction for younger remains. More complete remains allow for more detailed, thorough and potentially more value-laden anthropological assessment that provides greater potential for investigators to determine elements of the anti-mortem, peri-mortem or post-mortem processes. Furthermore, recognising that younger material often consists of complete, or near complete, bone elements and epiphyses, even when burnt to calcination in burn environments, highlights the importance of ensuring that search personnel are aware of the uniqueness of and characteristics of juvenile osteology. Knowledge of the shapes and sizes of fused, fusing and unfused bone epiphyses will greatly enhance their ability to recognise calcined bone material, and facilitate the discovery of human remains within the scene. Personnel who are trained in forensic archaeological methods will further enhance recovery and analysis as these individuals can ensure appropriate recording of bone positioning and contextual details to aid in element identification.

3.6. Conclusion

Calcined bone is fragile and difficult to recover from a fatal fire scene, but maximal recovery is essential for investigative and moral reasons. To ensure that the best possible recovery protocols are utilised it is important to understand how factors such as decedent age affect bone fragmentation. Juvenile bone differs significantly from mature bone showing differences in organic content, size and shape. These attributes affect the bone response to the burn environment. Younger bone, while traditionally thought to be more fragile than older bone, actually shows less fragmentation and destruction in the post-fire context. This discovery has important implications for the recovery of younger remains from fatal fire scenes. It is vital to have appropriately trained individuals complete the search and recovery aspects of the investigation as they will have more enhanced skills in the recognition and identification of juvenile bone. Younger bone has greater potential for more comprehensive osteological analysis as more complete bones allow for a more detailed investigation. While knowledge of these fragmentation differences between younger and older individuals will allow investigators to prioritise resources better for maximal benefit to the investigation, more research is required to refine our knowledge on the effect of decedent age on bone fragmentation. Future studies will need to consider a wider age range of individuals, a greater number of samples, and a more detailed look at fragment shape differences to gain a more full appreciation of the nuances of decedent age and burnt bone fragmentation relationships. A full understanding of these relationships will also require further investigation into the mechanics of bone fragmentation in burnt bone.

Burn Event	Piglet	Fattening pig
1	4	2
2	4	3
3	4	1

Table 3.1 The number of *Sus scrofa* limbs used in the burn events. All limbs used were forelimbs except for fattening pig material in burn 3 which used hindlimbs.

	Category 1			Category 2			Category 3								
	FP	P	D	FP	P	D	FP	P	D						
Burn 1	0.43	2.23	-1.81	2.47	9.73	-7.26	3.57	2.87	0.7						
Burn 2	1.05	0.37	0.068	4.37	6.52	-2.16	4.74	4.31	0.043						
Burn 3	1.57	0.4	1.16	6.33	5.06	1.27	6.91	1.11	5.8						
	Category 4			Category 5			Category 6			Category 7					
	FP	P	D	FP	P	D	FP	P	D	FP	P	D			
Burn 1	0.31	4.63	-4.31	6.63	6.54	0.09	10.34	19.3	-8.96	22.87	0	22.87			
Burn 2	1.87	0.74	1.13	4.51	7.14	-2.64	11.87	21.31	-9.43	6.31	0	6.31			
Burn 3	0.99	0.91	0.08	7.61	5.86	1.74	9.29	23.36	-14.07	13.18	13.65	-0.47			
	Category 8			Category 9			Category 10			Category 11			Category 12		
	FP	P	D	FP	P	D	FP	P	D	FP	P	D	FP	P	D
Burn 1	1.45	5.9	-4.46	7.48	15.95	-8.47	8.16	17.07	-8.9	12.52	15.79	-3.26	23.77	0	23.77
Burn 2	3.26	6.53	-3.27	7.59	9.36	-1.76	10.25	21.8	-11.55	8.47	21.92	-13.45	35.71	0	35.71
Burn 3	3.66	5.16	-1.5	10.05	9.71	0.34	8.65	14.46	-5.81	18.76	20.32	-1.57	13.01	0	13.01

Table 3.2 Proportional mass percentages for fattening pig, piglet remains and their difference for each burn event. F- Fattening pig proportional percentage mass, P- Piglet proportional percentage mass, D- Difference, fattening pig proportional percentage mass - piglet proportional percentage mass.

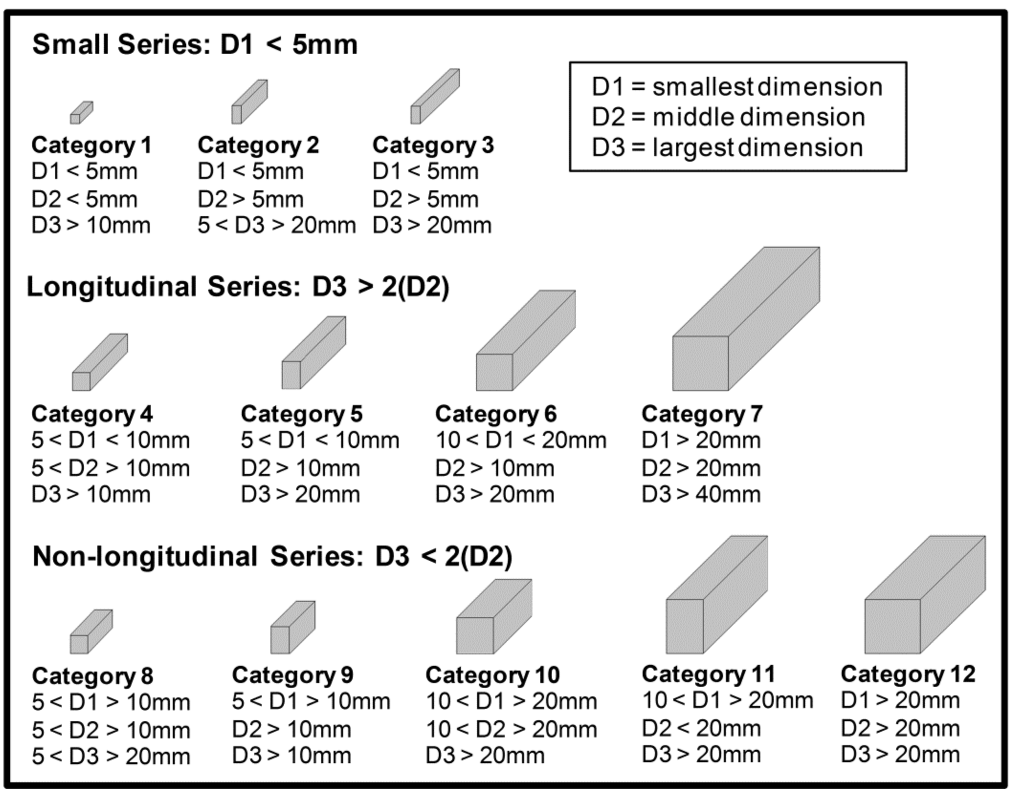

Figure 3.1 Size categories used for sorting calcined bone.

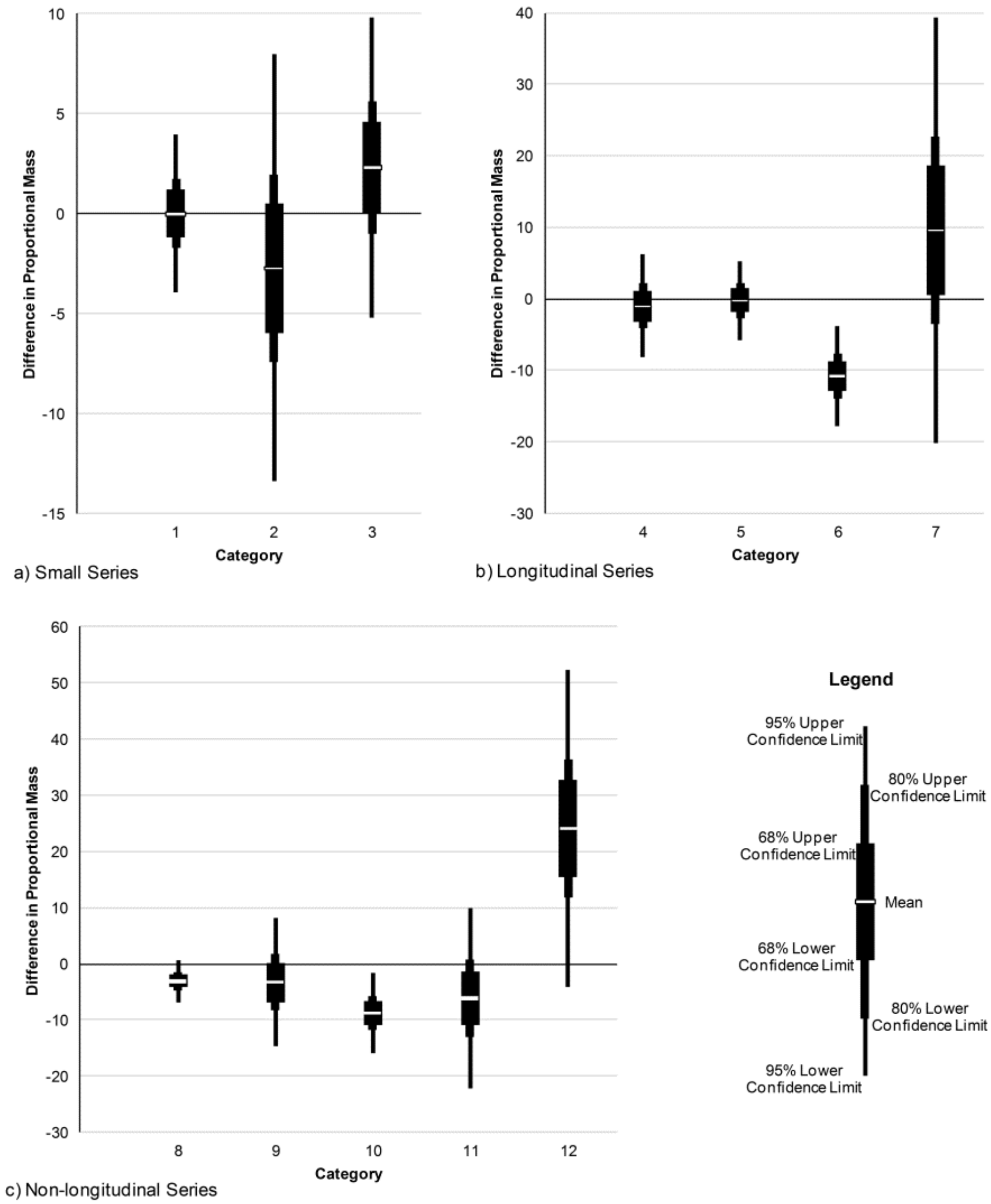

Figure 3.2 Mean and 68, 80 and 95% confidence intervals for difference in proportional mass between fattening pig and piglet remains.

Figure 3.3 Bone fragments from Category 3 Burn 3 for piglet and fattening pig remains. Piglet material consists of more complete, or almost complete bone pieces compared to more irregular fragments of fattening pig remains.

Figure 3.4 Bone fragments from Category 6 Burn 3 for piglet and fattening pig remains. Piglet material consists of more complete, or almost complete bone pieces compared to more irregular fragments of fattening pig remains.

Figure 3.5 Bone fragments from Category 9 Burn 3 for piglet and fattening pig remains. Piglet material consists of more complete, or almost complete bone pieces compared to more irregular fragments of fattening pig remains.

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Chapter Four: Post-burning fragmentation of calcined bone: Implications for remains recovery from fatal fire scenes[3]

4.1. Introduction

The recovery of calcined bone from a fatal fire scene is a painstaking and complex process. Not only is calcined bone fragile and typically highly fragmented, making identification and collection of remains challenging, but recovery needs to occur within the bounds of the larger investigation (Mayne Correia and Beattie, 2002, Fairgrieve, 2008). Any fatal fire scene needs to be determined safe before investigators can enter and the needs of the police, fire investigator, medical examiner or coroner, and other professionals require coordination to ensure all involved can complete their work in a timely manner with maximum information acquisition for all (Mayne Correia and Beattie, 2002, Dirkmaat *et al.*, 2012). Part of this requires the establishment of a time-line for remains recovery, and this process can benefit from knowledge of the effect of delayed recovery on remains fragmentation. Understanding how remains fragmentation occurs and progresses over specific time periods will allow recovery protocols to be adjusted improving the quantity and quality of material collected. This will help to ensure maximal retrieval and will aid the analysis of the material.

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4.2. Background

When human remains are burnt and the soft tissue is destroyed, underlying bone is exposed directly to the burn environment. As bone burning progresses, the bone material is transformed from its natural state to calcined bone through a number of intermediary stages which result in observable heat-induced changes in gross and microscopic appearance, colour, size and shape (Mayne Correia, 1997, Thompson, 2004, Devlin and Herrmann, 2008). During burning bone loses water and organic components and the hydroxyapatite crystals increase in size. Further, overall size and shape changes affect the structural integrity of the bone by altering the stress-strain relationships within each bone element, leading to mechanical failures and fracturing (Herrmann and Bennett, 1999, Thompson, 2005). The loss of organic material reduces bone elasticity, further promoting fragmentation of fully calcined material (Herrmann and Bennett, 1999, Thompson, 2005, Brickley, 2007). Anthropological analysis is possible on these fragmentary remains, and to capitalize on the information which can be obtained, recovery needs to be maximized for both quantity and quality of material recovered. This requirement would suggest that recovery immediately after a fire is a first priority. In practice, this goal needs to be balanced with overall scene requirements to recognise and respect the established prioritisation of investigator hierarchies. Therefore, it is important to empirically establish the effects of delay-until-recovery on remains fragmentation.

A better understanding of the post-burning degradation of calcined bone could lead to critical adjustments of recovery protocols to suit specific situations. Calcined remains are notoriously difficult to recover as bones and bone fragments can be hard to identify. It is common to encounter very large numbers of fragments, and the initial efforts at recovery and identification can be overwhelming. However, with realistic expectations of fragmentation, focused recovery systems could be developed to fit the needs of specific situations. The ability to predict fragment sizes will enable investigators to determine the best recovery approach for trained searchers, enhancing their ability to detect bone material. It will ensure that optimal equipment deployment and search strategies are used from the beginning of the search and recovery process, minimising recovery-associated damage to the remains. Implementation of these systems will facilitate the best skills deployment and time investment, resulting in maximum gains.

4.3. Methods and Materials

To investigate the effect of delayed recovery on bone fragmentation, fleshed *Sus scrofa* (domestic pig) limbs were burnt in a series of three outdoor wood fires, as outlined in Table 4.1. Three delay periods were investigated and compared with fragmentation following recovery the day after the fire (the baseline marked as 0 hrs delay). The following delay periods - 24 hrs, 56 hrs and 168 hrs (1 week) - were selected to represent a range of time more commonly encountered during fatal fire scene investigations as determined from an extensive review of local Alberta case files (See Chapter Two). Wood burning fires were used to ensure a repeatable burn environment that experienced changes in temperature and physical environment throughout the burn event. *Sus scrofa* limbs were sourced from local butchers, and as such their exact age at death was unknown but their close size and patterns of unfused epiphyses suggest they were of all of a similar age, between eight and 10 months (Bull and Payne, 1982, Knupp, 2012).

For each burn event limbs were placed in two fires, one with material for immediate recovery, and a second with material for recovery following the three delay periods. In the second fire, limbs for each of the delay periods of 24, 56 and 168 hrs, were separated by 1.25cm diameter, 0.5m iron rods (rebar). In the first burn event limbs were placed directly on the ground and in latter burn events limbs were placed on a wood base to promote burning and calcination of inferior surfaces. Wood and newspaper were used to build stable, burnable structures that were lit and left undisturbed except for periodical additions of wood fuel. No solvents were used to ignite, or sustain the fires. Wood fuel was added by hand, avoiding any direct contact with the bone. Fires were sustained for four to five hours until full calcination was observed, at which point they were left to burn out and cool overnight. The wood fuel consisted of a spruce/pine mix of 2″x4″ and 2″x6″ lumber, commonly found in the Alberta region and often used in home construction (Dufour, 2002). Similar time and temperature profiles for each fire segment was confirmed by temperature data collected from type J thermocouples placed amongst each limb group (0, 24, 56, and 168 hrs delay) with temperatures recorded at one minute intervals using a DaqPRO 5300 data logger.

Following burning, bone remains were recovered from the burn site at the specified delay periods. Recovery at 0 hrs delay occurred in the mid-morning of the day after burning, allowing for full cooling and temperature stabilization. No evidence for animal disturbance to the remains was observed in any of the experiments. All remains were collected by the author by hand, using tweezers for smaller fragments, with care taken to ensure no additional damage to any bone fragments. Bone fragments were stored in partially air filled polyethylene, sealable bags and supported in the short term by toilet tissue for immediate transport to the laboratory where they were removed from the bags without delay, evaluated for any possible transportation damage, and stored on soft-surfaced paper trays. Care was taken to recover as much bone material as possible from the burn site, but some fragments were too small to be consistently collected and, though noted, were necessarily excluded from data analysis. In the laboratory, bone was sorted by the principal investigator into one of 12 predetermined and defined categories within three series based on size and shape (See Figure 4.1). These categories were developed from the evaluation of preliminary test/practice burn events where material was sorted into perceived naturally occurring clusters. In the *Small series* (Categories 1 through 3) the shortest fragment dimension is less than 5 mm. Categories 4 though 7 form the *Longitudinal series* where the shortest dimension (D1) is greater than 5 mm and the longest dimension (D3) is greater than twice the second longest dimension (D2). The third series, the *Non-longitudinal series*, consists of categories 8 through 12 and in this series the shortest dimension (D1) is greater than 5 mm and the longest dimension (D3) is less than twice the second longest dimension (D2).

Sieves were not used to separate material for two primary reasons. First, they can cause considerable mechanical damage to fragile materials and induce further fragmentation; and second, they do not allow for shape differences as fragments are sorted by only two dimensions. By measuring three dimensions fragments could be separated into three distinct shape series (Small, Longitudinal and Non-longitudinal) and fragmentation characteristics could be assessed within each series. The number of categories used was based on preliminary test/practice burns to ensure that size categorisations reflected the material at hand and did not arbitrarily divide clear size groupings and thus obscure any trends in the data. The size categories selected reflect clear clusters observed in the preliminary test/practice burns. Following sorting each category was weighed and the proportional mass determined. Proportional mass was calculated as percentage weight for each category within each limb group (0, 24, 56 and 168 hrs delay). Proportional masses were calculated to allow direct comparisons between each category in the differing delay periods.

4.4. Results

4.4.1. 0 hrs and 24 hrs delay

When the recovery of remains is delayed by 24 hrs the effect on fragmentation is mixed (Figure 4.2). In the Small series there is a clear trend of higher fragmentation when recovery is delayed with higher proportional masses seen in all categories for almost all burn events. In Category 2, burn 3, lower proportional masses were recorded following 24 hrs delay, but both other burn events showed large increases in proportional mass. This increase in proportional mass is interpreted as being the major trend. The isolated data point showing a reduction in fragmentation likely originates from variable factors in the burn or post-burn environment altering the specific burn event and category.

In the Longitudinal series the effect of delayed recovery is more complex. In Category 4 there is no indication of a difference in fragmentation between 0 and 24 hrs delayed recovery. In Category 5 responses vary between the burns, but both burns 1 and 3 show clear reductions in proportional mass when recovery is delayed. In Category 6 two burns (1 and 2) again show reductions in proportional mass following a delayed recovery, although this is not seen in burn 3 where proportional mass was slightly higher after the delay. In Category 7 there is one outlier in burn 1 where proportional mass increases with delayed recovery, but in burns 2 and 3 proportional mass is markedly lower when recovery is delayed by 24 hrs. This general trend of lower levels of proportional mass following recovery indicates increased fragmentation when recovery is delayed by 24 hrs compared to immediate recovery.

In the Non-longitudinal series the pattern of difference between 0 and 24 hrs delay varies. In Category 8 there appears to be no difference between 0 and 24 hrs delay with proportional masses showing very similar levels. In Category 9 proportional masses are lower at 24 hrs delay in burns 1 and 3, but not burn 2. The opposite pattern is seen in Category 10 where proportional masses are higher following delay for burns 1 and 3. The pattern is again reversed in Category 11 where, like Category 9, proportional masses are lower following delay in burns 1 and 3 but higher in burn 2. This series of increases and decreases in proportional masses likely occurs when higher fragmentation in a larger category increases levels in the category below and lower fragmentation in a larger category decreases levels in the category below. In Category 12 proportional mass is lower following delayed recovery in burns 1 and 2 but not in burn 3 where it is markedly higher. This burn 3 data point is likely not representative of general trends in

Category 12, especially as this category often consists of a few large fragments where one or two fracturing events can have a marked effect on proportional mass. In general, for the Non-longitudinal series, fragmentation is increased when recovery is delayed by 24 hrs.

When all three series are considered there is a clear pattern of increased fragmentation when remains recovery is delayed by 24 hrs. This increase in fragmentation affects all categories and is evenly distributed between the three series. The fragmentation patterns suggest that almost all bone pieces are breaking down in a similar manner with no increased survival or degradation of any one fragment size or shape. The proportional mass data does suggest that time until recovery does not affect the smallest categories in each series but this is likely an artefact of the small nature of the bone pieces within these categories and should not be taken to indicate similar levels of fragmentation at 0 and 24 hrs delayed recovery. As the bone pieces are so small in these categories large changes in bone volume are required before marked changes in proportional mass will be observed. Increased fragmentation of these bone pieces may result in them becoming too small for collection, thus removing them from analysis and lowering category bone mass.

4.4.2. 24 hrs and 56 hrs delay

To assess fragmentation following a 56 hr delay-until-recovery, proportional masses for each size category were compared to those observed after a 24 hr delay (Figure 4.3). In the Small series proportional masses are generally higher following the longer delay period. There is no marked change in proportional mass in Category 1 at 56 hrs delay. In Categories 2 and 3 all but one burn event show higher proportional masses after 56 hrs delay and for the one data point that does not show an increase the decrease is very minor. This pattern suggests higher levels of fragmentation following the longer delay period with material from the Longitudinal and Non-longitudinal series breaking down and increasing bone volume in the Small series.

In the Longitudinal series the patterns of fragmentation change vary between categories. As observed when comparing 0 and 24 hrs delay, there is little change in proportional mass in Category 4 when the delay period is extended. In Category 5 increasing the delay period to 56 hrs results in higher proportional masses in all burns. This increase is not observed in Category 6 where burn 1 shows much higher levels after the longer delay, burn 2 shows similar levels and burn 3 shows much lower levels. These values are matched in Category 7 by the opposite pattern in burns 1 and 3 with the longer delay resulting in lower levels in burn 1 and higher levels in burn 3. These paired values likely arise because Category 7 often consists of only a few bone pieces and one or two fragmentation events can have a marked effect on category bone mass. Burn 2 levels in Category 7 show higher proportional masses after a 56 hr delay. Considering the changes in proportional mass across all categories in the Longitudinal series there is a general trend of increased fragmentation with a longer delay period although this increase is characterised by a reduction in total bone volume recovered and not a marked loss of Category 5, 6 or 7 material. Proportional masses in these categories generally increased when recovery was delayed by 56 hrs compared to 24 hrs suggesting bone fragments remained relatively stable and the total recovered bone mass was reduced. This total bone mass reduction may have resulted from bone pieces, too small to be recovered, breaking off the larger, relatively stable fragments as well as fragmentation of Category 4 bone pieces.

In the Non-longitudinal series fragmentation patterns again vary between the categories. As seen previously there is almost no difference between the delay periods in Categories 8 and 9. In Category 10 proportional mass is slightly lower after 56 hrs delay in burns 1 and 2 but higher in burn 3. In Category 11 proportional mass is higher at 56 hrs delay in burns 1 and 3 but lower in burn 2 and in Category 12 proportional mass is higher in burn 1, similar in burn 2 and lower in burn 3 following the longer delay period. These proportional mass patterns suggest increased fragmentation in a manner similar to that seen in the Longitudinal series in burns 1 and 3 with larger bone pieces remaining relatively stable and small fragments flaking off these pieces combined with fragmentation of Category 8 and 9 bone pieces reducing the total volume of bone recovered. In burn 2 the stability of the larger fragments is less apparent, perhaps due to the damp conditions experienced during recovery of this material.

4.4.3. 56 hrs and 168 hrs delay

Fragmentation following a delay of 168 hrs before recovery is compared to that following a delay of 56 hrs before recovery (Figure 4.4). In the Small series results indicate a general drop in proportional mass when recovery is delayed 168 hrs rather than 56 hrs. In Category 1 there is little difference in proportional mass between the delay periods, likely because the small nature of the material requires large changes in bone volume before marked changes in mass are observed. In Categories 2 and 3 the proportional mass after 168 hrs delay is similar to or lower than that observed at 56 hrs delay. This drop in proportional mass indicates a reduction in recoverable material, with higher levels of fragmentation resulting in less material being recovered from the scene.

In the Longitudinal series Category 4 shows almost no difference in proportional mass between the delay periods, a pattern seen in all delay period comparisons. In Category 5 proportional masses are consistently lower at 168 hrs delay than at 56 hrs delay and in Category 6 results are higher at 168 hrs except in burn 1 where they are lower. In Category 7 results vary between burns with burns 1 and 3 showing higher proportional masses after 168 hrs delay and burn 2 showing lower levels. These patterns suggest larger fragments in Categories 6 and 7 are not fragmenting substantially between 56 hrs and 168 hrs delay but rather remain as stable pieces. Proportional masses rise in these categories as the overall mass of bone recovered is lowered when smaller bone pieces fragment and cannot be recovered. This pattern is similar to that seen at 56 hrs delay however by 168 hrs delay bone in Category 5 is breaking down and not remaining stable as it did at 56 hrs delay.

In the Non-longitudinal series Category 8, like Category 4 in the Longitudinal series, shows no difference in proportional mass between the different delay periods. In both Categories 9 and 10 two burn events show very little difference between delay periods with the remaining burn event showing higher levels in Category 9 and lower levels in Category 10 after a longer delay period. Category 11 shows a similar pattern to Category 9 with two burn events showing similar proportional masses between delay periods and the third burn event showing an increase in proportional mass after 168 hrs delay. In Category 12 burns 1 and 2 show higher proportional masses and burn 3 shows lower levels. Overall there is a consistent pattern for little difference between the delay periods with slight increases in proportional mass in Category 12. This pattern is especially evident in burns 1 and 2. In burn 3 there appears to have been more fragmentation of Category 12 material at 168 hrs which increases levels in Category 11, however this change in patterning can result from only one or two fracture events as there are typically few fragments in Category 12. These patterns of proportional mass change suggest that when recovery is delayed by 168 hrs fragmentation in the Non-longitudinal series occurs across almost all categories at a rate equalling the reduction in recoverable material. Larger, Category 12, fragments seem able to withstand this fragmentation somewhat and remain relatively stable.

4.5. Discussion

When the recovery of calcined remains is delayed by 24 hrs, 56 hrs or 168 hrs there is a clear trend of increasing fragmentation over time. This trend is expected as continued exposure to a variable post-depositional environment, with changes in temperature, humidity and other factors, introduce new and changing stresses and strains to the calcined bone (McKinely, 1994). The brittle and fragile bone material is unable to withstand these changes and progressively fragments, either by the flaking off of small pieces or by fracturing into a number of pieces. The patterns of fragmentation and the bone pieces most affected depend on the time delay experienced.

When remains recovery is delayed by 24 hrs the fragmentation of almost all bone pieces increases. Larger fragments break down, lowering the amount of bone recovered in these categories, while concurrently increasing the proportional mass of the smaller fragments. Fragmentation is likely occurring in these smaller fragments, reducing the total volume of recoverable material. This overall increase in fragmentation is expected as after a delay of 24 hrs remains would have been exposed to changes in ambient temperature, humidity and other weather factors that likely impact fragmentation. Remains recovered at 0 hrs delay would not have been exposed to these daily cyclical changes as the fire burn out phase and the cooling process would have an impact on the immediate bone environment during the first 24 hrs post-burning. In burns 1 and 3 temperatures dropped below freezing and any water associated with the remains would have frozen and expanded, introducing new stresses to the brittle material. In burn 2 rainfall increased the moisture content of the fire scene and recovered bone which likely affected fragmentation. This effect of 'first exposure' after a delay of 24 hrs can explain the widespread fragmentation across the range of bone sizes as all bone fragments experienced conditions and new post-burning stress-strain relationships for the first time.

At 56 hrs delay-until-recovery, remains fragmentation again increases, but unlike at 24 hrs delay this increase is not widespread across the study's analytical categories. Larger pieces remain relatively stable losing only small fragments from their whole and the total volume of recoverable material is reduced by fragmentation of these and other small bone pieces. The stability of larger bone pieces is likely linked to overall structural integrity as these bone pieces typically consist of almost complete bones or bone portions and maintain some of their pre-burn shape. In contrast, small bone pieces generally consist of unidentifiable fragments that have broken off elements and are not structurally complete. These differences result in smaller bone pieces being unable to withstand changes in stress-strain relationships introduced by changes in the local environment between 24 and 56 hrs delay. Larger bone pieces are better able to withstand these forces and fragment less. This effect is only observed at 56 hrs delay as bone pieces have already responded to the exposure to various environmental conditions and any ‘weak spots’ in larger fragments have already been tested. Between 24 hrs and 56 hrs delay there is less exposure to new environmental conditions and the larger bone pieces that resisted fragmentation at 24 hrs delay continue to do so. Fragmentation of smaller bone pieces still occurs, however, as these structurally weaker fragments are less able to withstand continued exposure and the associated changes in stress-strain relationships. These smaller fragments are also less able to withstand the cumulative effects of increased time of exposure to such factors as increased rainfall or increased hours of sunshine (See Chapter Five).

When remains recovery is delayed by 168 hrs the trend of stability of larger fragments observed after 56 hrs delay is still observed. This effect is only seen in the largest of categories and some categories which had shown stability at 56 hrs delay show increased fragmentation at 168 hrs delay. This supports the idea of better structural integrity and bone completeness providing better resistance to fragmentation. Bone fragments in the largest categories are typically the most complete and continue to withstand the cyclical and cumulative changes in environmental conditions between 56 and 168 hrs delay.

4.6. Conclusion

Calcined bone is a brittle and fragile material prone to progressive fragmentation which can make recovery and analysis very challenging. Knowledge of the time frame of this fragmentation is key to aiding the recovery process as it allows appropriate decisions to be made regarding the critical nature of scene processing. It is clear that immediate recovery is advantageous as even a delay of 24 hrs results in breakdown of the material across all bone pieces. If recovery cannot be completed within 24 hrs, it is perhaps less critical that remains be recovered immediately thereafter because between 24 and 56 hrs continued fragmentation is somewhat restricted to smaller bone fragments. Smaller bone fragments, while still potentially highly diagnostic and valuable, usually exhibit fewer identifying features and are less likely to be fundamental to the laboratory investigation. By 168 hrs delay the larger bone pieces have also begun to fragment and any delay in recovery may result in significant further losses in valuable material for analysis. Knowledge of these patterns of fragmentation will allow investigators to prioritise the needs of multiple investigators at a fire scene and adapt recovery techniques to the remains in question, thus ensuring optimal collection of material critical for identification, and the greatest care in the recovery of remains for return to family.

Burn Event	Fire 1 0hr delay	24hr delay	Fire 2 56hr delay	168hr delay
1	2	2	1	2
2	3	2	2	2
3	1	1	1	1

Table 4.1 Number of *Sus scrofa* limbs used in burn events. Burns 1 and 2 used forelimbs, burn 3 used hind limbs.

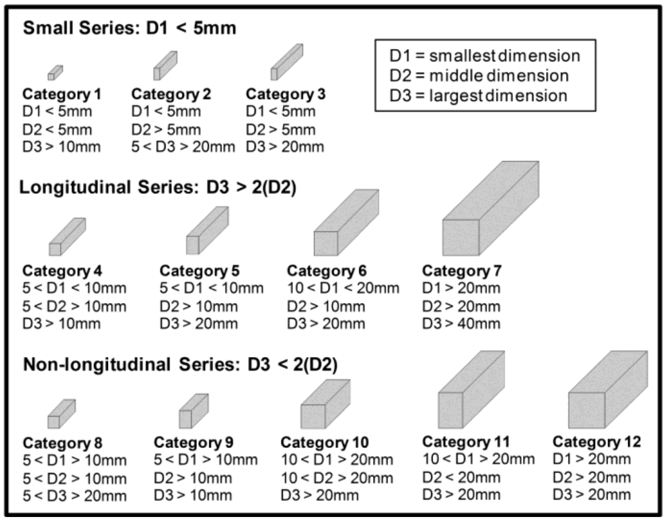

Figure 4.1 Size categories used for sorting calcined bone.

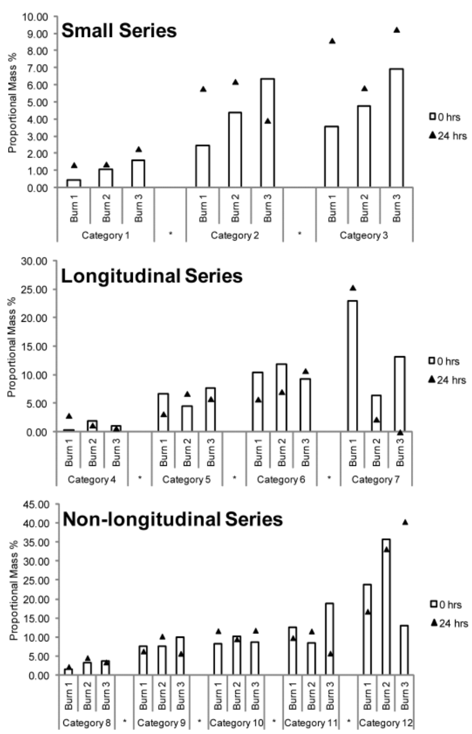

Figure 4.2 Proportional mass distributions at 0 and 24 hrs delay-until-recovery.

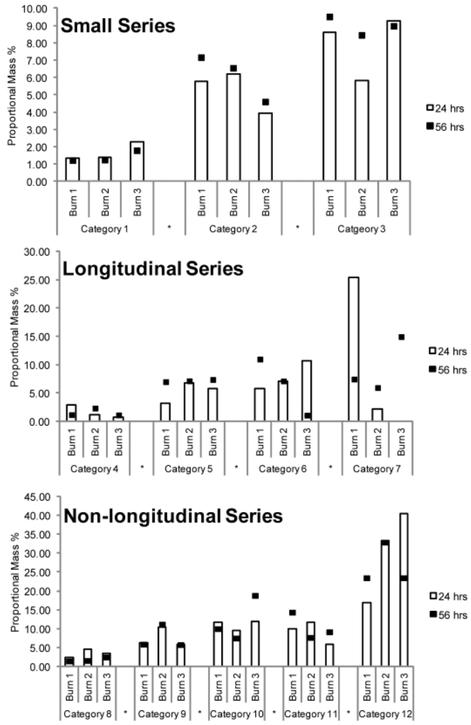

Figure 4.3 Proportional mass distributions at 24 and 56 hrs delay-until-recovery.

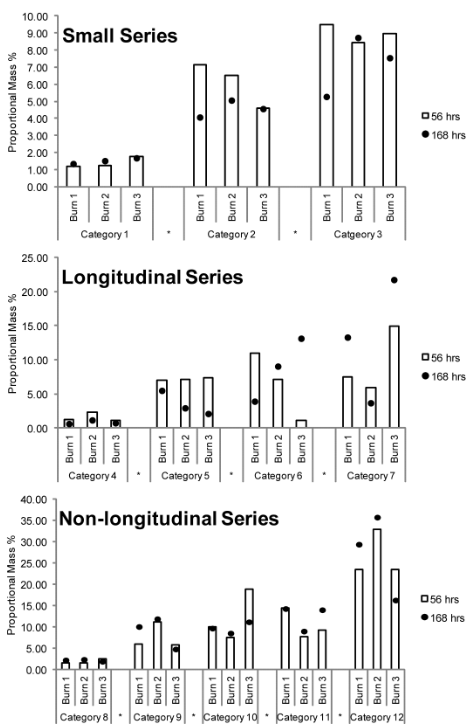

Figure 4.4 Proportional mass distributions at 56 and 168 hrs delay-until-recovery.

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Chapter Five: The effect of weather conditions on calcined bone fragmentation[4]

5.1. Introduction

Fatal fires, or fires involving human remains, are not an uncommon scene encountered by police, medical examiners, and coroners in North America. Data from the 2002 Fire Loss report shows an average of 368 annual fire deaths between 1993 and 2002 in Canada (Council of Canadian Fire Marshals and Fire Commissioners, 2007) and in the province of Alberta, 274 fire related deaths were investigated by the Office of the Chief Medical Examiner in the ten year period between January 1999 and December 2008 (see Chapter Two). Such scenes are particularly challenging to the investigators responsible for the detection, recovery, examination, and analysis of human remains, especially when all soft tissue is destroyed and the remaining bone is burnt. Anthropological analysis of these human remains can be highly informative, and to capitalize on this, scene recovery efforts need to be optimised to guarantee a high quantity and quality of recovered material. One aspect of ensuring good recovery is a thorough understanding of how remains fragment. Burnt bone is prone to progressive fragmentation (Chapter Four this manuscript, Mayne Correia, 1997, Dirkmaat *et al.*, 2012) and knowledge of this process, and the factors that affect it, will allow investigators to minimise post-burning fragmentation through developing scenario-specific recovery protocols and timelines. Valid expectations of the conditions of the remains will allow investigators to determine the training required by searchers and will

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give personnel some indication of the condition of the remains, enhancing their ability to discover bone material. This will ensure that optimal search strategies, like employing a walking search pattern to identify larger bone elements or a hands and knees search to locate smaller calcined bone fragments, are used from the beginning of the search process. Decisions on equipment, for example, the use of heavy machinery or the size of screening mesh, can also be made appropriately as can judgements on procedural decisions such as removing fire debris or leaving material *in situ*. Knowledge of fragmentation systems will facilitate a more streamlined recovery process as it can be appropriately organised and prioritized with other components of the investigation to insure minimal information loss for all involved.

Knowledge of how weather conditions affect fragmentation is an important element for understanding how bone responds to the burn environment and the fragmentation that will be encountered during recovery (Mayne Correia and Beattie, 2002). In regions that experience significant shifts in weather conditions, burnt bone may be exposed to very different conditions with different effects on fragmentation. To assess accurately the expected fragmentation and develop appropriate recovery systems, these factors need to be taken into consideration. Some key conditions that likely affect fragmentation levels are rainfall, snowfall and freeze-thaw cycles.

5.2. Background

When human remains are burnt the soft tissue is destroyed, exposing the bone to the burn environment. As bone burning progresses, the bone material is transformed from its natural state to calcined bone through a number of intermediary stages which result in observable heat-induced changes in gross and microscopic appearance, colour, size and shape (Mayne Correia and Beattie, 2002, Thompson, 2004, Devlin and Herrmann, 2008). During burning, as bone loses water and organic components and the hydroxyapatite crystals increase in size, overall size and shape changes affect the structural integrity of the bone material by altering the stress-strain relationships within each bone element leading to mechanical failures and fracturing (Herrmann and Bennett, 1999, Thompson 2005, Fairgrieve, 2008). The loss of organic material reduces bone elasticity, further promoting fragmentation of fully calcined material (Herrmann and Bennett, 1999, Thompson 2005, Fairgrieve, 2008).

Heat-induced changes observed in burnt bone have a negative impact on recovery and anthropological analysis (Mayne Correia, 1997, Mayne Correia and Beattie, 2002). Small bone fragments are difficult to locate and recover and can prove challenging to identify; however, physical anthropologists are adept at reconstructing bone elements from fragments, and recent research describing heat-induced bone changes is enabling investigators to interpret burnt remains more effectively (Thompson, 2004, 2005, Fairgrieve, 2008, Symes *et al.*, 2008, Walker *et al.*, 2008, Ubelaker, 2009, Arora *et al.*, 2010, Dirkmaat *et al.*, 2012). Significant improvements in the recovery of material from the scene can still be made by increasing the quantity and quality of material recovered, facilitating more thorough skeletal reconstruction and strengthening analysis and the interpretation of evidence (Olson, 2009).

5.3. Methods and Materials

To investigate the effect of weather conditions on bone fragmentation, fleshed *Sus scrofa* (domestic pig) limbs were burnt in a series of outdoor wood fires at different times of year as outlined in Tables 5.1 and 5.2. Burns were conducted in March, June and November in a warm summer continental climate, Köppen-Geiger classification Dfb (Kottek *et al.*, 2006). The March burn had ambient temperatures consistently below 0°C and is referred to as the *Freezing burn*. Significant rainfall was experienced during the June burn and it is referred to as the *Wet burn*. The November burn is referred to as the *Fluctuating burn* as ambient temperatures fluctuated around freezing on a daily basis during the recovery period. Limbs from piglets and older post-weaning pigs (fattening pig stage) were burned and different delay-until-recovery periods were investigated to replicate typical fatal fire scenarios. Piglet limbs were aged at six weeks and were obtained from the Swine Research Facility at the University of Alberta where they had been euthanized for other research projects. Fattening pig limbs were sourced from a local butcher, and as such their exact age at death was unknown, but their close size and patterns of unfused epiphyses suggest they were all of a similar age, between eight and 10 months based on standard slaughtering ages (Bull and Payne, 1982, Knupp, 2012). Fattening pig limbs were approximately twice the length of piglet limbs. The format for the burn events was such that all fires were started at approximately the same time on the burn day and were left to burn out and cool overnight before the timeline of recovery periods began the day after burning. Remains were recovered the day after burning (0 hrs delay) and at subsequent delay periods of 24 hrs, 56 hrs and 168 hrs (1 week) after the initial recovery to represent a range of time frames commonly encountered during fatal fire scene investigations as determined from viewing local Medical Examiner case files for Alberta (see Chapter Two). Wood burning fires were used to ensure a reasonably consistent burn environment across the burn events.

For each burn event *Sus scrofa* limbs were placed in two fires, one with piglet and fattening pig material for immediate recovery (0 hrs delay), and a second with fattening pig material for recovery following the three delay periods (24 hrs delay, 56 hrs delay, 168 hrs delay). In each fire, different aged limbs and limbs for each of the delay periods were placed in different segments of the fires, separated by 1.25 cm diameter, 0.5 metre long iron rods (rebar). In the first burn event limbs were placed directly on the ground, and in latter burn events limbs were placed on a wood base to promote burning and calcination of inferior surfaces. Wood and newspaper were used to build stable, burnable structures that were lit and left undisturbed except for periodical additions of wood fuel. Wood fuel was added by hand, avoiding direct contact with the bone. Fires were sustained for four to five hours until full calcination was observed, at which point fires were left to burn out and cool overnight. Wood used consisted of a spruce/pine mix of 2″x4″ and 2″x6″ lumber, commonly found in the Alberta region and extensively used in home construction (Dufour, 2002). Similar burn time and temperature profiles for each limb group (piglet 0 hrs delay, fattening pigs 0 hrs, 24 hrs, 56 hrs and 168 hrs delay) were confirmed by temperature data collected using type J thermocouples placed amongst each limb group of both fires, with temperatures recorded at one minute intervals using a DaqPRO 5300 data logger.

Following burning, bone remains were recovered from the burn site at the specified delay periods, recovery at 0 hrs delay occurring the day after burning. No evidence of animal disturbance to the remains was observed in any of the experiments. All remains were collected by the author by hand, using tweezers for smaller fragments with care taken to ensure no additional damage was done to any bone fragments. Bone fragments were stored in sealable plastic bags and supported by toilet tissue for immediate transport to the laboratory where they were removed from the bags, evaluated for any possible transportation damage, and stored on soft-surfaced paper trays. Care was taken to recover as much bone material as possible from the burn site, but some fragments were too small to be collected consistently and were thus necessarily excluded from data analysis. In the laboratory, bone was sorted by the principal investigator into one of 12 defined categories within three series based on size and shape (See Figure 5.1). In the *Small series* (categories 1, 2 and 3) the shortest fragment dimension is less than 5 mm. Categories 4 though 7 form the *Longitudinal series* where the shortest dimension (D1) is greater than 5 mm and the longest dimension (D3) is greater than twice the second longest dimension (D2). The third series, the *Non-longitudinal series*, consists of categories 8 through 12 and in this series the shortest dimension (D1) is greater than 5 mm and the longest dimension (D3) is less than twice the second longest dimension (D2). These categories were developed from the evaluation of preliminary test/practice burn events where material was sorted into perceived naturally occurring clusters.

Sieves were not used to separate material for two primary reasons. First, they can cause considerable mechanical damage to fragile materials and induce further fragmentation; and second, they do not allow for shape differences as fragments are sorted by only two dimensions. By measuring three dimensions fragments could be separated into three distinct shape series (Small, Longitudinal and Non-longitudinal) and fragmentation characteristics could be assessed within each series. The number of categories used was based on preliminary test/practice burns to ensure that size categorisations reflected the material at hand and did not arbitrarily divide clear size groupings and thus obscure any trends in the data. The size categories selected reflect clear clusters observed in the preliminary test/practice burns. Following sorting, each category was weighed and the proportional mass calculated within each burn event, (Wet burn, Freezing burn and Fluctuating burn). The proportion of the total mass accounted for by each category was calculated as a percentage allowing direct comparisons between each category in the different burn events.

5.4. Results

5.4.1. Small Series

Figure 5.2a shows the proportion of total mass accounted for by each category (proportional mass) in the Small series for each limb group. For the piglet remains proportional masses are highest in the Freezing burn and lowest in the Fluctuating burn for almost all categories. This patterning suggests higher levels of fragmentation in the Freezing burn, intermediate levels in the Wet burn and lower levels in the Fluctuating burn. In contrast to this, proportional masses recorded for the fattening pig remains recovered at 0 hrs delay indicate the highest levels of fragmentation in the Fluctuating burn, intermediate levels in the Wet burn and lowest levels in the Freezing burn. These differing responses to weather conditions suggest some age or size specificity of fragmentation as both sets of remains were burned in the same fire and recovered at the same time.

When recovery of remains is delayed the effect of weather on fragmentation is altered (Figure 5.2a). When recovery is delayed by 24 hrs proportional masses in the Freezing and Fluctuating burns show minor differences suggesting little difference in fragmentation, although there may be some increased fragmentation of Category 2 material in the Fluctuating burn. The Wet burn proportional masses suggest increased fragmentation of Category 3 material compared to the two cold weather burns. At 56 hrs delay proportional masses show little difference in Categories 1 and 3 across all three burn events. For Category 2 proportional mass is markedly lower in the Fluctuating burn suggesting increased fragmentation in this burn event. The expected concurrent increase in Category 1 fragments is present but very small; however, increased fragmentation in Category 2 might have produced fragments too small for collection and analysis rather than becoming Category 1 fragments. When remains recovery is further delayed to 168 hrs the highest levels of fragmentation are observed in the Freezing burn with the lowest levels in the Wet burn.

5.4.2. Longitudinal Series

Proportional mass distributions for Categories 4 through 7, the Longitudinal series, are shown in Figure 5.2b. As was seen in the Small series the piglet remains recovered at 0 hrs delay recorded the highest fragmentation levels in the Freezing burn and the lowest levels in the Wet burn. No Category 7 material was recovered in either the Freezing burn or the Wet burn suggesting higher fragmentation in these burn events than in the Fluctuating burn where Category 7 material was recovered. The lowest proportional mass for Category 6 material and the highest for Category 4 material was observed in the Freezing burn indicating higher fragmentation than in the Wet burn. For fattening pig remains recovered at 0 hrs delay the differences in fragmentation again mirror those seen in the Small series with the highest levels of fragmentation in the Fluctuating burn and the lowest levels in the Freezing burn. The Freezing burn shows higher proportional masses for Categories 6 and 7 and lower proportional masses for Categories 4 and 5 when compared to the Fluctuating burn indicating a better survival of larger fragments. Proportional masses in the Wet burn indicate increased fragmentation of Category 5 and 7 material resulting in higher proportional masses in Categories 4 and 6. This alternating pattern suggests an intermediate level of fragmentation as there is better survival of material from Categories 4 and 6 than seen in the Fluctuating burn.

When remains recovery is delayed by 24 hrs we see the highest levels of fragmentation in the Fluctuating burn, where no Category 7 material was observed. The Freezing burn shows the lowest levels of fragmentation with the highest proportional mass in Category 7 and the lowest in Categories 5 and 6. The Wet burn shows an intermediate level of fragmentation with some survival of Category 7 material but also some fragmentation increasing proportional mass in Categories 5 and 6. When recovery is further delayed to 56 hrs the Fluctuating burn shows the lowest levels of fragmentation with a high Category 7 and low Category 6 proportional masses suggesting that if Category 7 material survives a delay of 24 hrs it is relatively stable at 56 hrs delay. In contrast the Freezing burn shows the highest levels of fragmentation of larger Category 7 material after 56 hrs delay. Proportional masses in the Wet burn indicate balanced fragmentation across all categories with no single category dominating the proportional mass distribution. As seen at 56 hrs delay, at 168 hrs delay the Fluctuating burn shows the lowest levels of fragmentation with high proportional masses in Categories 6 and 7 and low proportional masses in Categories 4 and 5. The Wet burn shows the highest level of fragmentation with increased destruction of material from Categories 5 and 7 compared to the Freezing burn.

5.4.3. Non-longitudinal Series

Proportional mass data from the Non-longitudinal series is presented in Figure 5.2c. For the piglet remains, as in the Small and Longitudinal series, highest fragmentation is seen in the Freezing burn. This burn had the lowest proportional masses for Category 11 (no Category 12 material was observed for any burn event) and highest proportional masses for Category 9. There seems to be little difference in fragmentation between the Fluctuating and Wet burns which show similar proportional masses for all categories. The fattening pig remains collected at 0 hrs delay also show a similar pattern to that previously described with highest fragmentation in the Fluctuating burn and lowest fragmentation in the Freezing burn. The Fluctuating burn shows sequential rises and falls in proportional mass with low values in Categories 10 and 12 and high values in Categories 9 and 11. Proportional masses in the Wet burn also show an undulating pattern, but with peaks in Categories 10 and 12 indicating less fragmentation compared to the Fluctuating burn. Compared to the Freezing burn the Wet burn shows less fragmentation of Category 12, but higher proportional masses in Categories 8, 9, and 10 suggest an overall slight increase in fragmentation in the latter burn event.

When remains recovery is delayed the patterns of fragmentation are altered (Figure 5.2c). After a delay of 24 hrs proportional masses in the cold burns suggests more fragmentation of larger fragments in the Freezing burn compared to the Fluctuating burn which has higher Category 12 proportional masses and lower Category 11 material. Proportional mass distribution in the Wet burn suggests less fragmentation in the larger categories (Categories 11 and 12) compared to the Freezing and Fluctuating burns with apparent slight increases in fragmentation of intermediate Categories, 9 and 10. When recovery is delayed 56 hrs highest fragmentation is seen in the Freezing burn as was observed in the Longitudinal series. The Wet burn and the Fluctuating burn show rise and fall changes in proportional mass between categories where a higher level in Category 10 corresponds with lower levels in Categories 8 and 9 in the Fluctuating burn, and higher levels in Category 9 correspond with lower levels in Category 8 in the Wet burn. This pattern is not observed in the Freezing burn indicating increased fragmentation in this burn event as fragmentation is more evenly distributed across all categories. With further delays in recovery (168 hrs) cold conditions again impact fragmentation more than wet conditions. The Wet burn shows high Category 12 material with low proportional masses in Categories 11 and 10. This is opposite to the pattern seen in the Fluctuating burn where low Category 12 proportional masses and high proportional masses in Categories 11 and 10 indicate increased fragmentation. The low proportional masses in Category 9 however suggest less fragmentation of smaller material in this burn event. The Freezing burn shows intermediate levels of fragmentation with breakdown of Category 12 material resulting in increased proportional masses in Categories 9, 10 and 11.

5.5. Discussion

Fragmentation patterns differed considerably for piglet and fattening pig bone exposed to different weather conditions. These patterns can be interpreted and provide clues as to how some weather factors affect the fragmentation of calcined bone. In fattening pig remains recovered the day after burning the fragmentation levels are higher when ambient scene temperatures fluctuate around freezing than when temperatures remain well below 0°C. This result cannot be attributed solely to the fragment-producing effect of freeze-thaw cycling in the fluctuating conditions as both sets of remains (Freezing burn and Fluctuating burn) experienced a single freeze-thaw cycle with thawing occurring either *in-situ* (fluctuating conditions) or the laboratory (freezing conditions). *In-situ* thawing may have resulted in the loss of some bone pieces too small for recovery. However, these fragments would have been excluded from analysis of the remains from the freezing burn as they would have been below the defined reliable collection threshold. The difference in fragmentation observed between the Fluctuating and Freezing burn must then be attributed to differences in the rate of cooling. In the Fluctuating burn the minimum overnight temperature recorded was -5°C compared to -19.5°C in the Freezing burn, indicating a clear difference in the gradient of temperature loss. In the Freezing burn, any moisture in and around the bone surfaces would have frozen sooner than in the Fluctuating burn, reducing the amount of moisture within the bone fragment. How the increased exposure to moisture in the Fluctuating burn results in increased fragmentation is unclear, although anecdotal experience of working with damp calcined remains suggests it may relate to moisture penetrating micro fissures and cracks weakening the overall bone structure. The slower cooling period experienced in the Fluctuating burn may also have impacted fragmentation. McKinley (1994) suggests that hotter bone is more brittle than cooler bone and may be more affected by changes in the post-burn environment leading to fragmentation.

The effect of a slower cooling period and in-field thaw increasing fragmentation does not explain fragmentation in piglet remains. In this case the highest levels of fragmentation were observed when temperatures remained well below freezing, with less fragmentation observed in situations with fluctuating temperatures. This age based difference may relate to the fact that although the collected piglet bone showed higher proportional masses in the smaller categories, the bone material was typically less fragmented, with more complete or almost complete bone elements and unfused epiphyses than the fattening pig material. These more complete bone pieces, while still containing no organic material and having no elastic capacity, are better able to withstand the stresses and strains introduced by the penetration of moisture into the bone fragments. As almost complete bone pieces, and not isolated fragments, the piglet material retains more strength and stability, enabling it to survive some structural weakening, and thus fragment less than the fattening pig material under the same conditions. The resistance to fragmentation in piglet material may also result from the smaller initial size of the material. Smaller bones potentially fragment less during the burning process as they experience a smaller difference in micro-environment across a single bone surface ensuring more bones remain complete in the post-burning environment.

When remains recovery is not completed the day after burning, the conditions experienced in the Fluctuating and Freezing burn differ, not only by the rate of cooling, but also by the number of freeze-thaw events. In the Fluctuating burn any moisture within the bone expands and contracts with each freeze-thaw cycle, and in the freezing conditions this expansion only occurs on first freezing and contraction on final thawing in the laboratory. Thus the Fluctuating burn remains experience a dynamic changing environment compared to the more static situation in the Freezing burn remains. These Freezing burn remains do experience change as the continued exposure to cold temperatures allows for deeper penetration of freezing over time. How these differences affect bone fragmentation depends on time until recovery and bone fragment size and shape. When recovery is delayed by 24 hrs, freeze-thaw cycling has a greater effect on fragmentation of the Small and Longitudinal fragments, but not the Non-longitudinal fragments, possibly because these fragments are often more structurally complete than longitudinal fragments post-burning. As was observed when comparing the piglet and fattening pig material, at 24 hrs delay the Non-longitudinal series consisted of markedly more nearly-complete fragments than the Small and Non-longitudinal series. This structural integrity would have offered some resistance to the fragmenting effects of the freeze-thaw cycles. At 56 and 168 hrs delay higher fragmentation is seen at temperatures below freezing, indicating that in the longer time frame the effect of freeze-thaw cycles is less significant than continued exposure to below 0°C temperatures. This loss of fragmentation effect over time in fluctuating temperatures suggests that after two or three freeze-thaw events, repeated events do not induce further fragmentation.

In addition to the effect of freezing, moisture impacts fragmentation through rainfall. Remains from the Wet burns for piglet and fattening pig material collected the day after the fire typically showed fragmentation levels falling between the two other burns, suggesting that the rainfall experienced during recovery increased fragmentation. Recovery of this material was made in the rain, following periods of overnight rains; thus, remains were damp during recovery and were dried in the laboratory before processing. The dampening process would lead to increased fragmentation as moisture would have gained access to micro-fissures and cracks in the calcined bone, weakening the structure. When the material dried, the loss of water will have again altered the pressures and strains experienced by the bone which may have lead to further fracturing.

When recovery is delayed the effect of rainfall on fragmentation becomes more complicated. At 24 hrs delay, fragmentation patterns suggest that larger fragments are able to withstand the effects of rainfall and fragmentation does not increase in these categories, but at 56 and 168 hrs delay the effect of rainfall is more significant. This highlights the time specificity of the effect of rainfall, with remains able to withstand the effects of moisture for only short periods of time.

5.6. Conclusion

The fragmentation of calcined bone is very complex and highly nuanced with many factors having a significant impact on how bone responds to the burn environment and how fragmentation occurs. Data presented here show that fragmentation patterns are age and time specific, and are affected by weather conditions such as freeze-thaw cycles and rainfall. Knowledge of how these factors affect fragmentation allows investigators to implement protocols to minimise post-burning fragmentation by limiting remains exposure to moisture and freezing temperatures. Remains recovery can be delayed by factors such as scene safety or difficulties in locating remains and in these circumstances remains should be kept in a stable environment, prevented from freezing and protected from rainfall through the use of protective coverings and heating prior to and during recovery. If these steps are taken, remains recovery can be enhanced by limiting weather induced additional destruction of the remains. If it is not possible to protect the remains in this manner knowledge of the effect of these weather conditions on fragmentation allows investigators to develop scenario-specific recovery timelines and procedures to maximise remains recovery. It should be noted that while these data provide valuable direction for investigators, they do not address all potential burn environments or weather conditions that may affect fragmentation. Further research into the effect of fire type and other weather factors such as snowfall, hail, high winds, and extreme high temperatures, will enable further refinements and detail on the effect of weather conditions on burnt bone fragmentation.

Burn Event	Fire 1 Piglet 0hr delay	 Fattening pig 0hr delay	Fire 2 Fattening pig 24hr delay	 Fattening pig 56hr delay	 Fattening pig 168hr Delay
Wet burn	4	2	2	1	2
Freezing burn	4	3	2	2	2
Fluctuating burn	4	1	1	1	1

Table 5.1 The number of *Sus scrofa* limbs used in the burn events. All limbs used were forelimbs except for fattening pig material in the Fluctuating burn which used hindlimbs.

	Month	Ave. °C on Burn Day	Ave. °C over 168 hrs	Snow/Rain	Comments
Wet burn	June	12.3	11.8	Rain	Significant rain on first day of recovery Occasional rain during following week
Freezing burn	March	-8.3	-3.5	Minor snow	Significant snow pack on ground. Falling snow did not accumulate on remains
Fluctuating burn	November	2	-1.1		Temperature fluctuated around 0°C on a daily basis

Table 5.2 The weather conditions for the burn events.

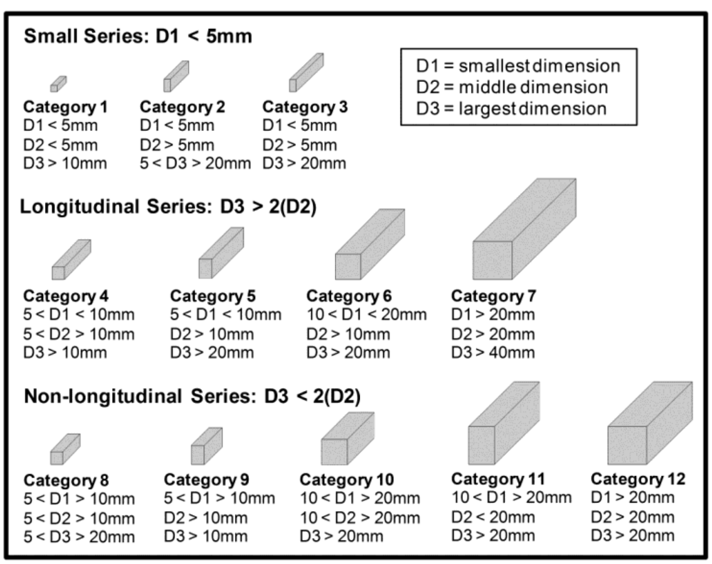
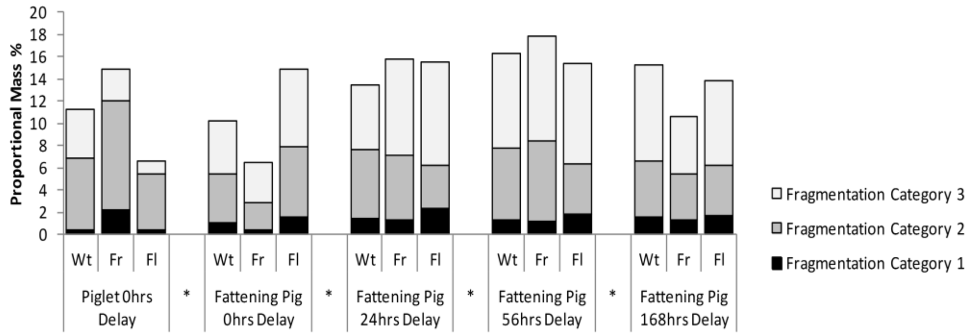
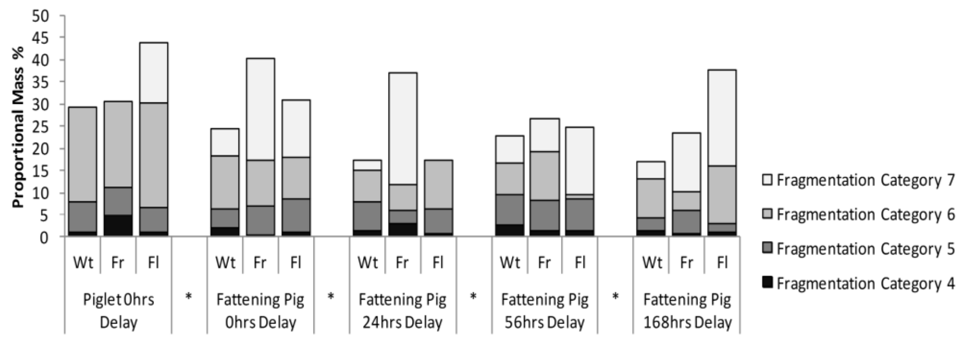


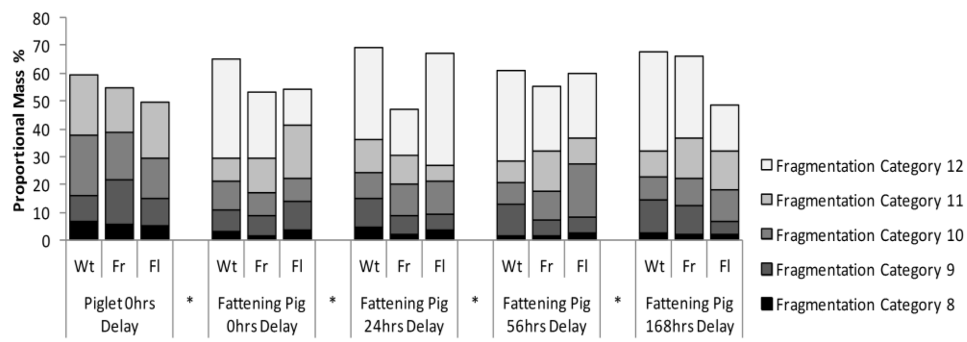
Figure 5.1 Size categories used for sorting calcined bone.



a) Proportional Mass Distribution for Small Series



b) Proportional Mass Distribution for Longitudinal Series



c) Proportional Mass Distribution for Non-longitudinal Series

Figure 5.2 Proportional mass distributions for piglet and fattening pig remains recovered following different delay periods. Wt- Wet burn, Fr- Freezing burn, Fl- Fluctuating burn.

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Chapter Six: Conclusion

6.1. Introduction

The recovery of burnt human remains from fatal fire scenes is a complex and challenging prospect for investigative personnel (Dirkmaat *et al.*, 2012). When burning has been severe and bone is calcined, remains usually consist of a large number of small fragments that are difficult to recognise and prone to further fragmentation and destruction in the search and recovery process (Fairgrieve 2008, Symes *et al.*, 2008, Dirkmaat *et al.*, 2012). In addition to practical difficulties of remains recovery scene managers have to balance the needs and priorities of different investigative departments to ensure accurate and appropriate information retrieval for all (Mayne Correia and Beattie, 2002). Considering the complicated circumstances of remains recovery from fatal fire scenes, it is essential that our knowledge of calcined bone fragmentation be improved. By better understanding remains fragmentation it is possible to develop scene specific recovery protocols to improve the quantity and quality of material recovered. This increase in knowledge and understanding is the central theme of this thesis. In Chapter Two the background and justification for the further studies was outlined through a description and analysis of the fatal fire deaths in Alberta and in Chapters Three, Four and Five the effects of decedent age, delayed recovery and weather conditions on the bone response to the burn and post-burn environment were investigated.

6.2. Major Research Findings

6.2.1. Fatal fire deaths in Alberta

Fire loss reports, regularly published by the Council of Canadian Fire Marshals and Fire Commissioners, provide valuable information on fatal fire deaths across Canada. These reports typically outline the number of fatal fire deaths with some population parameters but seldom include information on the effect of fire on human remains or outline enough detail to assist with research design investigating the destruction of burnt human remains. As such, the data presented in Chapter Two was collected and analysed to provide an outline of fire related deaths for the Alberta region between 1999 and 2008. These data were then used in the design process of further research questions, presented in Chapters Three, Four and Five, to ensure forensic applicability and investigative value of the work conducted.

Data presented in Chapter Two show that fatal fire deaths are not uncommon in Alberta. In the ten year period reviewed (1999-2008) a total of 274 individuals died in fatal fire incidents with the majority of these occurring in residential fires (65%) and vehicle fires following vehicle collisions (20%). While remains are infrequently burnt to full calcination this does occur and heat-induced amputation with calcination of the distal elements is more common. The incidence of calcined remains justifies the investigation into aspects of fragmentation of calcined bone. When assessing the age of fatal fire decedents this review highlighted that within residential fires, younger and older individuals are more at risk of dying in fatal fires. The relatively high levels of younger (0-10 years) deaths brings to light the need to investigate the effect of decedent age on bone response to burning to ensure that protocols and techniques developed using older remains are appropriate for use with younger individuals. Finally, this paper also assessed the seasonality of fatal fire deaths, confirming incidents occur year round and that remains are often exposed to a wide range of weather conditions.

6.2.2. Effect of decedent age on calcined bone fragmentation

Individuals of all ages are at risk from dying in fatal fires. This risk is increased for younger (0-10 years) individuals, likely due to behavioural activities such as fire-play and their reduced ability to escape the fire (Istre *et al.*, 2002, Shai, 2003). This increased incidence of juvenile fire fatalities identifies the need to investigate potential age associated differences in bone response to burning. Preliminary studies conducted on neonate remains suggest that while initially harder to destroy in the burn environment, infant remains are more easily broken down *post-burn*ing (Holck, 1997). Knowledge of the age specific bone response is a key component of developing appropriate and value-laden recovery protocols to ensure maximal benefit at minimum cost.

Data presented in Chapter Three show that contrary to popular understanding, younger remains typically fragment less and are more complete post-burning than older remains. This may be due to the smaller initial size of the material, differences in pre-burning bone composition or differences in bone shape. The relative completeness of calcined younger bone is significant for bone recovery as it identifies the need for searchers to be trained in juvenile osteology to improve discovery and identification of human bone fragments. The value of juvenile material for anthropological assessments is also highlighted as increased completeness of bone elements often enhances the accuracy and detail of the osteological assessment.

6.2.3. Effect of delayed recovery on calcined bone fragmentation

Numerous priorities exist within a fatal fire scene and remains recovery has to be conducted within the bounds of the larger investigation. When managing a fatal fire scene the needs of fire, police and insurance investigators need to be balanced with scene safety, optimal working conditions and many other scene specific factors. This task is further complicated by the time sensitive nature of evidence collection and interpretation with all investigative agencies operating along different optimal time lines (Mayne Correia and Beattie 2002, Fairgrieve, 2008). Considering this, it is important to understand how delaying or advancing human remains search and recovery will affect the condition of the remains and thus the quantity and quality of material to be recovered. Knowledge of the effect of time delays on remains fragmentation will also assist the search for remains as search personnel will be better able to form reliable predications of remains condition. An investigation into the effect of short-term delays in recovery on remains fragmentation is presented in Chapter Four.

The data presented in Chapter Four outline that when recovery is delayed by 24 hours there is a marked increase in fragmentation of the material, with a considerable loss of larger fragments. Between 24 and 56 hrs delay in recovery there is a further increase in fragmentation but it is less striking. Larger fragments are relatively stable with only the smaller fragments showing much increase in fragmentation. When recovery is delayed by 168 hrs (1 week) there is again a large increase in fragmentation with large and smaller bone pieces breaking down. These data are significant for scene investigators as they document the breakdown in human remains associated with delayed recovery and provide evidence to support the argument for immediate recovery of human remains from a fatal fire scene. With a delay of only 24 hrs there is a clear reduction in remains condition which may prove significant for anthropological assessment of the material. With further delays (up to 56 hrs) remains condition continues to deteriorate but this is less marked than at 24 hours delay, and during this time frame a short term delay in remains recovery may be justified in some circumstances. Remains recovery should however be expedited after this point to maximise the investigative value of the material.

6.2.4. Effect of weather conditions on calcined bone fragmentation

As demonstrated in Chapter Two, fatal fires occur in all seasons and in regions like Alberta which experience significant shifts in weather patterns, human remains may be exposed to a wide range of weather conditions. Many aspects of these weather conditions likely affect the post-burning fragmentation of remains and it is important to improve our understanding of these effects to develop season or weather specific discovery and recovery protocols to maximise the information available to investigators. Chapter Five of this thesis focuses on the effects of temperature and rainfall, assessing fragmentation in remains exposed to freezing temperatures, freeze-thaw cycles and rainfall.

When calcined remains are exposed to freezing conditions, temperatures fluctuating around 0°C and wet conditions, fragmentation rates are age specific and affected by time until recovery. Younger remains showed the highest levels of fragmentation in freezing conditions but this was not observed in older remains where the highest fragmentation was seen in fluctuating conditions. When remains recovery was delayed for older remains, fluctuating temperatures have the greatest effect on fragmentation in the short term (24 hrs delay), but in the longer term (56 hrs and 168 hrs) freezing conditions have a greater effect. Rainfall and damp conditions also increase fragmentation of calcined bone. These results highlight the value of keeping remains dry and at a stable temperature above freezing prior to recovery if possible.

6.3. Future Work

The results of the studies completed as part of this thesis call for future work in a number of areas. The data presented in Chapters Three, Four and Five provide a valuable, preliminary baseline upon which future work can build to deepen our knowledge of the factors affecting calcined bone fragmentation. It has been demonstrated that age, time until recovery and weather conditions all impact fragmentation and further studies are required to expand on these discoveries and outline the detail of calcined bone fragmentation.

The data presented in Chapter Three provides an initial outline of the differences between younger and older bone fragmentation. More specific future work is required to understand the nuances of the effect of decedent age and outline age specific responses to the burn environment. To achieve this it is essential to first improve our understanding of the mechanics of calcined bone fracture mechanics. At present it is not clear which differences between mature and immature bone are responsible for differences in fragmentation and the role played by bone size, bone shape and bone composition need to be determined. Burnt bone studies which control for these variables may go some way to answering these questions as will studies assessing the mechanics of heat-induced fracture production in juvenile bone. Alongside this research into fracture production in burnt juvenile bone it is also important to outline age specific fragmentation patterns. Knowledge of how bone of different ages responds to the burn environment will enable scene investigators to more accurately tailor search and recovery protocols taking into consideration the age of the suspected decedent. This research will need to ensure appropriate material is used to model human bone size, shape and composition as well as soft tissue structures.

In Chapter Four the effect of delayed recovery on remains fragmentation was outlined. This study provides valuable data for delays of 24 hrs, 56 hrs and 168 hrs and further work is required to investigate other delay periods. Conducting additional studies to quantify the differences in fragmentation between different delay periods will also prove valuable. In addition to this repeating the study in a range of differing weather conditions will enable further refinements to be made and for subsequent models to take weather conditions into consideration. Future studies may also consider other factors detrimental to remains recovery (such poor light conditions) and compare the effects of delaying recovery to recovery in sub-optimal conditions. An additional element of delayed investigations that also needs to be considered is the effect of delays between remains recovery and analysis on remains condition. This type of work will ensure scene investigators are equipped to make appropriate decisions on the time-line of remains recovery to ensure maximal benefit to the investigation.

The effect of weather conditions was investigated in Chapter Five. The data presented here was limited to assessing the effect of freezing conditions, freeze-thaw cycling and rainfall as these were the weather conditions experienced during field work. Significant future work is required to further investigate the effect of different weather conditions and the combination of different weather systems. To ensure the conclusions reached are robust and applicable in the field it is also important to conduct more burn events. This work can be assisted by conducting laboratory based research into the freezing of burned bone and the changes in stress-strain relationships as temperature, humidity and other environmental conditions are altered. By outlining bone response to specific changes in environment it will be possible to postulate potential changes in any given weather circumstance. This is essential for scene investigators as every scene or scenario is unique and bone condition needs to be estimated using first principles.

As well as the research question specific future work discussed above other areas of burnt bone fragmentation need further investigation. The effect of fire type and temperature-time profile on fragmentation needs to be considered. This thesis presents data outlining fragmentation in wood fires to enable a base understanding of the factors affecting burnt bone fragmentation and future research into more complex fires such as building or vehicle fires can build upon this data set. The effect of use of accelerants is another factor which needs to be investigated. Using accelerants can alter the burn pattern of the remains, or the surrounding material and how this alters the bone response to burning and thus fragmentation should be considered.

The future work outlined here is only the beginning of the work that needs to be conducted to gain a full understanding of burnt bone fragmentation. Many factors can alter the burn environment and the bone response to burning and these all need to be considered when assessing burnt bone fragmentation. Outlining the bone response to major burn variables and gaining a better understanding of burnt bone fracture dynamics is required to enable investigators to reliably predict how bone will react in any given circumstance. Future studies outlining the bone response to burning and ensuring the reliability and applicability to a range of burn circumstances is required to ensure scene investigators can accurately predict bone condition and select appropriate search and recovery protocols.

6.4. Final Remarks

The central aim of this thesis was to improve our understanding of factors affecting the fragmentation of calcined bone. It is only by understanding how calcined bone responds to different burn and post-burn situations that it is possible to develop better, more remains and scene specific recovery protocols and procedures. This is essential for calcined bone recovery as this material is difficult to recover and can be highly valuable to a forensic investigation.

This thesis assessed the effect of decedent age, delay-until-recovery and weather conditions on remains fragmentation and provides a baseline set of data for scene investigators and other researchers to work from when developing search and recovery protocols. Data presented here identifies the age specificity of the bone response to burning and highlights the need for further investigation into juvenile bone burning. The impact of delayed recovery is also presented and data provide evidence of delay associated bone destruction. Finally, the effect of some weather conditions on bone fragmentation is outlined and the detrimental effect of freezing temperatures and rainfall is highlighted.

6.5. Literature cited

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Chapter Seven: Appendices

7.1. Bone Mass Data

7.1.1 Burn 1: 13th March 2011

Category	Piglet 0 hrs Delay		Fattening Pig 0 hrs Delay		Fattening Pig 24 hrs Delay		Fattening Pig 56 hrs Delay		Fattening Pig 168 hrs Delay	
	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
1	1.4	2.2	1.5	0.4	4.5	1.3	3.6	1.2	4.3	1.3
2	6.1	9.7	8.7	2.5	19.4	5.8	21.3	7.2	13.1	4.1
3	1.8	2.9	12.6	3.6	28.8	8.6	28.3	9.5	17.0	5.3
4	2.9	4.6	1.1	0.3	9.7	2.9	3.6	1.2	2.1	0.7
5	4.1	6.5	23.4	6.6	10.6	3.2	20.9	7.0	17.8	5.5
6	12.1	19.3	36.5	10.3	19.2	5.7	32.8	11.0	12.7	3.9
7	0.0	0.0	80.7	22.9	84.8	25.3	22.3	7.5	43.0	13.3
8	3.7	5.9	5.1	1.4	7.7	2.3	4.5	1.5	7.4	2.3
9	10.0	15.9	26.4	7.5	21.3	6.4	17.7	5.9	32.7	10.1
10	10.7	17.1	28.8	8.2	39.2	11.7	29.9	10.0	31.5	9.8
11	9.9	15.8	44.2	12.5	33.1	9.9	42.9	14.4	46.3	14.3
12	0.0	0.0	83.9	23.8	56.3	16.8	70.0	23.5	95.0	29.4
Total	62.7	100.0	352.9	100.0	334.6	100.0	297.8	100.0	322.9	100.0

7.1.2 Burn 2: 2nd June 2011

Category	Piglet 0 hrs Delay		Fattening Pig 0 hrs Delay		Fattening Pig 24 hrs Delay		Fattening Pig 56 hrs Delay		Fattening Pig 168 hrs Delay	
	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
1	0.3	0.4	6.8	1.0	5.2	1.4	5.8	1.2	6.1	1.5
2	5.3	6.5	28.3	4.4	23.4	6.2	30.6	6.5	20.5	5.1
3	3.5	4.3	30.7	4.7	22.0	5.8	39.5	8.4	35.4	8.7
4	0.6	0.7	12.1	1.9	4.5	1.2	11.1	2.4	4.8	1.2
5	5.8	7.1	29.2	4.5	25.4	6.7	33.6	7.2	12.0	3.0
6	17.3	21.3	76.9	11.9	26.6	7.1	33.5	7.2	36.8	9.1
7	0.0	0.0	40.9	6.3	8.4	2.2	28.0	6.0	15.0	3.7
8	5.3	6.5	21.1	3.3	17.5	4.6	7.6	1.6	9.9	2.4
9	7.6	9.4	49.2	7.6	38.8	10.3	52.6	11.2	48.5	11.9
10	17.7	21.8	66.4	10.3	36.1	9.6	35.4	7.6	34.9	8.6
11	17.8	21.9	54.9	8.5	43.9	11.6	36.2	7.7	36.8	9.1
12	0.0	0.0	231.3	35.7	125.3	33.2	154.1	32.9	145.2	35.8
Total	81.2	100.0	647.8	100.0	377.1	100.0	468.0	100.0	405.9	100.0

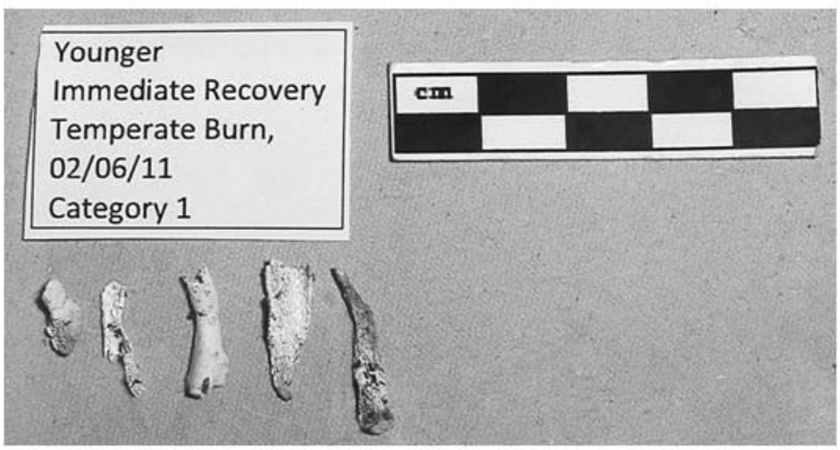
7.1.3 Burn 3: 2nd November 2011

Category	Piglet 0 hrs Delay		Fattening Pig 0 hrs Delay		Fattening Pig 24 hrs Delay		Fattening Pig 56 hrs Delay		Fattening Pig 168 hrs Delay	
	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
1	0.4	0.4	2.7	1.6	5.1	2.3	4.1	1.8	3.3	1.7
2	5.0	5.1	10.9	6.3	8.8	3.9	10.6	4.6	9.0	4.6
3	1.1	1.1	11.9	6.9	20.7	9.3	20.7	9.0	14.9	7.5
4	0.9	0.9	1.7	1.0	1.5	0.7	2.7	1.2	1.5	0.8
5	5.8	5.9	13.1	7.6	13.0	5.8	17.1	7.4	4.2	2.1
6	23.1	23.4	16.0	9.3	24.0	10.7	2.6	1.1	26.0	13.2
7	13.5	13.7	22.7	13.2	0.0	0.0	34.6	15.0	43.0	21.8
8	5.1	5.2	6.3	3.7	7.8	3.5	5.9	2.6	3.9	2.0
9	9.6	9.7	17.3	10.0	12.9	5.8	13.5	5.8	9.6	4.9
10	14.3	14.5	14.9	8.7	26.5	11.8	43.5	18.8	22.2	11.2
11	20.1	20.3	32.3	18.8	13.0	5.8	21.3	9.2	27.8	14.1
12	0.0	0.0	22.4	13.0	90.4	40.4	54.3	23.5	32.3	16.3
Total	98.9	100.0	172.2	100.0	223.7	100.0	230.9	100.0	197.7	100.0

7.2. Bone photographs

Cold burn = Burn 1 = Freezing burn as referred to throughout this thesis
Temperate burn = Burn 2 = Wet burn as referred to throughout this thesis
Cold burn 2 = Burn 3 = Fluctuating burn as referred to throughout this thesis
Younger = Piglet remains as referred to throughout this thesis
Older = Fattening pig remains are referred to throughout this thesis

7.2.1 Category 1




Older
Immediate Recovery
Cold Burn, 13/03/11
Category 1


Older
Immediate Recovery
Temperate Burn,
02/06/11
Category 1


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 1


Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 1
cm


Delayed Recovery
1 Day Delay
Temperate Burn,
02/06/11
Category 1
cm


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 1
cm


Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 1
cm


Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 1
cm


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 1
cm


Delayed Recovery
1 Week Delay
Temperate Burn,
02/06/11
Category 1
cm


Delayed Recovery
1 Week Delay
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Delayed Recovery
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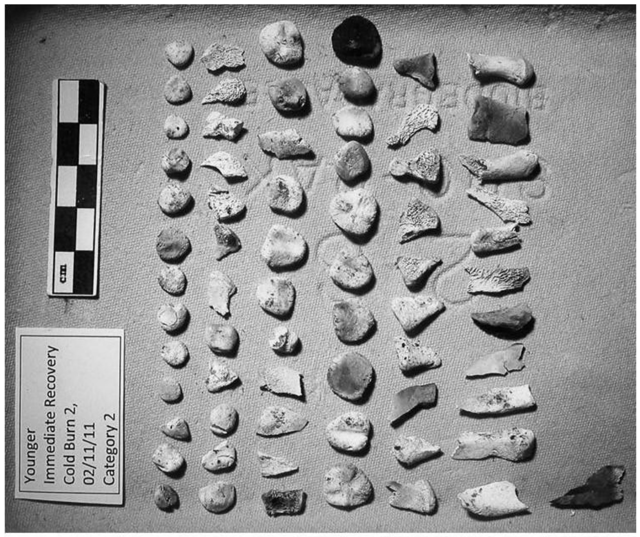
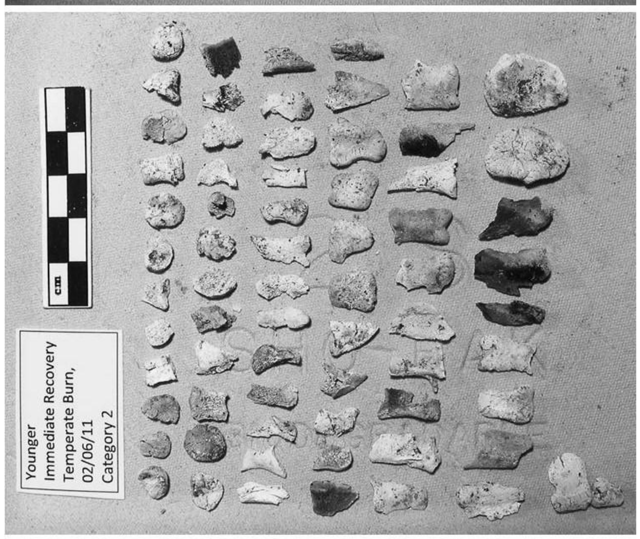
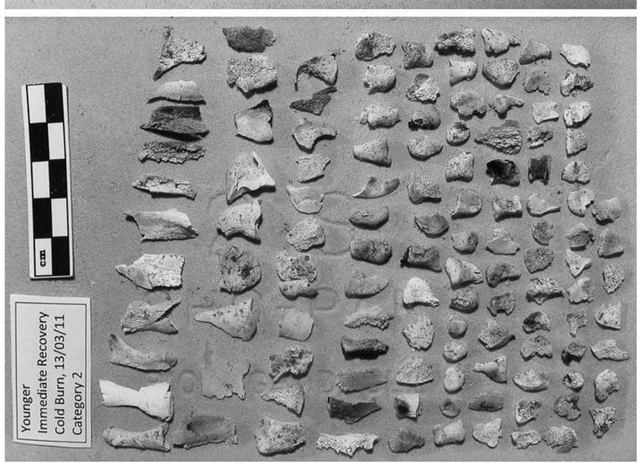
Cold Burn 2,
02/11/11
Category 1
cm

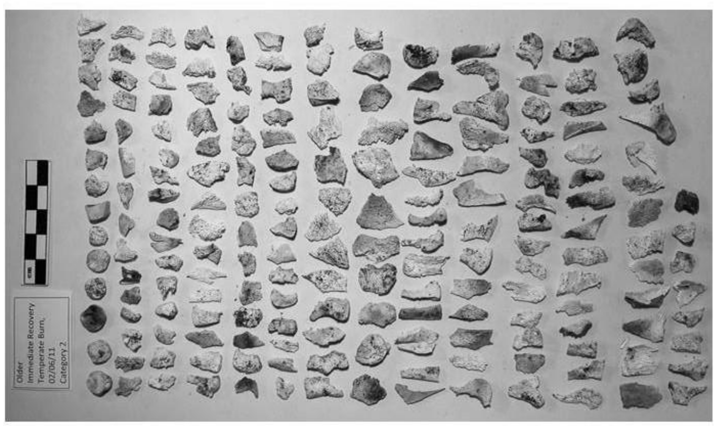
7.2.2 Category 2








Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 2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02/06/11
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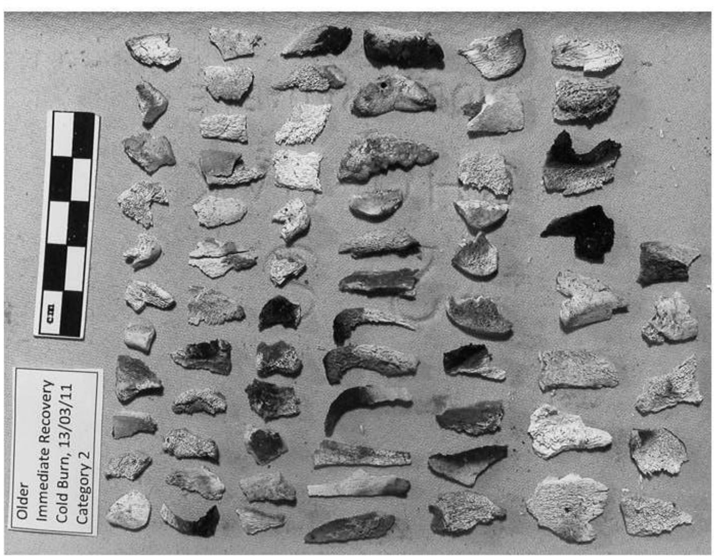
Older
Immediate Recovery
Cold Burn, 13/03/11
Category 2


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 2

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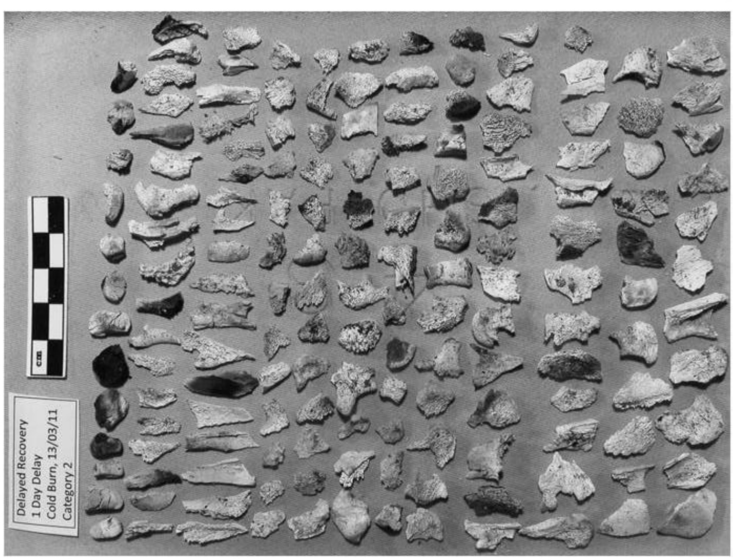
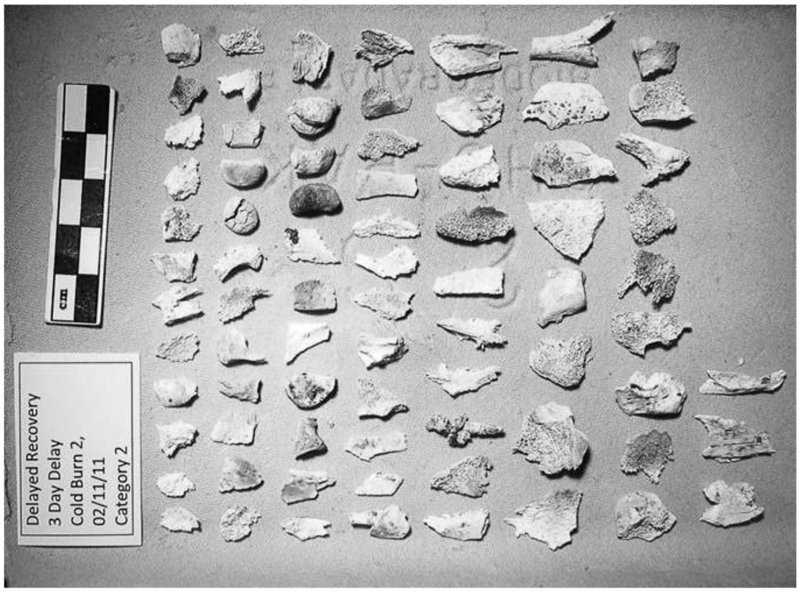
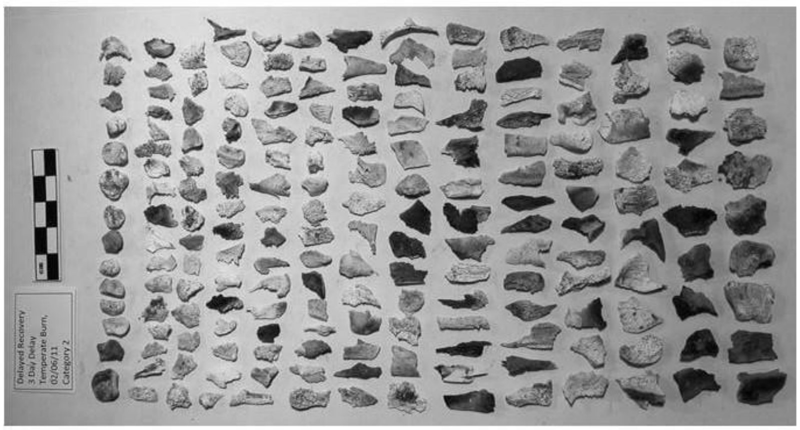
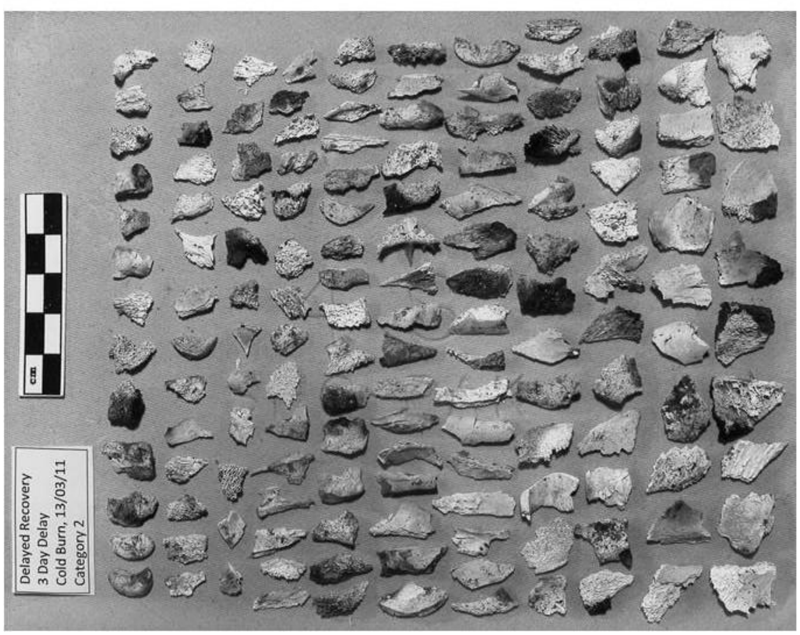
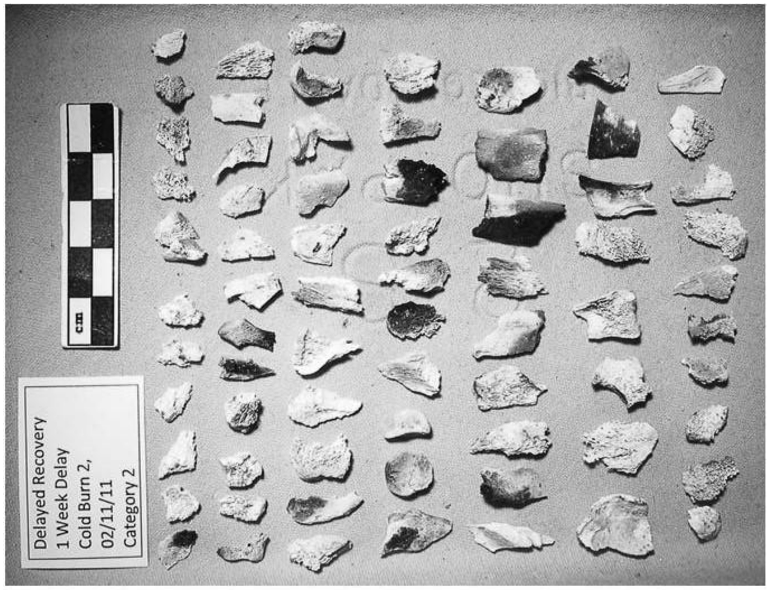
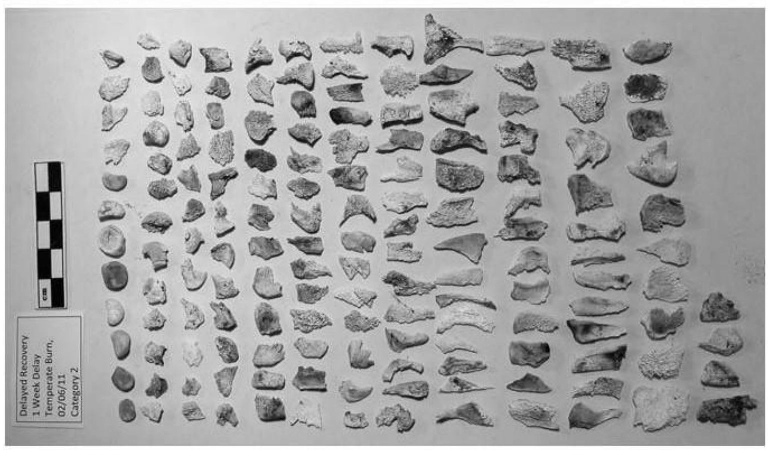
Temperate Burn,
02/06/11
Category 2

Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 2

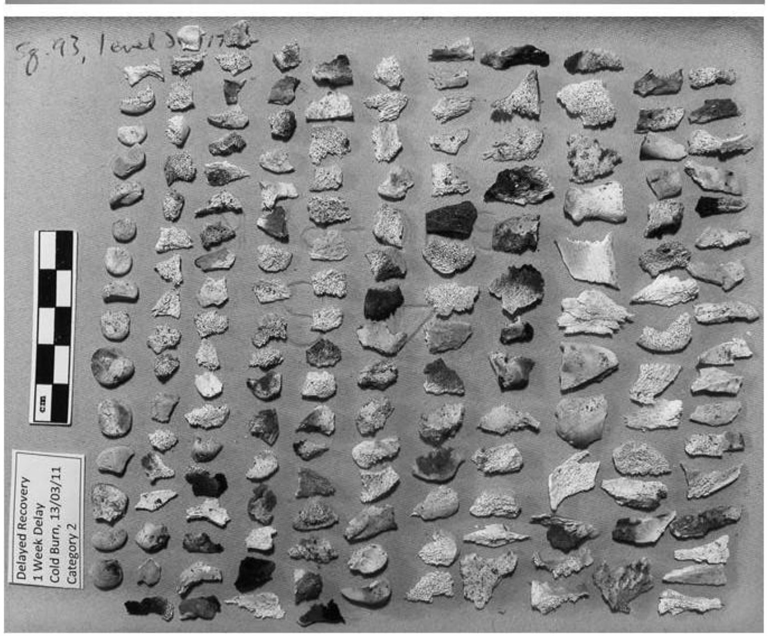

cm
Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 2


Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 2


cm
Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 2

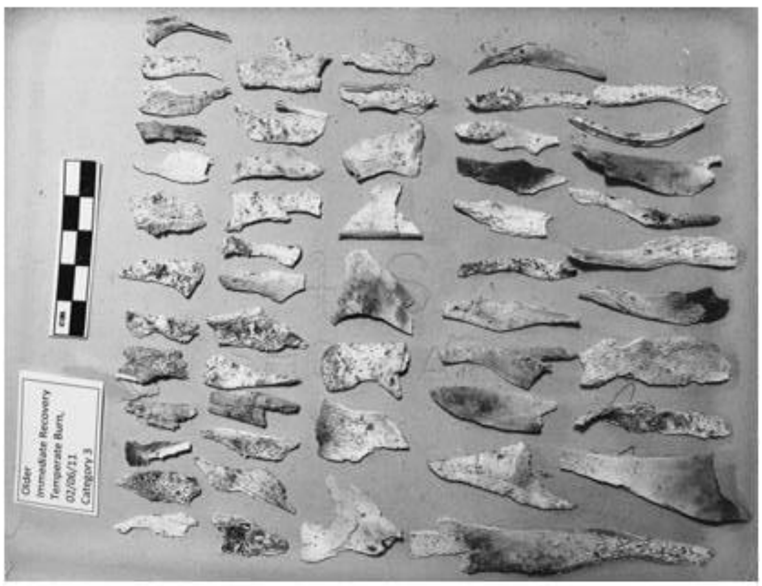

Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 2
cm

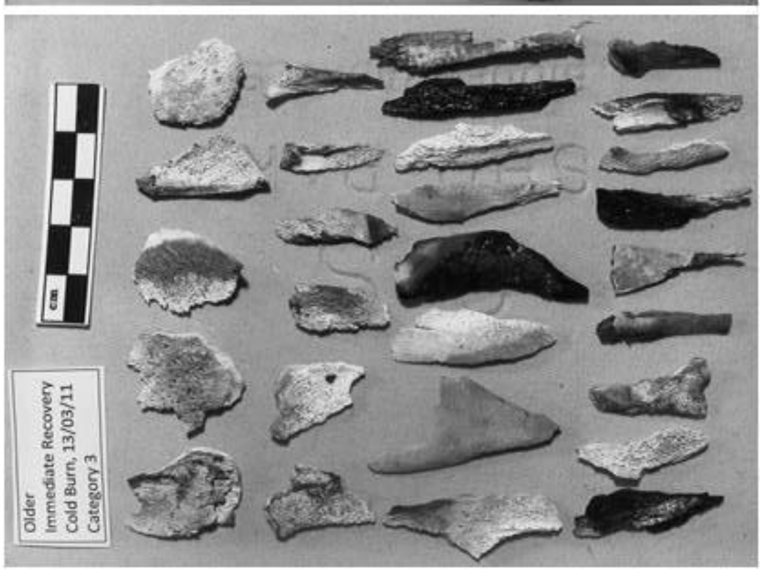

Delayed Recovery
1 Week Delay
Temperate Burn,
02/06/11
Category 2
cm

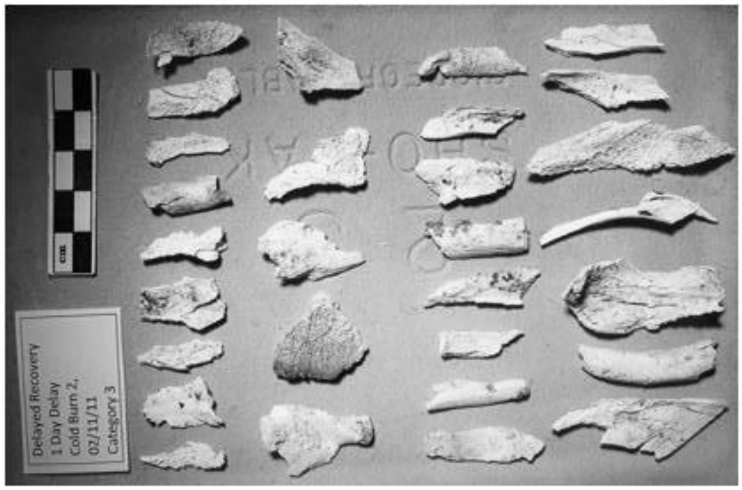

Delayed Recovery
1 Week Delay
Cold Burn, 13/03/11
Category 2
cm

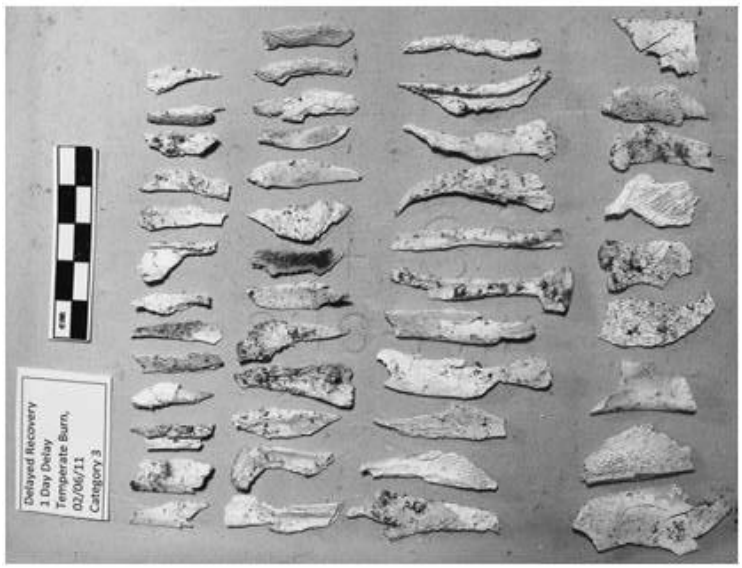
7.2.3 Category 3


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 3

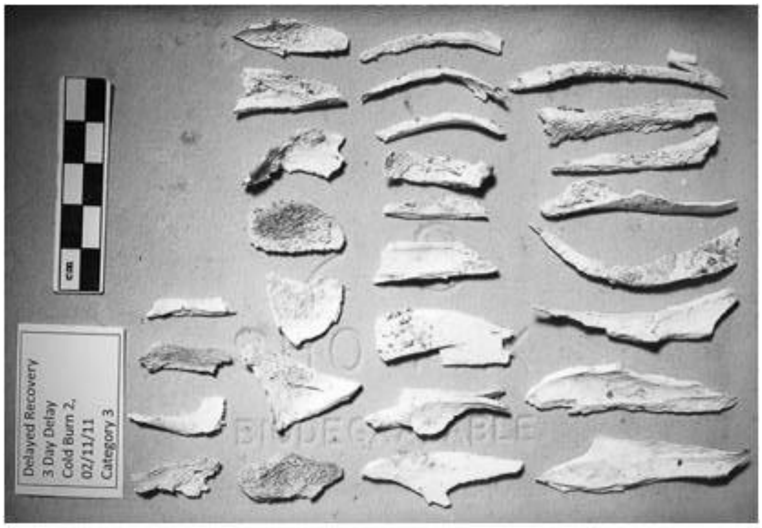

Older
Immediate Recovery
Temperate Burn,
02/06/11
Category 3

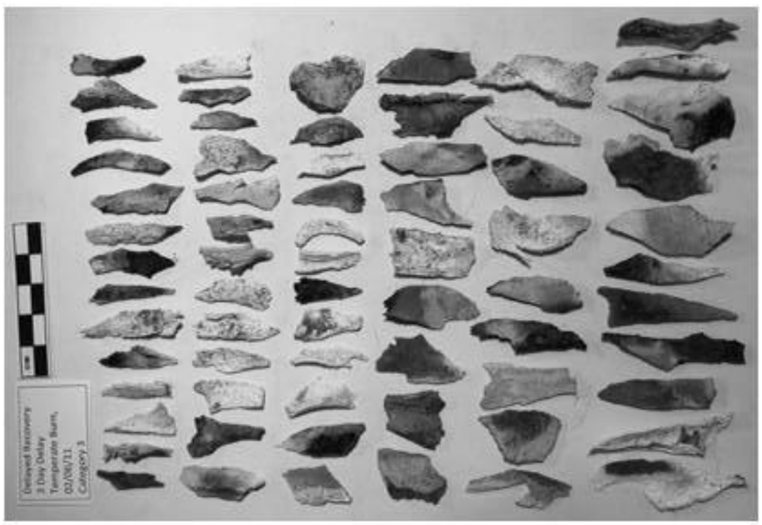

Older
Immediate Recovery
Cold Burn, 13/03/11
Category 3


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 3

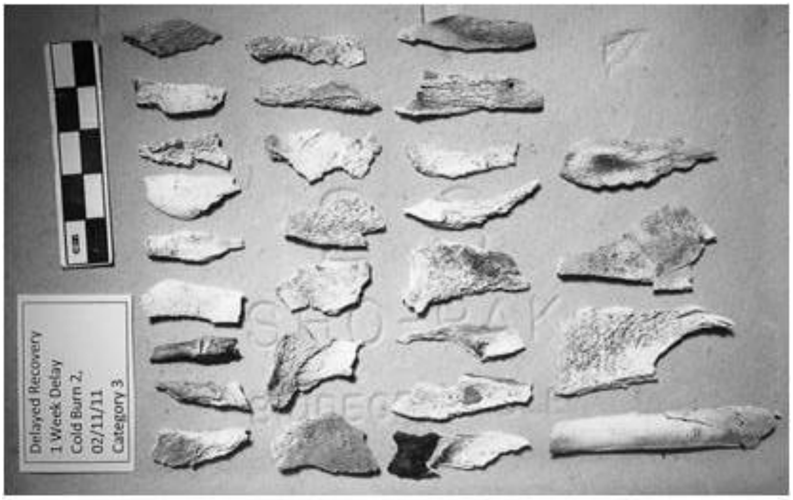

Delayed Recovery
1 Day Delay
Temperate Burn,
02/06/11
Category 3


Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 3

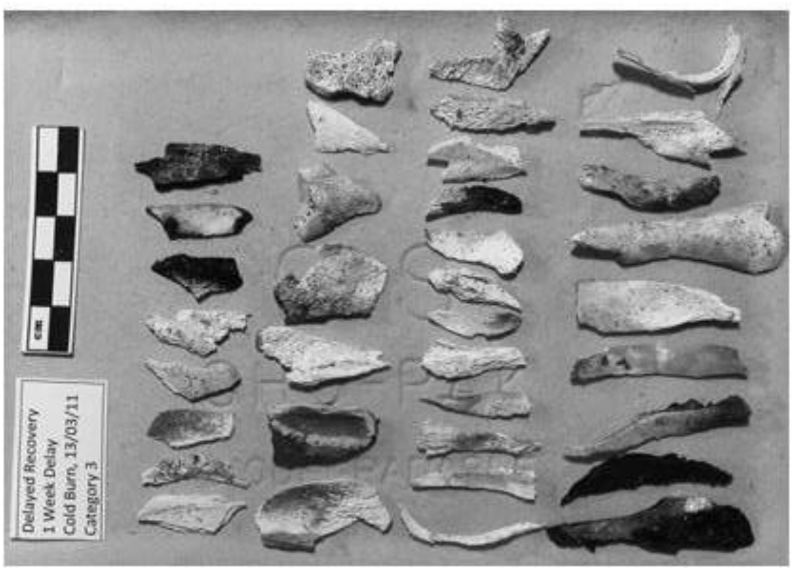

Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 3


Delayed Recovery
3 Day Delay
Temperate Burn,
Category 3

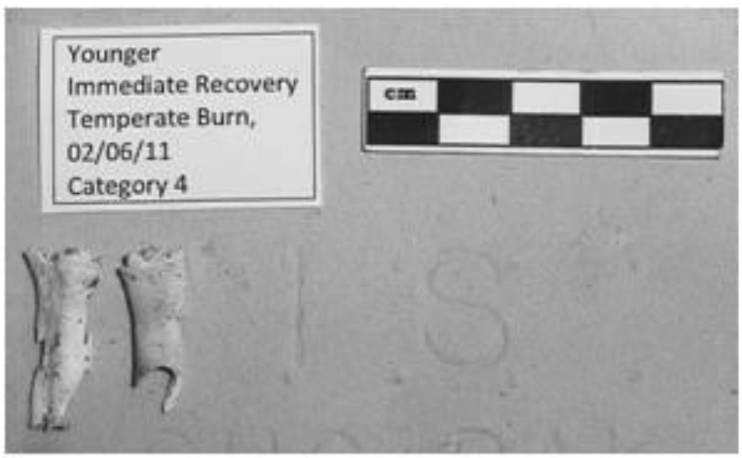

Delayed Recovery
3 Day Delay
Cold Burn, 11/03/11
Category 3


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 3


Delayed Recovery
1 Week Delay
Temperate Burn,
Category 2

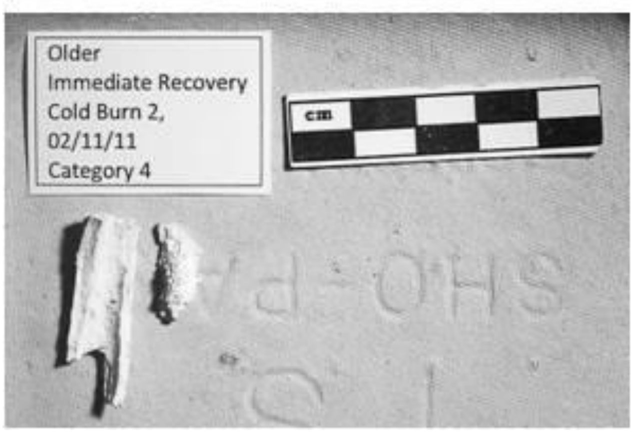

Delayed Recovery
1 Week Delay
Cold Burn, 13/03/11
Category 3

7.2.4 Category 4



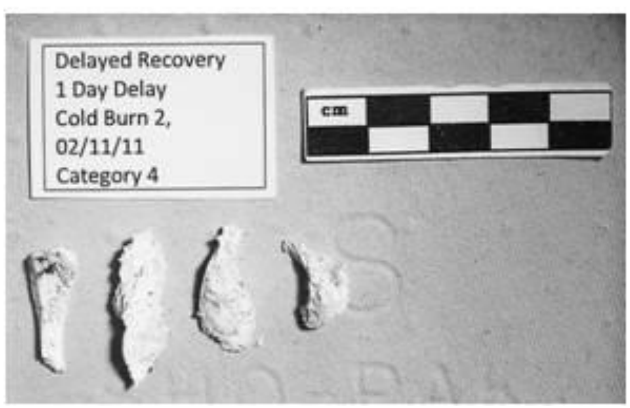

Older
Immediate Recovery
Cold Burn, 13/03/11
Category 4
cm


Older
Immediate Recovery
Temperate Burn,
02/06/11
Category 4
cm


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 4
cm


Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 4
cm


Delayed Recovery
1 Day Delay
Temperate Burn,
02/06/11
Category 4
cm


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 4
cm

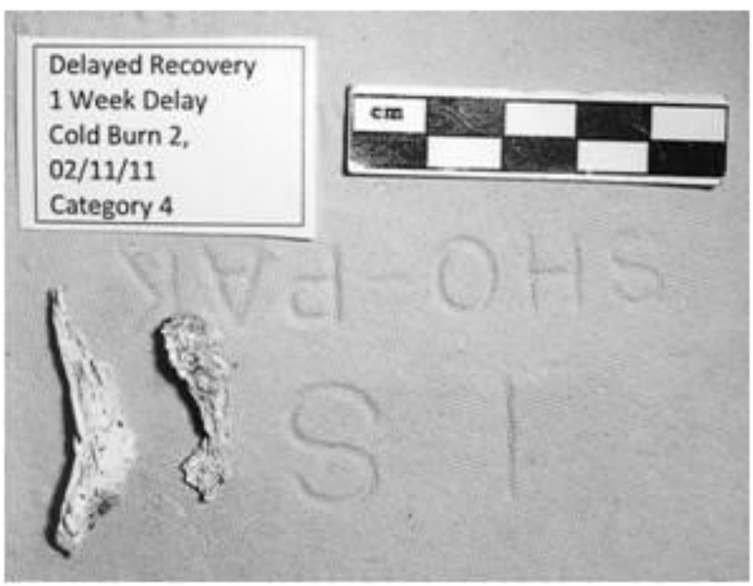

Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 4
cm


Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 4
cm


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 4
cm


Delayed Recovery
1 Week Delay
Cold Burn, 13/03/11
Category 4
cm


Delayed Recovery
1 Week Delay
Temperate Burn,
02/06/11
Category 4
cm


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 4
cm

7.2.5 Category 5


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 5


Older
Immediate Recovery
Temperate Burn,
02/06/11
Category 5


Older
Immediate Recovery
Cold Burn, 13/03/11
Category 5


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 5


Delayed Recovery
1 Day Delay
Temperate Burn,
02/06/11
Category 5


Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 5


Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 5


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 5
cm


Delayed Recovery
1 Week Delay
Temperate Burn,
02/06/11
Category 5

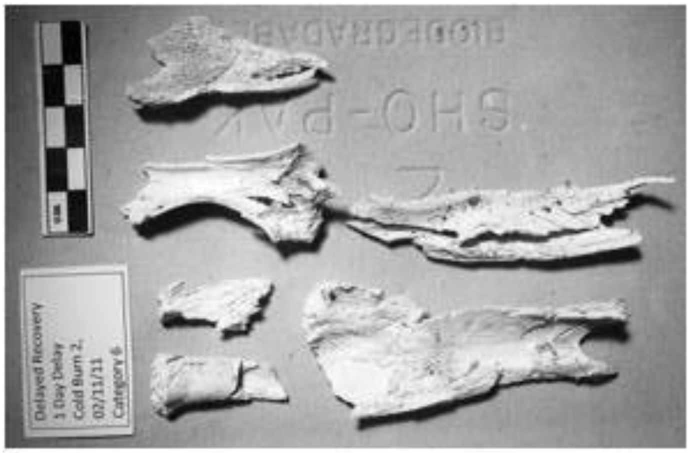

Delayed Recovery
1 Week Delay
Cold Burn, 13/03/11
Category 5

7.2.6 Category 6


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 6
GRADABLE
SHO-PAK


Older
Immediate Recovery
Temperate Burn,
02/06/11
Category 6


Older
Immediate Recovery
Cold Burn, 11/01/11
Category 6


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 6


Delayed Recovery
1 Day Delay
Temperate Burn,
02/06/11
Category 6


Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 6


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 6
Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 6
Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 6


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 6
BIODEGRADABLE


Delayed Recovery
1 Week Delay
Temperate Burn,


Delayed Recovery
1 Week Delay
Cold Burn, 13/03/11
Category 6

7.2.7 Category 7


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 7

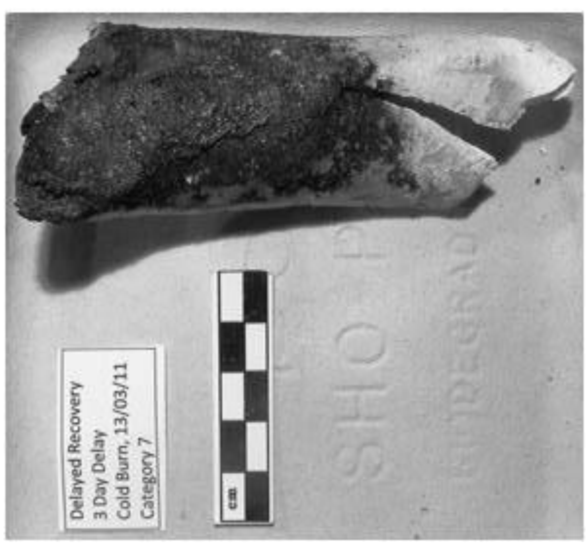

Older
Immediate Recovery
Temperate Burn,
02/06/11
Category 7


Older
Category 7


Delayed Recovery
1 Day Delay
Temperate Burn,
02/06/11
Category 7


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 7
cm


Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 7
cm


Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 7
cm


Delayed Recovery
1 Week Delay
Burn 2,
02/11/11
Category 7
cm


Delayed Recovery
1 Week Delay
Temperate Burn,
02/06/11
Category 7
cm


Delayed Recovery
1 Week Delay
Cold Burn, 13/03/11
Category 7
cm

7.2.8 Category 8


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 8
cm

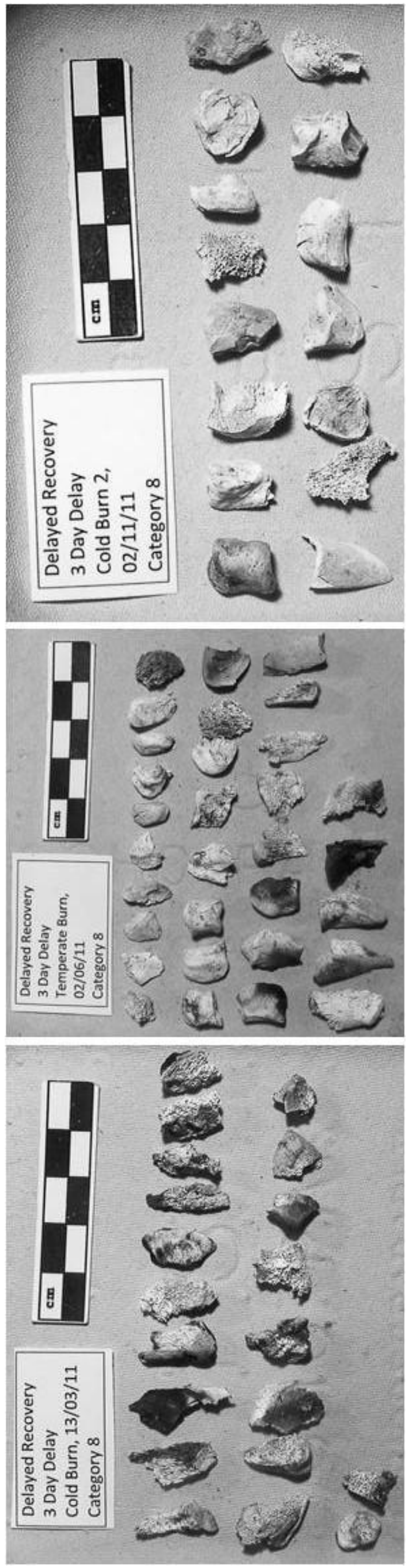

Older
Immediate Recovery
Temperate Burn,
02/06/11
Category 8


Older
Immediate Recovery
Cold Burn, 13/03/11
Category 8
cm


cm
Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 8


cm
Delayed Recovery
1 Day Delay
Temperate Burn,
Category 8


cm
Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 8


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 8
cm
Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 8
cm
Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 8
cm


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 8
cm


Delayed Recovery
1 Week Delay
Temperate Burn,
02/06/11
Category 8
cm


Delayed Recovery
1 Week Delay
Cold Burn, 13/03/11
Category 8
cm

7.2.9 Category 9


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 3


Older
Immediate Recovery
Cold Burn, 13/03/11
Category 3


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 9


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 9


Delayed Recovery
1 Day Delay
Cold Burn, 13/03/11
Category 9


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 9

7.2.10 Category 10


Older
Immediate Recovery
Cold Burn 2,
02/11/11
Category 10


Older
Immediate Recovery
Cold Burn, 13/03/11
Category 10


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 10
cm


Delayed Recovery
1 Day Delay
Temperate Burn,
Category 10


Delayed Recovery
1 Day Delay
Category 10


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 10


Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 10


Delayed Recovery
3 Day Delay
Cold Burn, 13/03/11
Category 10


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 10


Delayed Recovery
1 Week Delay
Temperate Burn,
02/06/11
Category 10


Delayed Recovery
1 Week Delay
Cold Burn, 11/03/11
Category 10

7.2.11 Category 11


Delayed Recovery
1 Day Delay
Cold Burn 2,
02/11/11
Category 11


Delayed Recovery
1 Day Delay
Temperate Burn,
Category 11


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 11


Delayed Recovery
3 Day Delay
Temperate Burn,
02/06/11
Category 11


Delayed Recovery
3 Day Delay
Category 11


Units: 17-40
Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 11


Delayed Recovery
1 Week Delay
Temperate Burn,
Category 11


Delayed Recovery
1 Week Delay
Category 11

7.2.12 Category 12


Delayed Recovery
3 Day Delay
Cold Burn 2,
02/11/11
Category 12


Delayed Recovery
3 Day Delay


Delayed Recovery
1 Week Delay
Cold Burn 2,
02/11/11
Category 12