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Burn Baby Burn: an Experiment in Archaeological Site Formation through Fire

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Burn Baby Burn: an Experiment in Archaeological Site Formation through Fire

by

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Abstract

The study of fire and how it affects archaeological sites has been a topic of interest for some time. Unfortunately, data retrieved from burned sites comes with little or no data regarding the site before it was burned over, particularly the pre and post-burn location of artifacts. This thesis presents an experiment where test plots of replica artifacts were burned in prescribed fires on the Sherburne National Wildlife Refuge. In an attempt to measure fire as a site formation process in prairie grassland and oak woodland, this experiment helps establish baseline data for the two common habitats in Minnesota and how fire may affect sites on the surface of the ground within them.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Fire is a ubiquitous phenomenon for all of human existence. It has been used as an effective tool and has acted as a mighty destructive force. In the world of land management fire still retains these roles. Land managers are tasked with protecting the places they are stewards of from wildfires and in some cases part of that protection involves burning land intentionally to reduce potential disaster of future wildfires. Both the suppression of wildfires and the process of prescribed burning have implications for archaeology. This thesis describes an experiment that was conducted to measure the effects of the latter on archaeological resources in common habitats in central Minnesota, oak woodland and prairie grassland.

The experiment examines physical characteristics and three dimensional locations of replica artifacts left on the surface of the ground before and after they were burned in prescribed burns performed on the Sherburne National Wildlife Refuge in Zimmerman, Minnesota. The goal of the research was to observe whether prescribed burning could have measurable permanent effects on various classes of artifacts that are commonly found in Minnesota. The results of the experiment suggest that in the habitats tested, prescribed burning may not damage sites or affect their integrity to a point where the sites can no longer yield important data.

Chapter 2: Background

Cultural Context

This cultural context serves to highlight major cultural periods in Minnesota and some of the resources people in the past would have had access to while living in the Pre-contact past. The major divisions of these cultural periods are knows as the Paleoindian, Archaic, Woodland, and Oneota periods (Gibbon 2012). This cultural context will briefly cover the diagnostic technologies of each period and will serve as a basis for why the artifact types used in the experiment were chosen.

The first people of Minnesota were known as the Paleoindian and they were in the state from 11,200 BC-7500 BC. Gibbon (2012) makes a distinction between early and late Paleoindian starting in 10,500 BC. The artifact type most commonly attributed to the Paleoindian period is large lanceolate spearpoints. Early Paleioindian points had a large flake down the center of the point known as a flute, and the abandonment of this fluting and the appearance of stemmed points and other tools such as adzes and scrapers are noted as the transition from early to late Paleoindian (Gibbon 2012:49). Paleoindians' hunter-gatherer lifestyle led them to be fairly mobile within their territory. As temperatures rose and the glaciers retreated, the state became covered in a mixture of coniferous and deciduous trees as well as forest grasses. This plant population allowed for animals like mastodons and giant beavers to thrive offering Paleoindians a large amount of faunal food sources. While there were mastodon, bison, and giant beaver available, Minnesota was likely home to deer, rabbit, porcupine, bear, weasel, and many other animals similar to the modern ones we observe today (Gibbon 2012). These available resources suggest that people during this time would have had access to animal hides, bones, and antlers to make tools.

The period after the Paleoindian was known as the Archaic. Like the Paleoindian period, the Archaic can be divided into sub-periods. The Early Archaic dates from around 8,000 BC-5000 BC and is defined by tools such as stemmed and notched spear points. The Middle Archaic dates from 5000BC-1500BC Additional tool types associated with this period are increasingly smaller than Paleoindian points and some had edges that appear to be multifunctional as cutting tools as well as for penetration (Gibbon 2012:74). These points were also small enough to be hafted to atlatl darts rather than thrusting spear shafts. The evidence for atlatl use comes from artifacts that have been identified as atlatl weights or bannerstones which have been associated with middle and Late Archaic technology (Gibbon 2012:74). The Late Archaic occurred form approximately 3000BC-500BC and during this time, two significant tool technologies were used. These artifacts were ground stone tools and copper. Ground stone is a term used in an attempt to classify a wide range of tools and materials. Essentially, a ground stone tool is a stone tool that was created by pecking, grinding, and polishing a stone to a desired shape. Common ground stone tools found in Minnesota include grooved mauls and axes. While the material used to create a ground stone tool may vary, the materials that have been used share a common trait. These stones are tough granular rocks that are not suitable for making tools through the process of flintknapping. Morrow (2016) gives examples of granite or sandstone as suitable stone types but also notes that glacial till contains a vast amount of stone types that are suitable as well..

Ground stone tools have both advantages and disadvantages when compared to chipped stone tools. The first easily recognizable disadvantage to ground stone tools is the time it takes to manufacture one. Morrow (2016) writes that if a person were to make an adze from both chipped stone and ground stone, the chipped adze could be made in less than an hour while the ground stone adze may take up to twelve hours or more. One marked advantage to the ground stone tool however is that it is made of a much tougher material and will likely last longer than its chipped stone equivalent (Morrow 2016).

Copper tools of the Archaic tradition began appearing circa 4,000 BC (Pleger 2016). The people who used and manufactured these copper artifacts became known as the Old Copper Culture. While they are known as Old copper Culture it is important to note that they also used stone and bone technology to create items for personal use and trading. The copper used to create these tools came from the Lake Superior Basin which was almost pure copper and was essentially ready to work raw from the ground. From this copper, these people produced, "spear points, knives, awls, harpoons, fishhooks, axes, chisels, celts and needles. Additionally, copper ornaments have also been recovered from this region including beads, bangles and bracelets" (Pleger 2016). Recognizing Old Copper Culture sites is important because they are the first metal-workers in North American and they developed an intricate trade system that made connections from the Great Lakes region to places all across the present day United States (Pleger 2016).

The last cultural period this context will cover is the Woodland period which dates from circa 1,000 BC-700AD. One of the most important distinctions between the Archaic and Woodland traditions is the introduction of pottery production and burial mounds. In Minnesota there are distinctive types of pottery that allow archaeologists to identify specific cultural groups and observe cultural interaction. Like the Archaic, the Woodland Tradition is divided into three sub-periods; Early, Middle, and Late. Another addition to the technology of the woodland Tradition is the bow and arrow which appears around 500 AD (Morrow 2016:122) People of the Woodland Period lived near lakes and rivers and used them for transportation and as a means for acquiring food. One of the most important resources for food at the time was wild rice. The invention of pottery allowed for the rice to be parched and stored for later use. Other food resources included deer and fish (Gibbon 2012). This cultural context is a brief overview of technology and materials available to people in the past in Minnesota. These materials and technology assisted in the selection of materials for the following experiment.

Literature Review and Theory

This project will explore a middle range theory perspective of archaeological site formation through fire. We can recognize fire as a factor in both cultural and natural site formation. In his doctoral dissertation, Michael Schiffer (1973) explained site formation processes and how they can be broken into two categories. These two categories are cultural and natural processes and Schiffer refers to them as c-transforms and n-transforms respectively. First n-transforms will be explored. N-transforms are the changes in site and artifact morphology that occur outside of human interaction. Schiffer mentions wind, water, bioturbation, and chemical reactions as sources for these changes. Wind can transport soil and other light materials to cover up sites, water can also transport soils or artifacts. Bioturbation refers to the disturbance of soils by living organisms, commonly, rodents on archaeological sites which can move artifacts or mix the stratigraphic profile of the soil. Lastly, chemical reactions are mentioned and the specific example Schiffer gives is how bones can have increased rate of degradation in acidic soils (Schiffer 1973:28). C-transforms are more complex than n-transforms because they can be associated with any change caused by human interaction. Schiffer presents stages of interaction with artifacts that can be considered c-transforms, these stages are: procurement, manufacture, replacement, use, discard, transport, and storage (Schiffer 1973:98). Fire cannot be placed in either category exclusively due to it being a naturally occurring phenomenon and a cultural practice such as heat treating stone, cooking meat, firing pottery, or modifying entire landscapes which is discussed later.

Schiffer (1983) writes of three major ways site formation processes can affect sites and the potential these processes have can provide an avenue for more complete hypotheses about the site. The three sections Schiffer divides the processes into and how they affect the artifacts are: simple properties of artifacts, complex properties of artifacts, and other properties of the deposits. Simple properties of artifacts Schiffer mentions are things like size, orientation, damage, patina, and accretions. The complex properties of artifacts include: vertical and horizontal distribution, artifact diversity, and measures of disorganization. Other properties of deposits include properties of the environment such as sediment, ecofacts, geochemistry, and site morphology such as slope. Schiffer also proposes strategies to analyze formation processes. Those strategies are: hypothesis testing, multivariate analysis, and use of published data to evaluate formation processes (Schiffer 1983).

In this experiment, the strategy of hypothesis testing is used in an attempt to observe changes on the simple and complex properties of artifacts in an active formation process. Schiffer (1983) stresses the importance of site formation analysis and that it should be conducted when possible because as he writes, “unless the genesis of deposits is understood, one cannot infer the behaviors of interest from artifact patterns in those deposits” (Schiffer 1983: 675). While the research presented in this thesis is not an exhaustive experiment in all potential forms of formation processes it simulates a process that has been recognized both as a natural phenomenon and a culturally induced environmental change. The following experiment examines fire’s effects on cultural resources on multiple levels. The first being what could happen when land managers are conducting prescribed burns, the second being what could have happened to the artifacts when Native Americans intentionally burned. Though these situations seem parallel to each other, the former is part of managing the archaeological record while the latter occurred during the creation of the archaeological record. There is similarity however in the fact that in both instances, a naturally occurring phenomenon is being used as a cultural site formation process.

The difficulty in studying sites that have been impacted by fire is not having data from the site before it was exposed to observe the formation of evidence. The objective of this project is to help generate data that will help reduce the need for pre-burn data because it seeks to establish baseline data that can be compared against newly identified archaeological sites. While it may not answer all of our questions about the effects of fire in the past, it should give us a place to start.

Wildfire effects on cultural resources have been a major area of study for land managers (CAL FIRE Archaeology program 2012; Deal et al. 2012). Federal agencies have cooperated with researchers in experiments as well as in conjunction with management strategies (Johnson 2003; Ryan *et al* 2012). The categories of effects on cultural resources are: direct effects, indirect effects, and operational/suppression effects (Gassaway 2011). *Direct effects* are effects associated with the fire itself due to heat exposure. *Indirect effects* are effects caused by loss of vegetation and soil cohesion due to fire, and *operational effects* are effects caused by the attempts to contain fire. Direct effects that are commonly seen on artifacts are the adherence of combustive residue, destruction of lithic materials such as potlidding, spalling, or cracking, melting of metal artifacts (Buenger 2003; Deal *et al* 2012; Sturdevant *et al*. 2013), contamination of radiometric dating, and color change (lithics) (Gassaway 2009). Indirect effects can include increased erosion and looting. The increased erosion can affect primary context of artifacts if they are displaced with soil movement. Looting also is a threat posed after a burn because artifacts on or near the surface are much more visible (Gassaway 2011; Keller 2016). Operational effects can occur during construction of the fireline, using heavy equipment, or employing suppression tactics. Constructing the fireline involves digging a line around the fire down to mineral soils, this can cause site disturbance particularly for artifacts on or near the surface of the ground. Heavy equipment such as a bulldozer is sometimes used to clear debris or assist in digging the line. When firefighters intentionally light fire to decrease potential burn area this has the potential to expose more artifacts and also inadvertently exposes them to direct and indirect effects. Other suppression tactics like water drops from aircraft can also move surface artifacts or move loose dirt disturbing site context (Gassaway 2011).

Johnson (2003) explains how wildfire effects can be observed and used by archaeologists to understand it as part of the site formation process. He also says many archaeologists in the past do not consider fire during their survey and excavations. “Responsible archaeology demands observational evidence as tests for theories about the past and informative observation requires theories that describe the formation of the evidence” (Kosso 1991:626). Without considering fire in the past, archaeologists leave out a potentially significant formation process that could influence site interpretation. Johnson observed effects of a 20,000 acre fire in Northern Utah and describes direct effects such as charring or disintegrating, as well as indirect effects such as post-burn erosion that can affect site formation through artifact displacement. The area of Johnson’s study was in a mostly desert area so while the habitat is not analogous to Minnesota, the effects outlined in his article are important to consider. (Johnson 2003).

Deal *et al.* (2012) wrote a technical report for the USDA outlining the effects of wildfire on cultural resources. This technical report covers several avenues of artifact classes and how they can be affected by fire. Deal writes that most fire effects on cultural resources have been studied after a fire without any pre-burn data available; this makes it difficult for archaeologists to quantify how much the fire affected them. This is especially important because the study I am proposing may help fill in some of those research gaps. The study of how wildfire affects cultural resources is not a new concept, but establishing baseline data for regions across the country can help resource managers anticipate effects from a generally unpredictable force.

Ryan *et al* (2012) also write about fire's effects on archaeological sites and how it can be viewed as a site formation process. Artifact classes that are mentioned in the report are: chert, ceramics, obsidian, groundstone and architectural stone, bone, and botanical remains. A section specific to site formation is written in the portion about groundstone and architectural stone. In this section is the summary of an experiment conducted in partnership with the Center for Environmental Archaeology and Texas A&M University where archaeologists created simulated subsurface features made from rocks and what they referred to as pseudo artifacts. These features were placed around different sized ponderosa pine trees. After fire burned through the area and these trees had burned away these features fell into the hole left behind and changed the structure of the feature as deep as 40 centimeters. The archaeologists recognized that the physical structure of the feature deteriorated and reestablished itself but information could still be retained at a site. After mentioning some effects on the other types of artifacts, the issue of radiometric dating is mentioned. The authors write that mixing of modern carbon from the burn and archaeological charcoal could give false age dates in radiocarbon testing. In their study of the Long Mesa Fire in Colorado, radiocarbon dates of sites within the burn area dated to 1910 AD which to the investigators seemed too young. They did not have access to control samples from previous investigations to verify their radiocarbon tests so they had to use alternative methods to date the site. Another portion of their study was to try to determine if subsurface sites are protected from fire to the degree that is assumed (Ryan *et al* 2012).

The authors write that the results of previous post fire studies suggests that sites deeper than 10 centimeters are generally protected and effects are rarely observed deeper unless fire catches in a tree's root system and burns underground. The results of their studies appeared to be consistent with the other studies by observing effects within the first 10-15 centimeters of the sites they studied. This is different form surface sites where they describe the potential effects ranging from "negligible to extreme" (Ryan *et al* 2012: 155). Another problem the authors state is that due to modern firefighting suppression there has been increased accumulation in fuel loads in modern areas. The suppression of wildfires stops the available fuel from burning and new growth creates additional fuel available for the next fire. This increases the chances for fires to do considerable damage to the archaeological record. The authors urge resource managers and archaeologists to consider these factors because, "Understanding the role of fire as a site formation process is essential for every cultural resources specialist working in landscapes that have been touched by fire" (Ryan *et al* 2012: 156). An examination of fire history on the area archaeologists work in could affect site interpretations

While it is pretty easy to see how wildfire affects sites in a negative way; some effects are actually helpful to archaeologists. In some cases, fire can be used to locate archaeological sites and help make new discoveries. One example is the work from Doug Scott at the Little Bighorn Battlefield. A large portion of the site had been hidden in the thick grass cover. After a wildfire had burned the area in 1983 a multitude of artifacts were revealed. The newly exposed artifacts allowed for new interpretations of how the battle commenced and where people's remains were located on the battlefield (Scott 2014). Another study in Montana was performed by Josh Chase

(Keller 2016) working for the Bureau of Land Management. Chase was trying to find a way to study how Native Americans used the plains in the area. Chase decided to perform a prescribed burn on the grassland to see what could be uncovered. Before the burn could be done, Chase decided to conduct an experiment on mock sites to see if artifacts they expected to find (bison bones in particular) could survive a wildfire. The experiments involved creating mock sites in a test area and lighting the space on fire. Chase worked with a crew to place mock stone and bone artifacts in the test plots. After the burn was over he found that the artifacts were unharmed. This was attributed to the fast moving nature of grassland fires; they produce intense heat but the duration is relatively short (Keller 2016).

After the test burn was completed, Chase lit 600 acres of grassland. After the prescribed burn, he discovered more than he had anticipated (Keller 2016). Chase found evidence of bison corrals and vision quest sites in the form of stone circles. These sites were covered in vegetation for hundreds of years and without the burn, it is unlikely that they would have been found. Chase was able to make these discoveries because the artifacts he was working with were not susceptible to the effects of fire (Keller 2016). This instance shows that fire is an effective tool to help find sites in grasslands when stone artifacts are in the equation. However, habitats across the country with heavier fuel models and longer burning fuels might cause damage to artifacts. One such region that has different fuel models and fuel loads is the Midwest. *Fuel model* is a term used in Anderson (1982) as a way to estimate potential fire behavior such as the rate that the fire could spread. This is done by determining the *fuel load* which is the amount of consumable fuel within a given area. This allows firefighters to consider risks of prescribed burns as well as resources that may be necessary to contain a fire.

Another factor that plays into cultural resources being affected by fire is when fires historically were set intentionally. Thomas Vale (2002) wrote about recognizing pristine and humanized environments and how fire regimes and their frequency could provide evidence of both human influenced and natural environments. Vale writes that one way to gauge whether or not a landscape is pristine or humanized is to evaluate whether a landscape's characteristics such as vegetation, wildlife, or landforms would be retained whether or not humans were within the landscape (Vale 2002:5). Vale presents three "gradients of impact" which are modification intensity, spatial extent, and temporal persistence (Vale 2002:30). Vale writes that the latter two, spatial extent and temporal persistence of fires in North American habitats allow for Native American set fires to be one of the more significant effects of humans modifying their environment. To understand to what extent depends on the landscape and the available fuels. Vale (2002) writes that the interval for fire availability can be as little as one growing season in grasslands while some heavier forests could take hundreds of years before they are burned. In the Western United states, factors such as drought, types of vegetation, and lightning strikes were natural contributions to the fire cycle and remain so today. Vale (2002: figure 1.8) shows that the pre-European fire regimes for the grasslands suggest that both natural and anthropogenic fires would have been frequent on the ground surface.

This cyclical burning, whether natural or cultural, can be viewed in one particular environment in Minnesota, the oak savanna. Leach *et al* (1988) wrote about how historic savannas can be identified and gives suggestions on restoration. How oak savannas were created and maintained gives additional evidence that anthropogenic burning may have been taking place. Oak savannas are dependent on fire to exist. The cycle of fires burning through the savanna kills vegetation that would act as competition to the oak trees but allows for the prairie grasses to regenerate. Oak trees are resistant to fire, so the periodic burning of their environment is actually helpful rather than a hindrance due to competing plants being burned away (Leach 1988).

Cuthrell *et al* (2013) studied an area in Southwestern California that showed evidence of anthropogenic burning to maintain a grassland habitat. This allowed for humans to exercise some control over the faunal resources by strategically modifying the landscape to manage food sources. Omer Stewart wrote several papers that were compiled by Lewis and Anderson (2009) about how Native Americans used fire to modify the landscape to their advantage when it came to plants and animal habitats. One interesting use of fire by Native Americans was to drive out or direct game. Stewart suggests that this practice must have some roots in hunter-gatherer societies further in the past. Baker (2002) used a few different types of evidence to study whether or not Native Americans in the past burned landscapes intentionally and whether it had significant impact on their environment. The first line of evidence was through oral history. The stories told in journals of European settlers suggested that the Native Americans lit the fires to improve availability for their horses to graze or improve hunting grounds. Baker (2002) also mentions that not all of the accounts can be believed as settler bias and not actually witnessing the ignition in many cases may suggest that it was less frequent than it was attributed. Another line of evidence used to study Native American use of fire was the increase of charcoal associated with pollen from plants that indicated human presence (Baker 2002: 66). One area of Colorado experienced an increase in charcoal during what has been evaluated to be a wetter period that wouldn't have provided favorable conditions for naturally occurring fires. This spike in charcoal could suggest that Native Americans were igniting the fires instead (Baker 2002: 67). Baker (2002) concludes with suggesting that populations of the Rocky Mountains were likely too small to have had much impact on the fire regimes in the area and it is more likely that changing climate, drought conditions, and lightning are more responsible for landscape burning.

Another factor that changed how fires interacted with their environments was the practice of firefighting. The first wildland firefighters were established in 1886 when the US cavalry assumed command of Yellowstone National Park (National Parks Service 2017). From this point onward, increased suppression efforts increased fuel loads in some of these areas. Succesional habitats such as woodland taking over grassland would have been slowed down or stopped by regular wildfire in their natural progression and thus fire suppression increased the fuel loads in some of these areas. Increase in fuel load allows for increased fire behavior when a fire ends up igniting (Anderson 1982). This also builds a case for why archaeologists need to recognize signs of fire and what artifact changes have occurred to identify previous burn areas. There seems to be a lack of literature examining fire as a part of archaeological site formation processes and instead it tends to lean towards viewing fire's effects on artifacts (Deal *et al* 2012; Johnson 2003). If land managers are implementing management strategies based around future fires without recognizing evidence of fire effects from the past, they may unintentionally miss out on potential data about how sites have been formed.

One study that was used to observe fire's effects on artifacts was conducted in 2003 by Brent Buenger for his dissertation. Buenger wrote about the effects of wild and prescribed fire on artifacts and writes that fuel load, fire behavior, temperature, duration of heat exposure, artifact proximity to heat, and the type of artifact are the most important things to consider when examining the effects. Buenger offers thorough description of effects of fire on different materials from lithic materials like cherts and obsidian, metals, glass and ceramics. Buenger also writes about previous studies of the effects of prescribed burns on test sites and notes that the experiments offered incomplete data and methodology (Buenger 2003). None of the experiments mentioned in Buenger were performed in Minnesota.

Buenger performed both field and lab research to examine effects of fire on cultural resources. The field portion of the research included prescribed fire experiments which have since been conducted in similar fashion by Sturdevant *et al* (2013) described below. Experimental 2X2 meter plots of replica artifacts were placed in burn areas and observed for effects. The burned habitats were: mixed grass prairie, ponderosa pine, mixed conifer forest, riparian zone and sagebrush, and piñon-juniper. Buenger suggests that prescribed burning can be done without significantly damaging cultural resources if fuel loads are reduced and burning takes place away from important resources (Buenger 2003). However, if important sites are not known ahead of time, there is still a risk of losing important data.

Buenger (2003) also performed lab based experiments subjecting artifacts to increasing temperatures in a muffle furnace from 100° C to 1000° C. The results of this portion of the experiment suggested that bone artifacts begin to be affected at lower temperatures starting at 300° C and are significantly affected as temperatures increase. Obsidian flakes began to have visible changes after 300° C and began to crack more and more as temperatures rose. Cherts began to change color at 200° C and became more pronounced at higher temperatures. Other effects to chert included fracturing and spalling and even being destroyed in the final heat of 1000° C. This portion of the experiment is useful as it sets different thresholds for thermal alteration of common artifacts. What this part of the experiment does not account for is the variability of temperature in both wild and prescribed fire because temperatures are not likely to stay consistent throughout the duration of the burn. This study and Sturdevant *et al's* (2013) experiments will form the basis for my research design outlined below.

One challenge encountered when looking for literature was finding studies specific to Minnesota. I was able to locate one that seems to be incredibly useful. Jay Sturdevant (2013) conducted an experiment in the Midwest to see how artifacts were affected in prescribed burns in different national parks around the region. The method of testing was to use prescribed burns on replicated artifacts to view the changes that occur when artifacts are exposed to simulated wildfire. The states were Arkansas, Iowa, Kansas, Minnesota, and South Dakota. The only test area in Minnesota used by Sturdevant was Voyageur National Park in the far northern part of the state. In Minnesota, Sturdevant's study at Voyageur National Park is significant for several reasons. One area the burn was in was a pine stand that was approximately 200 years old. This fuel load caused the prescribed fires to burn for a longer time ranging from just over one hour to three hours (Sturdevant et al. 2013).

The artifacts tested by Sturdevant in Minnesota included: bone, ceramic, glass, leather, ferrous metal, brass, pewter, lead, copper, tin, and chipped and ground stone. All types of artifacts were affected in one way or another, ranging from superficial such as surface discoloration to a lead projectile starting to melt. This is likely related to differences in time and temperature of the burn as Buenger (2003) states these are the two most important factors when it comes to producing effects. Sturdevant had a good distribution of artifact classes to test. The only downside is that he was only able to test in a woodland setting with fairly heavy fuel loads. This makes sense because the area he tested in would be the most likely to produce damaging effects to artifacts but further baseline data can be established for the state of Minnesota if other habitats are tested.

This experiment tests other types of habitats in Minnesota. In their recommendations for future research, Sturdevant *et al* (2013) mention that there are many conditions in Midwestern wildfires that do not have significant impacts to archaeological sites because the artifacts were recoverable and recognizable. However, they do state that areas with heavier fuel loads have potential to degrade or destroy sites entirely referencing Voyageur National Park and a few others specifically because of the presence of 100 and 1000 hour fuels (Sturdevant et al. 2013). The *hour fuel* measurements are based on relative humidity and moisture absorbed in the fuel at a given time. The 100 and 1000 hour fuels are larger fuels that take more time to reach conditions that allow for burning. The hour designation for a fuel refers to approximately how long a fuel takes to adjust to wet or dry conditions based on diameter of the fuel. 1000 hour fuels have diameters of three to eight inches and do not burn easily. If these fuels do burn however, higher heat will be generated and an increase in fire behavior can be expected. Considering that the state of Minnesota has multiple biomes such as grassland, deciduous woodland, and coniferous forest with various respective fuel types, more research in these areas may be necessary to define what areas of the state have cultural resources that are at a higher risk of damage due to fire.

Studying how fire affects sites can help with interpretation of past behavior, as well as understanding what data may be lost. It is also important to highlight why experiments involving these effects can be valuable to the science of archaeology. Paardekooper (2008) writes that for an experiment in archaeology to be valuable it has to be possible to repeat the experiment. This allows for other researchers to attempt to replicate and potentially falsify or bolster the hypotheses of the original experiment. The experiment designed for this thesis fits this criterion. Paardekooper also writes, “During any stage in the experiment, one will find the need to improvise - and document these improvisations. Hardly ever does an experiment go exactly as planned” (Paardekooper 2008:1). This was true for this experiment because several adjustments had to be made to ensure the completion of the experiment. What follows is the explanation of how the experiment was set up and how through several adjustments it was completed.

Chapter 3: Methods

Research Design

The goal of this project was to establish baseline data for the effects of fire on artifacts consistent with Pre-Contact sites in Minnesota. There is literature from multiple agencies across the country about how wildfire affects cultural resources (Buenger 2003, Sturdevant *et al* 2013, CAL FIRE Archaeology Program 2012) as well as how fire assists in the location of unknown sites (Keller 2016)**.** However, there is still some more work that can be done in studying what happens to sites between people leaving the artifacts and archaeologists finding them.

Research Questions

How does wildfire in grassland and oak woodland habitats…

1. affect the color, texture, and morphology of chipped stone tools on the ground surface?
2. affect color, texture, and ability to recognize bones and antlers on the ground surface?
3. affect copper tools on the ground surface; could a wildfire melt them beyond recognition?
4. affect both hafted and unhafted groundstone tools on the ground surface?
5. affect the spatial position of replicated pre-contact tools and materials?
6. affect color, texture, and ability to recognize leather/hide on the ground surface?

The methods outlined below explain how the research questions will be addressed. First, replicated tools of various materials (chipped stone, ground stone, copper, bone, antler, and leather) were gathered and were placed in habitats commonly found in Minnesota. The habitats in which experiments were conducted were grassland and deciduous woodland. The intention was to have an additional habitat choice of oak savanna but weather and the available amount of burn days didn’t allow for a third experiment. The sites were to be set up the same in terms of number of artifacts, spatial distribution, and materials. The idea was to establish a control in the experiment and allow for the environment in which they are placed to be the variable. All artifacts were to be placed on the surface of the ground because burying them would likely reduce the heat they are exposed to. Burying the artifacts also would not offer an accurate simulation of natural site formation processes such as soil accumulation over time or bioturbation. It would also be difficult to ensure that the buried artifacts were at the same depth. Another limitation was access to multiple temperature measuring devices. The data logger set only had one thermocouple probe so the decision was made to measure the air temperature in a prescribed fire. Without the ability to measure the temperature of the soil as well there would be no way of knowing what temperatures buried artifacts were exposed to. With this in mind, my experiment simulated a fire burning over a site as if it was currently in use or sites that haven't had enough soil formation to be covered yet. The experiment could also simulate a site that has been recently exposed on the surface of the ground. The sequence of the experiment took place in three major steps: pre-burn, active burn, and post burn analysis. The hypotheses for the experiment and the explanation of how each step was performed are described below.

Expected Outcomes (Hypotheses)

1. The Knife River Flint in the woodland setting is expected to show signs of heat damage in the form of cracking or potlidding. In the grassland setting there should be little to no observable damage but a heavier buildup of char residue.
2. Unhafted ground stone artifact in the woodland setting will suffer surface discoloration, and possible heat spalling due to them being collected on a shoreline and that they may have residual water retained in small cracks or pores in the rock. On the hafted stone axe it is expected that more surface damage underneath the hafted portion where the pitch glue and haft make contact with the stone will be observed. This is expected because this

would concentrate flammable material right onto the surface of the stone which is expected to in turn concentrate more heat in those areas. In the grassland setting, while the artifacts may experience high temperatures, it is not predicted that the duration of the burn will be enough to cause surface damage to the unhafted stone. The hafted stone may have a higher chance of damage for the same reason as the woodland setting if the pitch glue and handle are able to catch on fire.

3. The copper in the woodland setting is expected to show signs of color change and possible deformity. This will depend on factors such as duration of heat exposure and overall intensity of the fire as Buenger (2003) suggested. In the grassland setting, no damage is expected and it is also hypothesized the pieces will be able to be cleaned to their original state in the laboratory portion of the experiment after the burns.
4. The bones and antler pieces in both settings are predicted to experience permanent color change. It is not expected to observe any cracking or splitting in either setting because of what is written in Perez *et al* (2017). Perez writes that in their experiment with burning animal bones, that fresh bones experienced a high degree of cracking and other structural damage while dry bones only experienced color changes. The bones provided for the experiment had been dermestid cleaned and then dried. The antlers are expected to experience color change as well. The antler pieces used were from sheds that had been found in the woods and stored inside for several years so they were expected to react similarly to the way dry bone would without cracking or splitting.
5. The elk hide is expected to be the only artifact that will be unrecoverable. Due to the oils used in tanning and the natural oils left in the skin, they may act as accelerants and completely destroy the hide or at the very least burn it beyond recognition.

Pre-Burn

Before each burn, the replicated tools were brought out to the area that was to be burned and placed on the surface in the arrangement depicted in the drawing below (Figure 1). All artifacts were grouped with like materials and each category of artifact was placed at least one meter from one another. Within each artifact group, the artifacts were laid out in a grid pattern and assigned a number. These groups were recorded on a GPS unit as well as mapped by using a total station for which we established a datum on site by pounding an 18-inch rebar stake into the ground. This established horizontal and vertical control for the replicated artifacts during the burns.

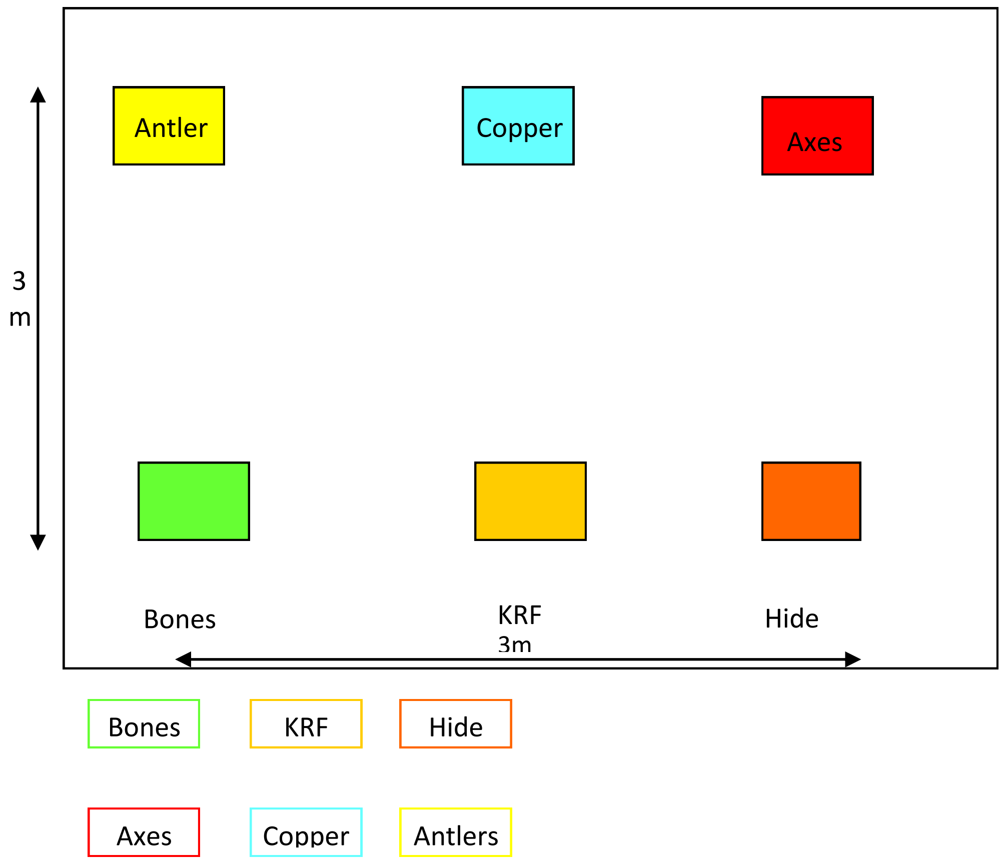

Figure 1. Map of intended locations of artifact replica placement pre-burn.

Chipped Stone Artifacts

To examine how stone artifacts react in a fire, I knapped 90 flakes of Knife River Flint to use in the experiment. Each site was assigned 30 flakes in anticipation of running experiments in three habitats. Each flake was measured for maximum length, width, thickness, and weight and recorded in an Excel spreadsheet. This ensured that I had multiple examples to examine after the fires to look for similarities in effects. This would also allow me to attempt to quantify the changes the flakes experienced from the burns. I chose to use Knife River Flint for this portion of the project because it is a common well known tool stone in the Midwest and archaeologists in this region may be interested in how it is affected by fire. These flakes were marked with a permanent marker and were placed label up on the ground for the burns. I used a Munsell color book to describe the color of the flakes in case there was change after the burns.

Ground Stone Artifacts

To test how ground stone artifacts may be affected by fire, I prepared two simulated ground stone tools (axes) per site tested (6 total). At each site, One of these was hafted on a wood handle with pitch glue and the other was left unhafted. The stones selected were from the shore of Lake Superior and they were chosen for their size and shape being similar to examples of stone celts. Each stone was measured for maximum length, width, thickness, and weight. The axes in their respective plots were intended to be as close to the same size as possible. The intention of this was to test to see how ground stone tools change after going through a fire. I chose to have one hafted and one unhafted example to see if the haft protects the stone surface where it covers, or if it concentrates more heat on that area of the stone. These simulated axes were marked with a permanent marker and were placed label up during the burns. To check for color change, I recorded the color of each stone using a Munsell color book to define colors before and after the burns.

Copper Artifacts

To examine the effects of fire on copper artifacts, I cut 15 flat rectangular pieces out of a piece of copper tubing per site (45 total). Copper tubing was chosen because I was unable to procure native copper for the experiment. I also chose the copper tubing because the material was uniform and it provided the most likely avenue for consistency for this artifact class. The pieces were made to be as close to the same size as possible. Each piece was individually measured for maximum length, width, thickness, and weight to establish a baseline for determining if any material is lost or deformed in the fires. The reason I chose to use copper in this experiment is because I was unable to find any experiments in addition to Sturdevant *et al*. (2013) where copper was tested. Sturdevant *et al* (2013:68) also mentions copper as one of the artifact types most susceptible to damage from a wildfire. Copper melts at approximately 1,084° C. I anticipated that this temperature would be difficult if not impossible to achieve in a prescribed burn where the goal is to maintain as much control as possible. In a large wildfire, that level of temperature is possible, but specific conditions of fuel types, terrain, and other environmental factors would have to be met to achieve such a temperature (Gabbert 2011). All copper pieces were stamped with a number punch to keep track of the pieces. The pieces were placed number side up for the burns.

Bone/Antler Artifacts

For each site I used two pieces of antler and two leg bones from whitetail deer were also used (4 bones and 4 antler pieces total). The antlers and bones were measured for maximum length, width, thickness and weight. The goal was not to establish a statistical model for antler and bone burning but to see what kinds of changes may occur in a fire. Such changes could include metric, morphological, and superficial alteration. To test color change, I used a Munsell color book to describe color before and after the burn. Each bone and antler has been marked with a permanent marker and was placed with the label facing upwards for the burns.

Leather

To test for what may happen to leather or other skins in a fire, approximately one square foot of tanned elk skin was placed at each site. Elk skin was chosen because it is what I had immediate access to, it was also chosen because it is slightly thicker than whitetail deer skin so if it was completely destroyed it could be reasonably predicted that buckskin would have as well. The use of one piece of elk skin was chosen not to establish a statistical model but to see what physical changes may occur in a fire like the case with the bones or antlers. The pieces of hide had been marked with a permanent marker and were placed hair side up during the burns.

Ceramics

In an attempt to test as many types of replica artifacts as possible I looked for options on procuring samples of sherds of pottery that were analogous to Pre-Contact examples. All of the other artifact types had either been produced by myself or had known provenience. To the best of the researcher's knowledge none of them had been burned previously. Keeping this in mind I researched how to make pottery and the factors of finding the right clay, time to dry before firing, as well as type and proportion of temper to clay made it unlikely that adequate sherds could be produced in time for them to be burned. I contacted staff at the Historic Fort Snelling museum in St. Paul, Minnesota to see if they had any ideas. I was told they had samples of unprovenienced sherds that could be used for the experiment. I decided these would not be appropriate for the experiment because there would be no way of knowing whether or not the sherds had been exposed to wild or prescribed fires in the past. There would also be unknowns and questions to address such as temper proportion, type of temper, or how the original pots themselves were fired. Considering the Sherburne National Wildlife Refuge could not wait to start their prescribed burning, the decision was made to not include pottery in the experiment.

Burn

During the course of each prescribed burn, the goal was to record the maximum temperature and burn duration. This was a tough challenge. Smaller fires can be measured by using infrared cameras if the operator can be close to the fire. For prescribed fires the easiest way to measure the temperature over time is to use a data logger connected to thermocouple probes that measure temperature and export the data on a graph. Sturdevant *et al* (2013) and Kennard *et al* (2005) used similar devices to measure prescribed fire temperatures and this was likely the best opportunity to maintain consistent data collection. A Neulog data logger and thermocouple probe that recorded the temperature was selected for this task. The data logger was sealed in a canister made from PVC components and was buried thirty centimeters underground next to each test plot on the northern side to protect it from the fire. The probe that the logger read from, however, was approximately 5 centimeters above ground. This height allowed for the probe to measure air temperature without touching any of the fuels in the test area so an accurate air temperature could be logged. This method was ideal because the data logger was able to save and graph the data in an easy to read format rather than just reading and recording from an infrared thermometer by hand in during a burn.

Post-Burn

After each respective burn, the position of all the replicated objects placed before the burns were re-measured. The important changes to look for were artifact displacement, soil erosion/destruction, and missing or completely destroyed artifacts. All changes in location were measured again by total station and recorded for three-dimensional provenience. Soil from the surface after the burn and the horizons from where the data logger was buried were examined to see how deep the fire reached into the soil. If any of the artifacts were unable to be recovered by performing pedestrian walkover, the plan was to shovel skim the surface of the test plot and screen the dirt through 1/8th inch screen. All replicated tools were recovered and were analyzed using the procedures outlined below.

Chipped stone tools

All chipped stone flakes were measured before being cleaned of any char residue. After they had been cleaned of any char residue with water and a toothbrush, they were measured again. This was intended to observe loss of weight, as well as the amount of char residue that adheres to the surface of the flakes. These data will be used to try to determine percentage of weight lost for a given material type when subjected to extreme temperatures. Other aspects that were examined included color change in the flakes due to heat exposure and any surface defects such as cracking or spalling. Some lithic materials change color when they are deliberately heat treated (Deal et al. 2012), but if an archaeological site area has been through a forest fire it is possible that it was naturally heat treated rather than culturally modified. To observe color change, a Munsell color book was used to record the pre and post burn colors of the flakes.

Ground Stone Artifacts

Analysis of the ground stone artifacts entailed examining the hafted artifact handles and noting how much is present if any is left over, and examining the surface of the tools for surface defects (cracking, heat spalling). The portion of the tool that was covered by the haft was examined and compared to the same area of the surface of the unhafted tool. The intent was to see if the hafted portion of the tool offered any protection or sustained any extra damage from being hafted with the pitch glue. The artifacts were measured for maximum length, width and thickness as well and compared to the pre burn measurements.

Copper Artifacts

All copper tools were examined in the same fashion as the chipped stone by measuring before and after cleaning to measure char adherence and weight changes. The copper also was examined for any possible deformity that could be caused by getting close to copper's melting point such as change in length, width, thickness, oxidation/corrosion, or overall surface morphology.

Bone/Antler Artifacts

The bone and antler were subjected to the same measurement and cleaning procedures as the other artifacts. This will help document the temperature and type of fire that bone and antler can withstand. Post-burn color of cleaned bones and antler pieces were compared to pre-burn color using a Munsell color book.

Leather

Recovering any of the elk hide after each burn was not expected. The plan was that if any was able to be recovered, it would be measured for length, width, thickness, and weight. Surface modifications such as cracking or stiffening would also be described.

Field days (burn days)

Selecting the units to place our plots in was based on what refuge staff told us were high priority to be burned and likely based on long range forecasts. Primary researcher Ian Hanson had previously gained certification as a wildland firefighter and was offered a position to work on the fire crews during the prescribed burn season. Obtaining certification involved completing two online courses through FEMA; as well as attending a week long course at Itasca Community College to learn about fire behavior, fire suppression, and fire management. Above the educational requirements, qualifying as a firefighter for the Sherburne National Wildlife Refuge involved a thorough medical examination and a physical fitness test where Ian had to carry a forty pound backpack for three miles with a time limit of forty-five minutes. This is the bare minimum standard for all personnel working as a wildland firefighter. This position allowed for first-hand experience during the burns and a chance to conduct the experiment hands on working on the fire crew rather than placing and leaving the plots to be burned. After all of the artifacts were measured and prepped, we received a call that one of the heavier woodland units was going to be burned over the following day. Dr. Muñiz of St. Cloud State University and I placed a plot (Figure 2, A-C). The thermocouple probe was left running while buried in its canister overnight so it would not have to be set up before ignition. We left that site and went to a grassland unit that we had been informed was a high priority unit (Figure 2, D).

Figure 2. A, Overview of first attempt in woodland habitat. B, Ian Hanson holding Stadia Rod on top of artifact to be mapped. C, Ian Hanson and Total station used for mapping. D, Ian Hanson and equipment after mapping first attempted grassland plot.

Upon arrival to the refuge the next morning, the plan had changed and a different unit was going to be burned so all of the artifacts had to be relocated from one area to another. The unit we moved to most closely resembled Anderson's (1982) fuel model 9 due to it being an oak stand with of leaf litter on the ground. This was fortunate because it matched the fuel model of the unit we moved from. With the assistance of Dr. Muñiz the plot was placed and location data was gathered moments before the ignition began (Figure 3). Unfortunately, over the course of leaving the probe container buried, some water had leaked into the canister and rendered the battery for the probe inoperable. Resetting the probe was attempted to get it ready in time for ignition but the readings were showing ambient air temperature at over 500° Fahrenheit and by the time the ignition crew was getting ready to start, the data logger stopped working altogether.

Figure 3. A, Ian Hanson placing artifacts in new test plot. B, Dr. Mark Muñiz operating total station. C, photograph depicting test plot location and showing vegetation of the area. D, Photograph of Knife River Flint flakes as they were placed pre-burn.

Ignition started at approximately 1:30 P.M. and the borders of the unit were all lit at 2:35P.M. This left the inner portion of the unit to burn. The time that the fire burned near the test plot based on what could be seen from a safe distance outside the fire ground was from 1:50 P.M. until 2:15 P.M. While it was unfortunate to lose the temperature data, the rest of the results were gathered and the experiment was not a total loss. To prepare for the next unit to be burned, a new battery was able to be purchased that worked for that burn unit.

Conducting a prescribed burn requires personnel and mechanical resources to ensure that burn objectives are performed and completed safely. For this burn there were multiple fire apparatus on site and others standing by in case the fire went outside the boundaries and needed to be extinguished. Ian’s role in this burn was to observe the burn boundary, put out small spot fires with hand tools, and radio for assistance if necessary. Due to the small size of the unit it was easy to keep the fire within its boundaries. Some photographs of the habitat and how the fire acted are shown in Figure 4

Figure 4. A, Photograph of initial ignition. B, Photograph of smoke column generated by burn approximately 10 minutes after ignition. C, Photograph of fire beginning to encroach on test plot area. D, Photograph of fire in area near test plot. Note fire is mostly creeping through the oak litter with limited flame height.

The second unit burned was in a grassland setting. The burn took place near the "Blue Mound" on the refuge. This grassland area fit into Anderson's (1982) fuel model 1 as the area was mostly filled with big blue stem and little blue stem grasses. This area was chosen because since the unit was mostly a large grass field, a head fire (main body of a ground cover fire) had potential to produce higher temperatures as it swept through the area. Another reason this unit was chosen was that it was on the list of high priority units to burn for the refuge. This combination made an ideal situation for the experiment. After the test plot was established with the assistance of St. Cloud State University students Brook Hoffman and Noel Jones, the plot sat for a while waiting to be burned. Other burn units around the refuge were burned during this time, but in each case there wasn't anyone available to help reset the plots so the plot stayed where it was in the hopes that weather would line up to get the unit burned. Photographs of the burn unit and preparing the plot are depicted in Figure 5.

Figure 5. A, Grassland habitat with approximate plot area outlined. B, Knife River Flint flakes 1-30 laid out in test plot. C, Axes 1 and 2. D, Noel Jones of SCSU assisting with plot setup.

As stated before, conducting prescribed burns and experiments within that context takes preparation, manpower, and machinery. To illustrate the challenges that land managers face as they try to plan and coordinate their resources to complete a burn, written here is a description from the point of view of the primary researcher as he experienced working on the fireline. This narrative gives a unique perspective not given in the previously mentioned studies (Deal *et al* 2012, Sturdevant *et* al 2013).

As the refuge was nearing the end of the burn season they notified me that there was a slim chance that the Blue Mound unit would be burned. Because of this I decided to leave the plot where it was but recover the other grassland plot Dr. Muñiz and I had set in the hopes that if another grass unit was selected I could place it like we did with the woodland plot. After recovering the original grassland plot I received a message that the weather looked clear for a burn at the Blue Mound unit. In preparation for weather to change I kept the recovered plot ready for quick deployment. The following morning I received a phone call early in the morning that the plans to burn the Blue Mound were not looking likely due to wind direction and that I should prepare to place my other plot as this would likely be the last day of the prescribed burn season. I attempted to contact anyone who could help me place the unit but nobody was available in such short notice. At around 6 A.M., I received another phone call that the wind direction had shifted and the Blue Mound unit was clear for burning.

Upon arrival to the refuge I buried my data logger canister next to my test plot before the briefing. Without knowing how long it would take for the fire to reach the plot I set the logger to record for 30 hours taking a temperature sample once every 4 seconds which added to 15 samples per minute. This was the maximum amount of samples per minute the unit could process for running an experiment that length of time. This burn unit was much larger than the previous one I had a test plot in and thus more personnel and machinery were involved. My assignment for the burn was to patrol the eastern boundary of the burn unit in a pump outfitted UTV suppressing any spot fires that jumped across the control line. Since the wind was coming from the west, ignition started on the east side in the northeast corner of the unit moving south to create a backing fire, which is a slow moving fire “backing” into the wind. This allowed for small growth of the fire and to create more burned area or “black” as firefighters refer to it. The black is considered to be a safe zone and the reason it is generated is so when the rest of the unit is ignited from the windward side, the black acts as a shield to stop the head fire as the areas that have already burned cannot burn again. As the burn progressed it became apparent that it was going to take a while before the fire reached my test plot reaffirming that a 30 hour test was necessary.

Part way through our progress toward the outheast corner the team I was on was sent to do some ignition on the interior of the unit to burn around a pond. After this was completed we received a radio transmission that a spot fire had escaped the boundary on the East side of the unit and all personnel were called to suppress the now wildfire. Ignition operations temporarily ceased to perform initial attack on the fire and additional units were called from Litchfield, MN to assist. Winds were gusting as fast as 25 miles per hour during this time which meant the fire moved just as quickly through the tall grass. Refuge firefighters contained the fire along the edge of a nearby river and when the Litchfield units arrived they took over suppression operations as we resumed the prescribed burn.

After the western portion of the unit was lit, Fire Management Officer Kris Larson sent me to generate more black on the east side to create more of a buffer between the now incoming head fire and the unburned portion of the field across the control line so we wouldn’t be dealing with another wildfire. Video screenshots from a point-of-view camera I was wearing depicting the ignition and fire behavior in the grassland are recorded in the figure below (Figure 6). It was well after dark before the burn was completed and resources were being released. Just like the woodland unit before it was a few days before the artifacts were recovered. With the assistance of fellow grad student Rae Schira of SCSU, the artifacts were recovered with post burn location data recorded.

Figure 6. A, Photograph form Ian Hanson's point of view during ignition operations to create more "black." B, Photograph of same spot as 6-A approximately 30 seconds after A was taken. Note fire furthest from camera has increased in intensity and rate of spread. C, photograph of burned area, while the grass has burned there is a large amount of charred remains and no apparent penetration into the soil.

Chapter 4: Analysis

To analyze the results of the location data an Excel spreadsheet was used to compare the difference in northing, easting, and elevation coordinates between the pre and post burn locations of each individual artifact. Analysis starts with the woodland plot since it was burned first. After calculating the difference a few things were noticed. In the northing and easting differences, all artifacts except for the elk hide moved less than 2 centimeters. A few notable changes however were: Flake 73 had shifted 4 centimeters east and was on top of Flake 74, Flake 77 had flipped over to label side down, and Flake 88 also flipped over to label side down. The elevation average of the flakes suggests that on average the flakes rose 5 millimeters. This is likely due to human error while keeping the stadia rod for the total station steady and level. The elk hide had moved 4 centimeters east and 41 centimeters north. The movement northward aligned with the topography of the test plot as it was on a slight slope where north was the downhill direction; it is likely that wind during the burn swept it away from its original location. All elevation changes were less than one centimeter except for the elk hide which had a movement upward of 1.7 centimeters.

This change in higher elevation is likely from measuring a large object and it having shriveled and wrinkled so it was no longer lying flat. Table 1 below shows the differences and the average calculations. Each column shows the absolute value of the differences between the pre and post burn coordinates. Absolute value was used because the goal was to find the average variance in the site disturbance and not be concerned whether the artifacts moved more east or west. Figure 7 shows a mapped expression of before and after locations and a photograph of the site area to make visualizing the site easier. Table 1 shows the absolute value of the easting, northing, and elevation differences for each artifact. These are labeled Easting_Diff ABS(m), Northing_Diff ABS(m), and Elevation_Diff ABS(m) respectively with the ABS acting as an abbreviation for absolute value.. Table 1 also shows the average and standard deviation of the values. For full spreadsheet showing before and after location coordinates see APPENDIX A.

Table 1. Artifact location differences northing, easting, and elevation (woodland plot)

	Artifact #	Easting_Diff ABS(m)	Northing_Diff ABS(m)	Elevation_Diff ABS(m)	
KRF	61	0.002	0.022	0.002	
	62	0	0.016	0.005	
	63	0.006	0.019	0.002	
	64	0.003	0.013	0.002	
	65	0.005	0.021	0.002	
	66	0	0.021	0.003	
	67	0.002	0.021	0.002	
	68	0.024	0.006	0.001	
	69	0.001	0.025	0.01	
	70	0	0.039	0.033	
	71	0.01	0.009	0.011	
	72	0	0.058	0.011	
	73	0.044	0.025	0.001	
	74	0.009	0.021	0.001	
	75	0.001	0.021	0.001	
	76	0.006	0.017	0.005	
	77	0.025	0.013	0.005	
	78	0.002	0.013	0.004	
	79	0.001	0.044	0.001	
	80	0.009	0.016	0.005	
	81	0.014	0.039	0.021	
	82	0.017	0.038	0.024	
	83	0.031	0.101	0.002	
	84	0.001	0.035	0.014	
	85	0.026	0.041	0.028	
	86	0.01	0.045	0.017	
	87	0.005	0.008	0.029	
	88	0.045	0.005	0.023	
	89	0.024	0.017	0.021	
	90	0.001	0.012	0.003	
		0.0108	0.026033333	0.009633333	AVG
		0.012742056	0.019002602	0.009843723	StDevP

	Table 1	Continued			
	31	0.011	0.021	0.006	
	32	0.01	0.011	0.004	
	33	0.009	0.037	0.014	
	34	0.017	0.039	0.025	
	35	0.004	0.013	0.01	
	36	0.002	0.027	0	
	38	0.015	0.016	0.008	
	39				
	40	0.009	0.014	0.025	
	41	0.005	0.039	0.032	
	42	0.001	0.011	0	
	43	0.006	0.012	0.006	
	44	0.002	0.037	0.009	
	45	0.006	0.005	0.001	
		0.072	0.032	0.016	
		0.012071429	0.022428571	0.011142857	AVG
	5	0.017243899	0.011842504	0.009716386	StDevP
Antler	6	0	0.009	0.018	
		0.028	0.016	0.004	
		0.014	0.0125	0.011	AVG
	5	0.014	0.0035	0.007	StDevP
Bone	6	0.019	0.006	0.002	
		0	0.014	0.018	
		0.0095	0.01	0.01	AVG
	5	0.0095	0.004	0.008	StDevP
Axes	6	0.003	0.022	0.005	
		0.001	0.016	0.008	
		0.002	0.019	0.0065	AVG
		0.001	0.003	0.0015	StDevP
	3				
Hide		0.041	0.412	0.017	

Table 1. Absolute value of differences in easting, northing, and elevation coordinates, averages, and standard deviations after the woodland burn. ABS(m) refers to the absolute value expressed in meters of the difference between the pre and post burn coordinates of each dimension.

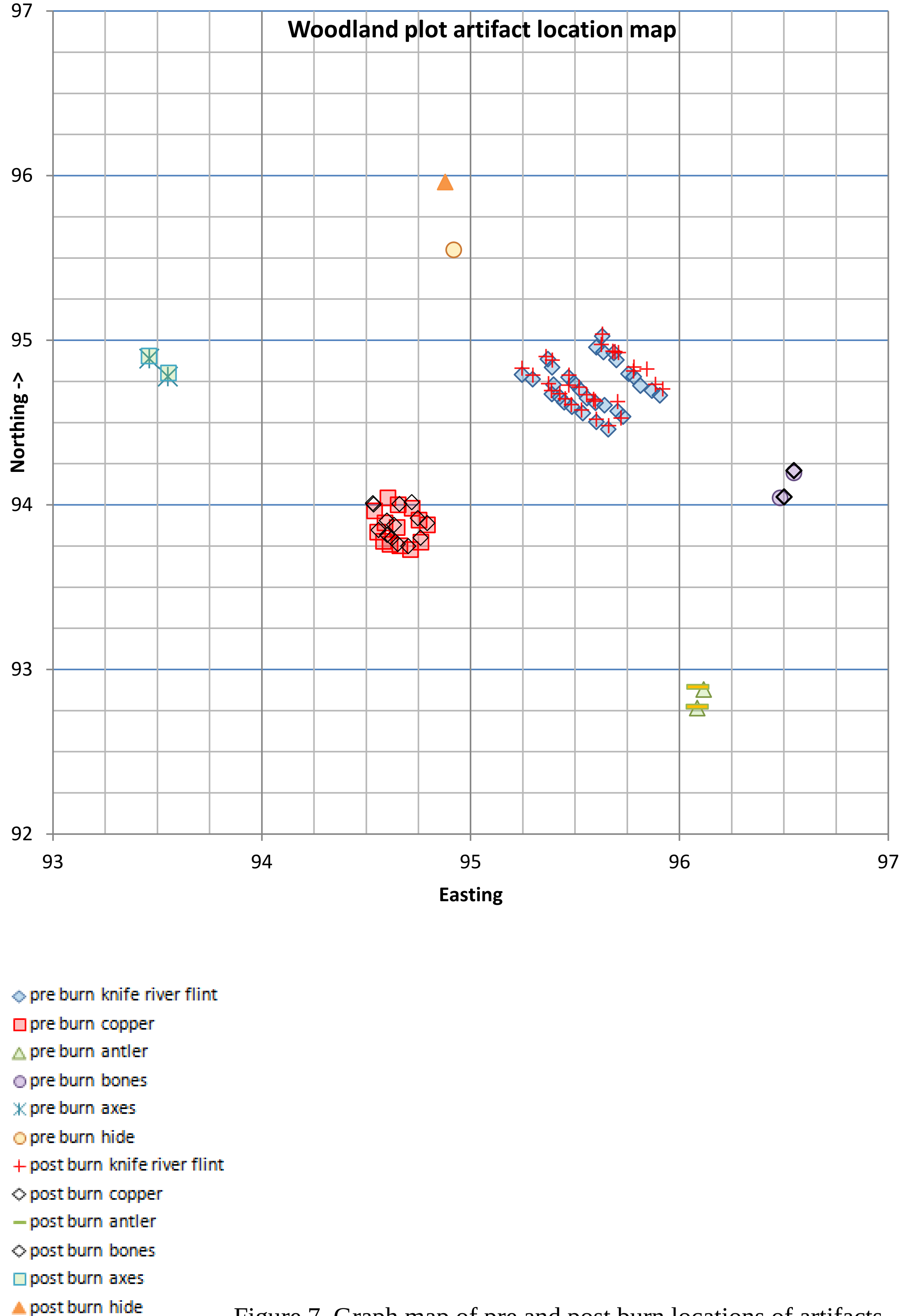

Figure 7. Graph map of pre and post burn locations of artifacts,

Figure 8. Photograph of site area with approximate boundaries outlined.

To compare location data of the grassland plot, the same techniques as the woodland plot were used. After finding the differences in northing, easting, and elevation coordinates and averaging those differences and finding the standard deviation. In the grassland plot, all artifact types except for the axes and the hide moved less than 2 centimeters in the Easting and Northing axes. Axe 2 which was hafted apparently moved 5 centimeters east. This large shift was likely due to the artifact having a large surface area between the stone and handle portion and guaranteeing the point of the stadia rod fell on the same place of the artifact is unlikely, similarly Axe 1 moved 3 millimeters west and had absolutely no movement north or south which suggests that the same point on the stone may not have been measured.

These differences fall within human measurement error because of having multiple people assisting with placement and recovery of the site. The changes that are more difficult to explain are the changes in elevation. After calculating differences in elevation the spreadsheet shows that every artifact rose up rather than went down. This was unlikely so the pre and post burn coordinates were checked again to be sure that they were in the correct order which they were. The next step was to look at the averages and see if they were consistent which might suggest there was some error in programming the total station instrument or target height.

What was found was that the Knife River Flint rose on average 3.2 centimeters, the copper rose 1.7 centimeters, the antler rose 1.4 centimeters, the bones rose 1.5 centimeters, the axes rose on average 1.9 centimeters and the hide rose 6 millimeters. The range of averages suggests that there was not just one error isolated to programming the total station. A likely possibility is that it was a combination of multiple factors such as: the challenge of being exactly on the datum of the site, an error in programming the total station location, and operator error of running the machine and holding the stadia rod. Because the elevation data can be considered flawed and unreliable a scatterplot showing the elevation change has not been included. This decision was made to eliminate the risk of the data being misunderstood or misrepresented. For full transparency Table 2 below still includes the averages and the complete spreadsheet of pre and post burn coordinates is included in Appendix B. As with Table 1 the ABS in the columns is an abbreviation for absolute value. Following the table is Figure 8 which shows a graphed map of pre and post burn locations as well as a photograph of the site area with approximate boundaries outlined.

Table 2. Artifact location differences northing, easting, and elevation (grassland plot)

	Artifact #	Easting Difference ABS(m)	Northing Difference ABS(m)	Elevation Difference ABS(m)	
KRF	1	0.011	0.014	0.024	
	2	0.012	0.016	0.039	
	3	0.005	0.009	0.034	
	4	0.028	0.007	0.028	
	5	0.01	0.006	0.046	
	6	0.007	0.001	0.025	
	7	0.007	0.014	0.034	
	8	0.026	0.016	0.039	
	9	0.009	0.002	0.03	
	10	0.007	0.001	0.029	
	11	0.004	0.018	0.033	
	12	0.002	0.005	0.028	
	13	0.008	0	0.029	
	14	0.007	0.006	0.037	
	15	0.013	0.008	0.034	
	16	0.007	0.011	0.026	
	17	0.008	0.007	0.03	
	18	0.003	0.002	0.039	
	19	0.008	0.007	0.035	
	20	0.048	0	0.031	
	21	0.014	0.038	0.035	
	22	0.02	0.015	0.035	
	23	0.001	0.011	0.033	
	24	0.009	0.008	0.029	
	25	0.023	0.019	0.026	
	26	0.009	0.016	0.027	
	27	0.006	0.003	0.029	
	28	0	0.011	0.02	
	29	0.004	0.098	0.039	
	30	0.011	0.003	0.036	
		0.0109	0.0124	0.031966667	AVG
		0.0096033	0.017653328	0.005492318	StDev.P
	1	0.005	0.01	0.021	
copper	2	0.005	0.002	0.032	
	3	0.006	0.018	0.011	

Table 2 Continued

	4	0.01	0.003	0.035	
	5	0.021	0.003	0.038	
	6				
	7	0.006	0.001	0.013	
	8	0	0.001	0.021	
	9	0.006	0.01	0.014	
	10	0.006	0.004	0.02	
	11	0.009	0.002	0.021	
	12	0.005	0.019	0.023	
	13	0.004	0.015	0.024	
	14	0.004	0.011	0.016	
	15	0.001	0.006	0.014	
		0.004	0.012	0.009	
		0.00613333	0.0078	0.0208	AVG
	1	0.00466	0.006013319	0.008368194	StDev.P
	2	0.003	0.003	0.014	
antler		0.01	0.009	0.014	
		0.0065	0.006	0.014	AVG
	1	0.0035	0.003	8.88178E-16	StDev.P
	2	0.007	0.015	0.027	
bone		0.016	0.013	0.002	
		0.0115	0.014	0.0145	AVG
	1	0.0045	0.001	0.0125	StDev.P
	2	0.003	0	0.035	
axes		0.051	0.001	0.004	
		0.027	0.0005	0.0195	AVG
		0.024	0.0005	0.0155	StDev.P
	1				
		0.418	0.035	0.006	
Hide					

Table 2. Absolute value of differences in easting, northing, and elevation coordinates, averages, and standard deviations after the grassland burn. ABS(m) refers to the absolute value expressed in meters of the difference between the pre and post burn coordinates of each dimension.

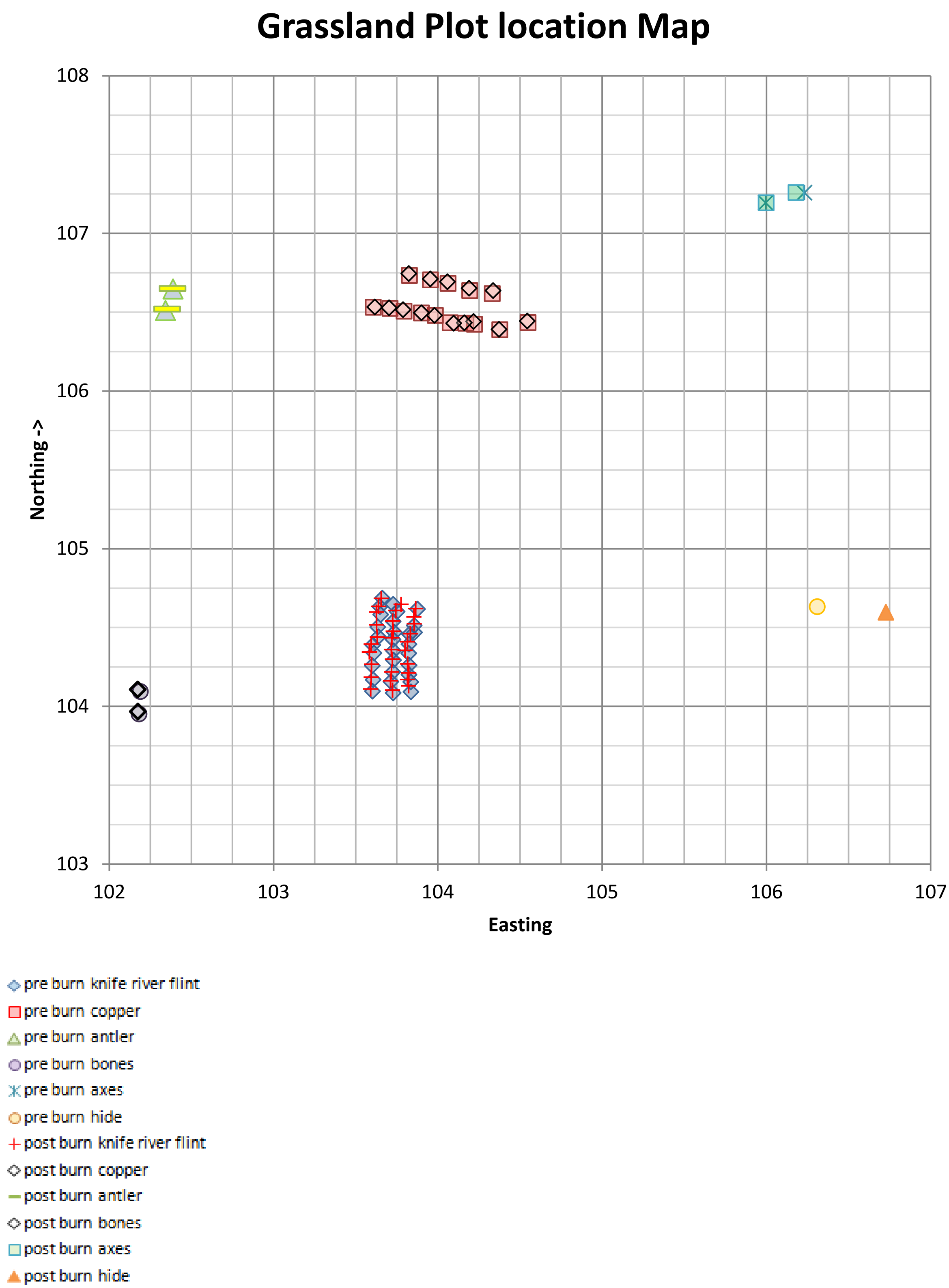

Figure 9. Graph map of pre and post burn locations of artifacts.

Figure 10. Scatterplot map showing pre and post burn location data, and photograph showing location of plot in grassland

After examining location data the next step was to compare pre and post burn measurements of maximum length, width, thickness, and weight of each artifact. After measuring each artifact after the burn which included the weight before and after cleaning the artifacts, the average of the differences in length, width, and thickness were calculated. The measurement data from the woodland plot was the first of the two plots to be analyzed. To start finding the average difference in length, width, thickness, and weight for each artifact, the post burn measurements were subtracted from the pre burn measurements. Some of these differences produced a negative number which suggested that some of the measurements were larger in the post burn than the pre burn.

The artifacts likely did not grow longer so the average and standard deviation of the differences were taken to see if human error in measuring could have accounted for this. The results of the averages are as follows. Average differences of Length, Width, Thickness, and Weight for the Knife River Flint were: loss of .22 millimeters in length, loss of .03 millimeters in width, gain of .05 millimeters in thickness, and loss of .02 grams. These averages suggest that the differences were minimal and well within range of human and instrument error of measuring irregularly shaped objects. Another goal was to see the difference in weight before and after the artifacts were cleaned to see if there was a measurable amount of charred accretions that stuck to the artifact. Like explained above, the post clean weights were subtracted from the pre cleaned weights and found the average differences. What was found was that the average difference was .03 grams higher than before cleaning. Considering the differences were so minute and the majority of post clean weights were higher than the pre cleaned weights I believe that the subtle differences could have been due to scale sensitivity or water retained on the artifacts after cleaning rather than measureable accretion. The scale was tared before each artifact was placed on the scale so mechanical malfunction of the scale was unlikely. Perhaps if access to an even more sensitive scale was available, charred residue might have been possible to measure. The same procedures were followed for the rest of the artifacts and the results were as follows. The Copper pieces experienced an average gain of .18 millimeters in length, gain of .21 millimeters in width, gain of .005 millimeters in thickness, loss of .008 grams, and gain of .004 grams after cleaning. It must be noted that the copper results were taken from a sample of 14 rather than 15 like the grassland plot. This was because copper piece 37 had gone missing before any plots were placed and was never burned. Antlers had an average gain of .78 millimeters in length, gain of .06 millimeters in width, loss of .71 millimeters in thickness, gain of 1.69 grams, and gain of

.4 grams after cleaning. Bones had an average gain of .77 millimeters in length, gain of .09 millimeters in width, loss of .36 millimeters in thickness, gain of .01 grams, and gain of .36 grams after cleaning. Axes had an average gain of .18 millimeters in length, gain of 1.2 millimeters in width, gain of .35 millimeters in thickness, gain of 3.215 grams, loss of 2.96 grams after cleaning. The apparent change in weight was from the residual glue that helped hold the stone axe head in place in the handle. This residual glue added a few grams of weight before cleaning. After cleaning the stone axes were the same weight as before the burn. The elk hide had only one piece per site so averages were not applicable but the differences in measurements were significant. The differences were: a 270 millimeter loss of length, 135 millimeters of lost width, a 1.4 millimeter increase in thickness, and a loss of 30.4 grams which was a 27 percent loss of weight. The loss of weight is the most reliable metric measurement because as the hide burned it shriveled, folded, and dried in a way that it couldn’t be laid flat making the length and width difficult to measure. The increase in thickness was interesting to observe as the skin became more compact. Below is a table showing all of the differences in measurements and the original measurements have been included in Appendix C.

Table 3: Artifact Measurement Differences between Pre and Post burn (Woodland Plot)

KRF#	LengthDifference (mm)	Width Difference (mm)	Thickness Difference (mm)	weight difference (g)	cleaned weight difference (g)	
61	1.19	-0.43	-0.1	-0.02	-0.14	
62	0.03	0.31	-1.64	-0.31	-0.27	
63	0.09	-0.25	0.13	-0.57	-0.05	
64	-0.27	-1.72	-0.1	-0.29	-0.18	
65	0.59	0.51	-0.15	0.33	-0.02	
66	-0.64	-0.8	-0.53	0.49	0	
67	-0.43	-0.11	0.2	0.54	-0.01	
68	-0.96	-1.33	-0.86	-0.7	-0.01	
69	0	0.32	-0.22	-0.1	0	
70	-0.27	0.11	-0.17	0.84	-0.01	
71	0.17	0.4	0.38	-0.31	-0.09	
72	-0.01	-0.09	-0.26	-0.22	-0.01	
73	-0.44	0.47	0.34	0.04	0.01	
74	0.55	0.07	0.13	-0.55	-0.01	
75	0.56	-1.3	0.09	-0.04	0	
76	0.68	-0.36	0.07	-0.35	-0.01	
77	-0.47	0.03	0.79	0.62	-0.02	
78	-0.27	-0.33	0.75	0.26	0	
79	0.36	3.59	0.23	0.19	-0.03	
80	0.81	-0.08	0.91	-0.05	-0.03	
81	0.08	0.06	0.15	0.05	0	
82	0.48	0.86	-0.38	-0.45	0	
83	-0.19	0.38	0.18	0.01	-0.02	
84	-0.54	0.78	-0.34	1.14	0.01	
85	-0.24	0.18	-0.58	-0.67	-0.02	
86	0.48	0.34	0.26	-0.29	-0.01	
87	-1.14	0.28	-0.07	0.26	-0.01	
88	5.38	-0.14	-0.84	0.59	-0.01	
89	0.82	-0.34	0.14	0.15	0	
90	0.4	-0.58	-0.14	0.13	-0.06	
	0.226666667	0.027666667	-0.0543333	0.024	-0.033333333	AVG
	1.098533366	0.88480387	0.5063575	0.443114733	0.355032762	StDevP

Table 3
Continued

Copper #		length Diff	Width Diff	Thick Diff	Wght Diff	cln wght diff	
	31	-0.04	-0.88	0.04	-0.47	-0.03	
	32	-0.04	-1.02	0.01	-0.29	0.01	
	33	0.04	-0.95	0.06	0.22	0.03	
	34	-0.6	0.07	0.03	0.79	-0.02	
	35	-0.63	-0.93	0.1	0.03	-0.02	
	36	-0.63	0.67	-0.16	-0.13	-0.02	
	38	-1.02	0	0	1.05	0	
	39	0.04	-0.21	0	-0.14	-0.01	
	40	-1.13	-0.07	-0.04	-0.15	0	
	41	2.54	-0.27	-0.07	-0.01	0	
	42	0.47	-0.17	-0.03	-0.2	0	
	43	-0.95	-0.28	0.08	-0.45	-0.01	
	44	-0.58	0.56	-0.04	0.47	0.01	
	45	-0.03	0.48	-0.05	-0.6	0	
		-0.182857143	-0.214285714	-0.005	0.008571429	-0.004285714	AVG
		0.883244252	0.545523527	0.065109797	0.459997782	0.014982984	StDevP

Antler #	5	-2.67	-0.07	-0.22	-1.37	-0.4	
	6	1.11	-0.04	1.64	-2	-0.62	
		-0.78	-0.055	0.71	-1.685	-0.4	AVG
		1.89	0.015	0.93	0.315	0.11	StDevP

Bone #	5	-1.78	0.02	0.66	-0.1	-0.4	
	6	0.24	-0.19	0.05	0.08	-0.32	
		-0.77	-0.085	0.355	-0.01	-0.36	AVG
		1.01	0.105	0.305	0.09	0.04	StDevP

Axe #	5	0.02	0.03	-0.07	-6	6	
	6	-0.39	-2.43	-0.63	-0.43	-0.09	
		-0.185	-1.2	-0.35	-3.215	2.955	AVG
		0.205	1.23	0.28	2.785	3.045	StDevP

		length diff	width diff	thick diff	wght diff	% wght lost
Hide #	3	270	135	-1.41	30.4	27%

After these averages were calculated the same procedures were used on the data from the grassland plot and the results are: The Knife River Flint average difference in length width, thickness, weight, and cleaned weight were a loss of .18 millimeters in length, gain of .53 millimeters in width, gain of .17 millimeters in thickness, a loss of .17 grams, and a gain of .02 grams after being cleaned. The copper pieces on average had a gain of .18 millimeters in length, a gain of .21 millimeters in width, a gain of .005 millimeters in thickness, a loss of .008 grams, and a gain of .004 grams after cleaning. The antler had an average loss of 1.28 millimeters in length, a loss of .6 millimeters in width, a loss of .11 millimeters in thickness, a gain of 1.05 grams, and a gain of .05 grams after cleaning. The leg bones experienced an average loss of 1.5 millimeters in length, a loss of .08 millimeters in width, a loss of .41 millimeters in thickness, a gain of .26 grams, and a gain of .13 grams after being cleaned. The axes experienced an average gain of .72 millimeters in length, a gain of .08 millimeters in width, a loss of .14 millimeters in thickness, a gain of 2.5 grams, and a loss of 2.5 grams after cleaning. Like in the woodland plot, after the hafted axe was cleaned of the residual glue it was measured to be the same weight as before the burn. The unhafted axe remained the same weight as well. The hide differences were: loss of 243.76 millimeters in length, loss of 188.65 millimeters in width, an increase in thickness by .67 millimeters, a loss of 9.48 grams in weight which amounts to a 12.5 percent of weight lost. A table showing the differences in artifacts and the averages is shown below. A complete spreadsheet showing the before and after measurements in included in Appendix C

Table 4: Artifact Measurement Differences between Pre and Post burn (Grassland Plot)

KRF #	Length difference (mm)	Width Difference (mm)	Thickness Difference (mm)	Weight Difference (g)	Clean weight diff (g)	
1	-0.16	0.01	-0.09	0.15	-0.16	
2	-0.14	-0.61	-0.01	1.06	0.01	
3	0.3	0.27	-0.4	-0.77	0	
4	-0.31	-0.37	0.02	0.33	-0.06	
5	-0.04	1.21	-0.41	-0.66	-0.01	
6	0	0.4	-0.17	0.23	-0.01	
7	0.07	-2.99	-0.02	-0.45	-0.05	
8	0.42	0.78	0.15	1.32	-0.02	
9	-1.33	-0.01	0.02	0.43	-0.09	
10	0.07	-0.61	-0.02	0.75	0.01	
11	-0.65	-0.4	-0.24	0.02	0.01	
12	0.42	1.26	-0.25	-0.45	-0.06	
13	0.16	0.52	0.18	-0.49	-0.03	
14	0.16	-0.93	-0.14	0.99	-0.02	
15	0.42	-0.06	0.01	0.21	0	
16	-0.12	-0.04	-3.87	-0.01	-0.01	
17	0.05	-0.31	0.3	-0.22	-0.03	
18	-0.01	-0.13	0.53	0.19	-0.01	
19	-1.48	-0.51	-0.16	0.27	-0.03	
20	-0.56	0.15	-0.03	0.85	-0.02	
21	0.15	-0.14	0.4	-0.55	-0.03	
22	0.15	0.38	-0.27	0.11	0.02	
23	0.31	0.51	-0.32	-0.67	0	
24	0.14	0.37	-0.16	-0.47	0	
25	6.03	-0.18	-0.08	0.96	-0.01	
26	0.28	-0.85	0.09	0.09	0	
27	0.01	1.16	-0.27	1.12	-0.03	
28	0.53	-0.58	0.01	0.5	-0.01	
29	0.3	-0.09	0.12	-0.15	0	
30	0.34	0.2	-0.14	0.36	0.01	
	0.183666667	-0.053	-0.174	0.168333333	-0.021	AVG
	1.17771101	0.7825648	0.719025266	0.580126902	0.035246749	StDevP

Copper#	length Diff	Width Diff	Thick Diff	Wght Diff	cln wght diff
1	0.01	-0.25	-0.24	0.05	-0.02
2	0.03	-0.1	-0.13	0.08	0
3	0.04	-0.65	0.69	0.17	0

Table 4 Continued

4	0.06	-0.26	0.32	0.08	0	
5	0.03	-1.64	1.61	0.17	-0.06	
6	0.03	-0.09	0.12	0.14	0	
7	0	-0.01	-0.01	0.09	0	
8	0.01	-0.77	-0.78	0.16	0	
9	0.05	-1.25	1.3	0.19	0	
10	0	-0.4	0.4	0.02	0	
11	0.03	-0.06	0.03	0.17	-0.06	
12	0.01	-0.03	-0.02	0.04	-0.02	
13	0	-0.06	-0.06	0.04	0	
14	0.04	-0.47	0.51	0.06	0	
15	0	-0.31	0.31	1	0	
	0.022666667	- 0.423333333	0.27	0.164	-0.010666667	AVG
	0.019136933	0.462798252	0.576518285	0.230240454	0.020483055	StDevP

Antler #	length_Diff	Width Diff	Thick Diff	wght Diff	cln wght diff	
1	3.78	0.97	-0.09	-0.61	-0.07	
2	-1.23	0.23	0.3	-1.48	-0.03	
	1.275	0.6	0.105	-1.045	-0.05	AVG
	2.505	0.37	0.195	0.435	0.02	StDevP

Bone #						
1	2.16	0.54	0.25	-0.01	-0.12	
2	0.82	-0.39	0.56	-0.5	-0.14	
	1.49	0.075	0.405	-0.255	-0.13	AVG
	0.67	0.465	0.155	0.245	0.01	StDevP

Axe #						
1	-0.19	-1.56	0.31	0	0	
2	-1.25	1.41	-0.03	-5	5	
	-0.72	-0.075	0.14	-2.5	2.5	AVG
	0.53	1.485	0.17	2.5	2.5	StDevP

Hide #	length diff	width diff	thick diff	wght diff	% wght lost
3	243.76	188.65	-0.67	9.48	12.50%

Temperature Data

Attempts were made to record temperature change over the course of the burns but as described earlier only the grassland burn yielded results. Over the course of the 30 hours the data logger was running it collected over 23,000 temperature readings. The highest reading the logger recorded was 817.5° Fahrenheit. The overall time the spike in temperature lasted was approximately five minutes. Figures 9 and 10 display the temperature trend line during the entire experiment as well as a chart highlighting the temperature spike and the return to ambient air temperature over almost 9 minutes.

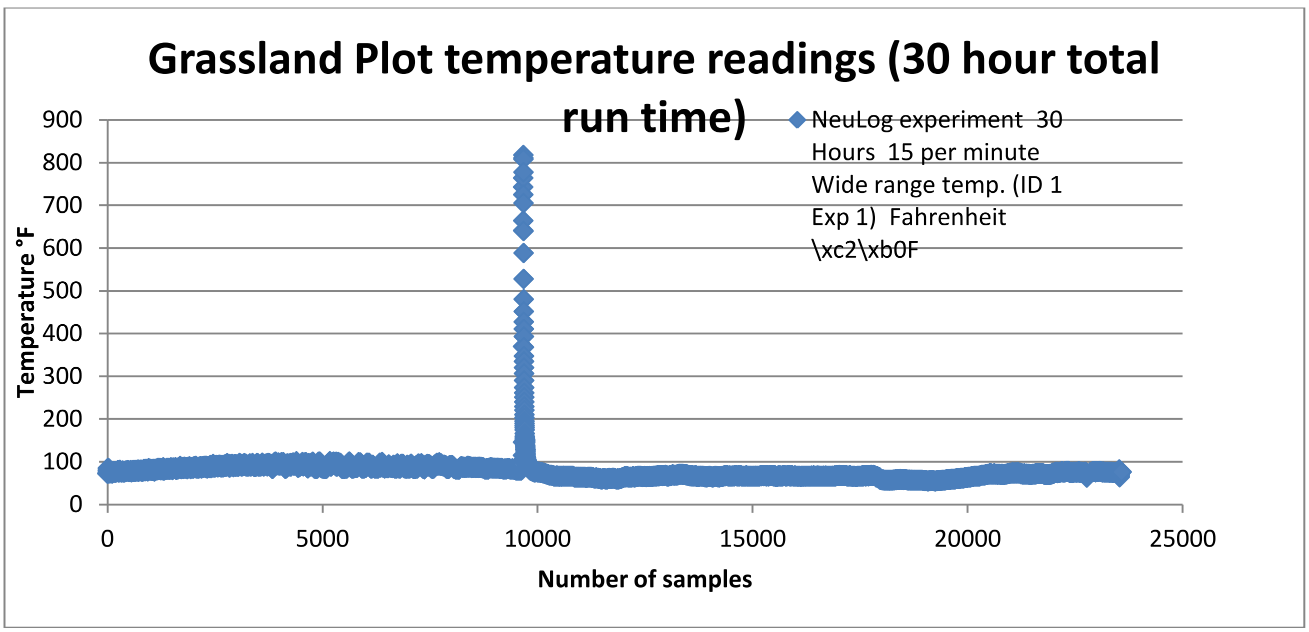

Figure 11. Temperature data graph showing large spike in temperature as the site was burned over.

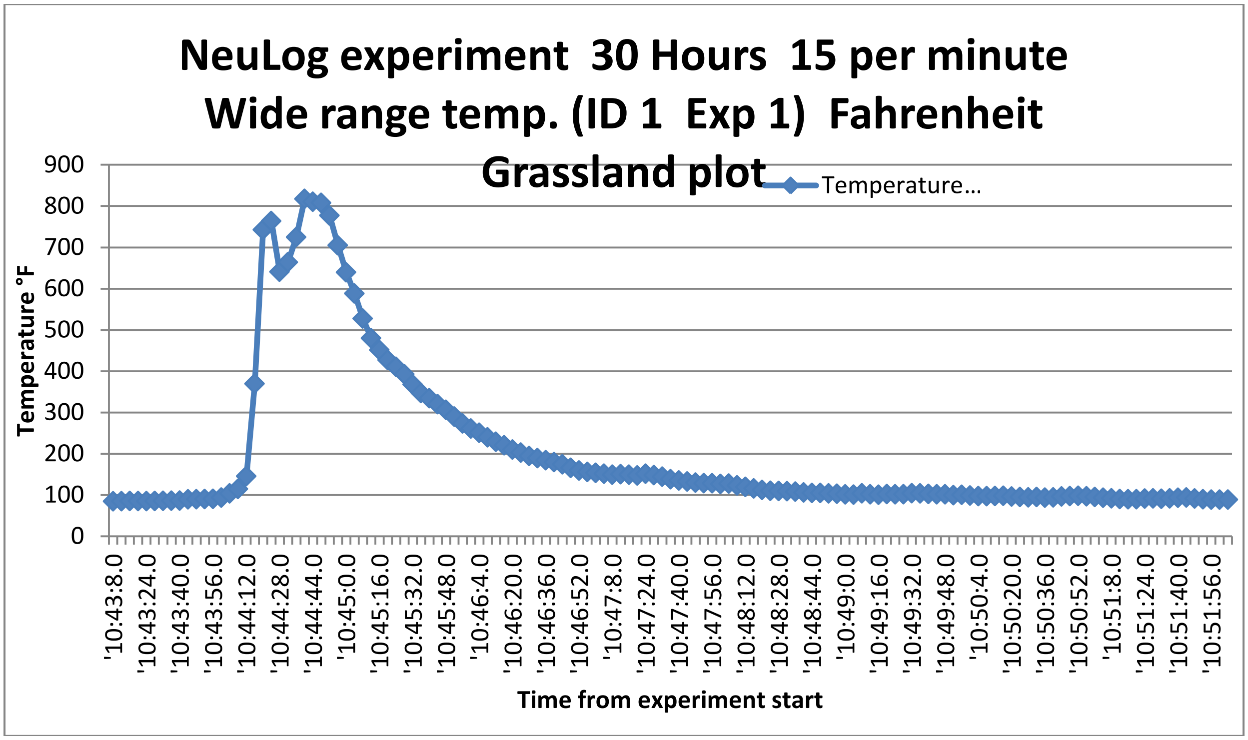

Figure 12. focused portion of temperature plot depicting approximately 10 minutes of where the fire was near the test plot.

Examining Figure 9, it is apparent that there was a very short lived spike in temperature as the burn progressed near the site. Figure 10 tells a more complete story of the spike as it can be seen that the temperature appears to have had multiple peaks. The likely reason for this is due to the wind conditions that were occurring during the burn. As the wind moved around the area, there may have been multiple instances where the fire was pushed in and out of the site area before all of the grass was consumed. Wind conditions like this could affect how much damage artifacts sustain due to them not being continuously exposed to the flames.

Artifact physical changes (woodland environment)

Chipped stone artifacts

To examine visible physical changes to each artifact, a photograph was taken of each replica artifact before they were burned, after they were burned, and after they were cleaned.

This allowed for a record to be kept without having to rely solely on written description. First, the changes that some artifacts in the Woodland plot experienced were examined. Starting with Knife River Flint the flakes are a medium to dark brown before the burn (10 YR 3/2) and the cortex that some flakes had on them was a white (7.5YR 9.5/1). After the burn and being cleaned, there appears to be no permanent color change on any of the flakes. A few flakes seem to have some char residue worked into their surface but the smooth nature of the flint was easy to clean. None of the flakes experienced any potlidding, spalling, or cracking like expected. Figure 11 shows before and after photographs of several artifacts described in this section.

Ground Stone Artifacts

The simulated ground stone artifacts produced unexpected results. It was expected that the hafted portion of the axe would sustain more damage due to the pitch glue's potential to act as an accelerant and burn the handle as well as the stone. However, what appears to have happened was the glue and handle actually shielded the stone's surface and as seen in figure 12, and kept the covered portion looking as if it hadn't been through a fire at all. The likely explanation is that the fire either did not burn hot enough or long enough for the handle or glue to catch fire and damage the surface. Like the flakes, the Munsell color of each simulated axe was recorded. Axes 5 and 6 were in the woodland plot with axe 5 being the hafted one. Axe 5 had a munsell color of Gley 2 4/10G and axe 6 had a color of 7.5YR 5/1. After being cleaned, the portion of axe 5 that was covered retained this color and the portions outside of the haft seem slightly darker at Gley 2 3/10. It is likely that some soot worked its way into pores in the rock causing this slightly darker shade. Axe 6 appears to have no apparent color change or any visible damage.

Copper

The pieces of copper produced mixed results from the woodland burn. None of the pieces showed apparent deformity or sign of melting. Without temperature data for the woodland plot we don't know if the fire got anywhere near copper's melting temperature but based on the fire behavior observed during the burn it seems unlikely. Some pieces were discolored from their shiny reddish brown to having a blackened rusty appearance or even a light grey. The discoloration on these pieces was not able to be removed with the wet toothbrush method but likely would be with a more abrasive tool. Some pieces of the copper looked as though they had not been burned at all (Figure 13).

Antler and Bone

The antler and bone in the woodland plot were antlers 5 and 6 as well as bones 5 and 6. Before the burns the antler colors were 2.5Y 7/2 for antler 5 and 2.5 Y7/8 for antler 6. Bone 5 had a color of 2.5 Y 7/6 and bone 6 was 2.5 Y 8/6. The only piece to exhibit a noticeable color change was antler 5 which changed to a 7.5YR 5/4 which is a brown compared to the near white it was before. Neither the antlers nor bones appeared to experience any cracking or other damage which aligns with the results from Perez *et al* (2017) and the expected outcome.

Leather

The elk hide was a surprise by being recoverable at all in the woodland environment. What remained was barely recognizable until it was dusted off but what was left was a shriveled mass with a texture similar to burnt bacon.

Figure 13. A: Antler Piece 5 pre-burn. B: Antler 5 Post burn and cleaned. C: Flake 80 pre-burn. D: Flake 80 post-burn and cleaned. E: Hide piece 3 pre-burn. F: Hide piece 3 post burn.

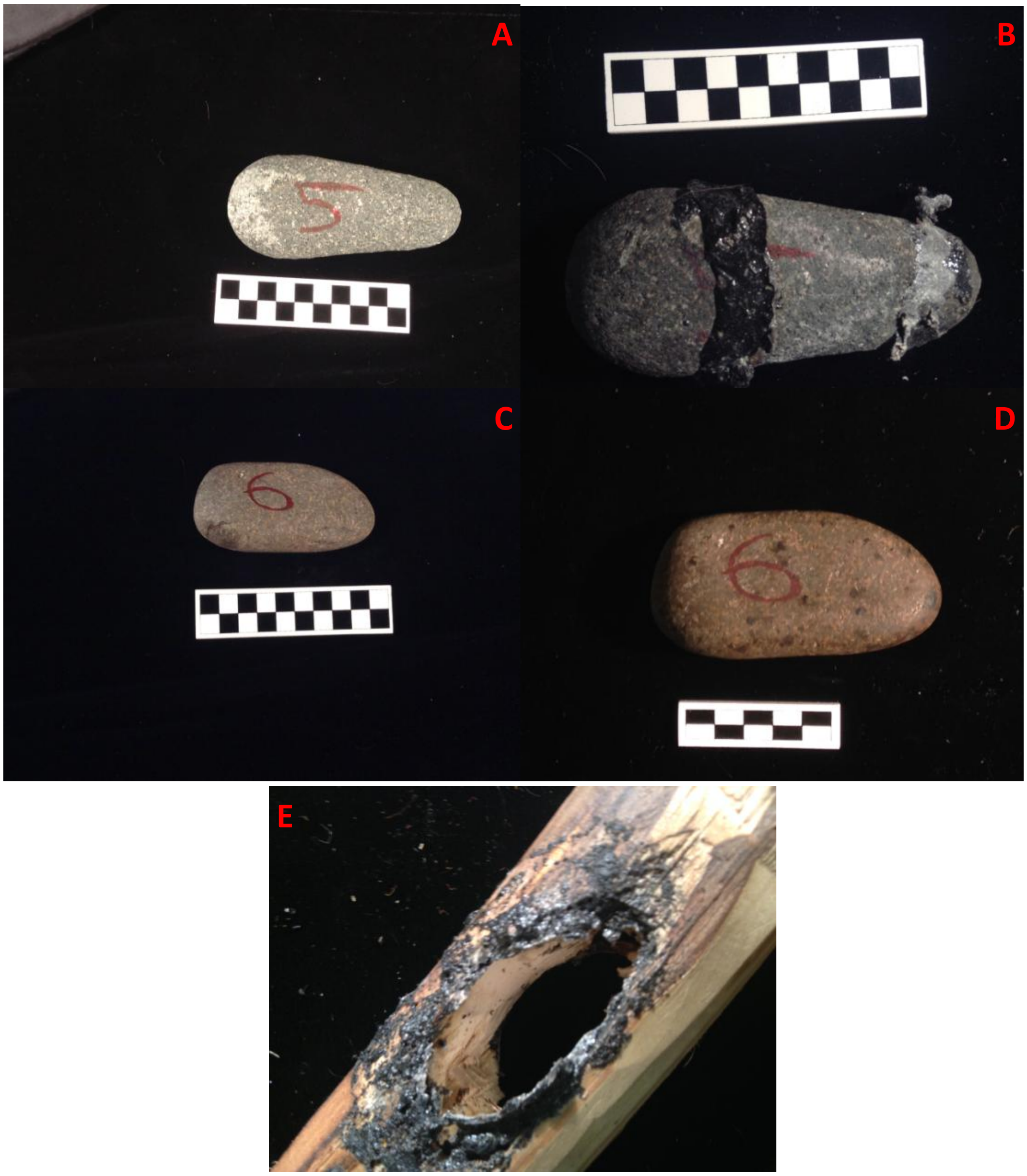

Figure 14. A. Axe 5 pre-burn. B. Axe 5 post-burn. C. Axe 6 pre-burn. D. Axe 6 post-burn. E. Axe 5 handle after stone removal. Note apparent undamaged interior surface.

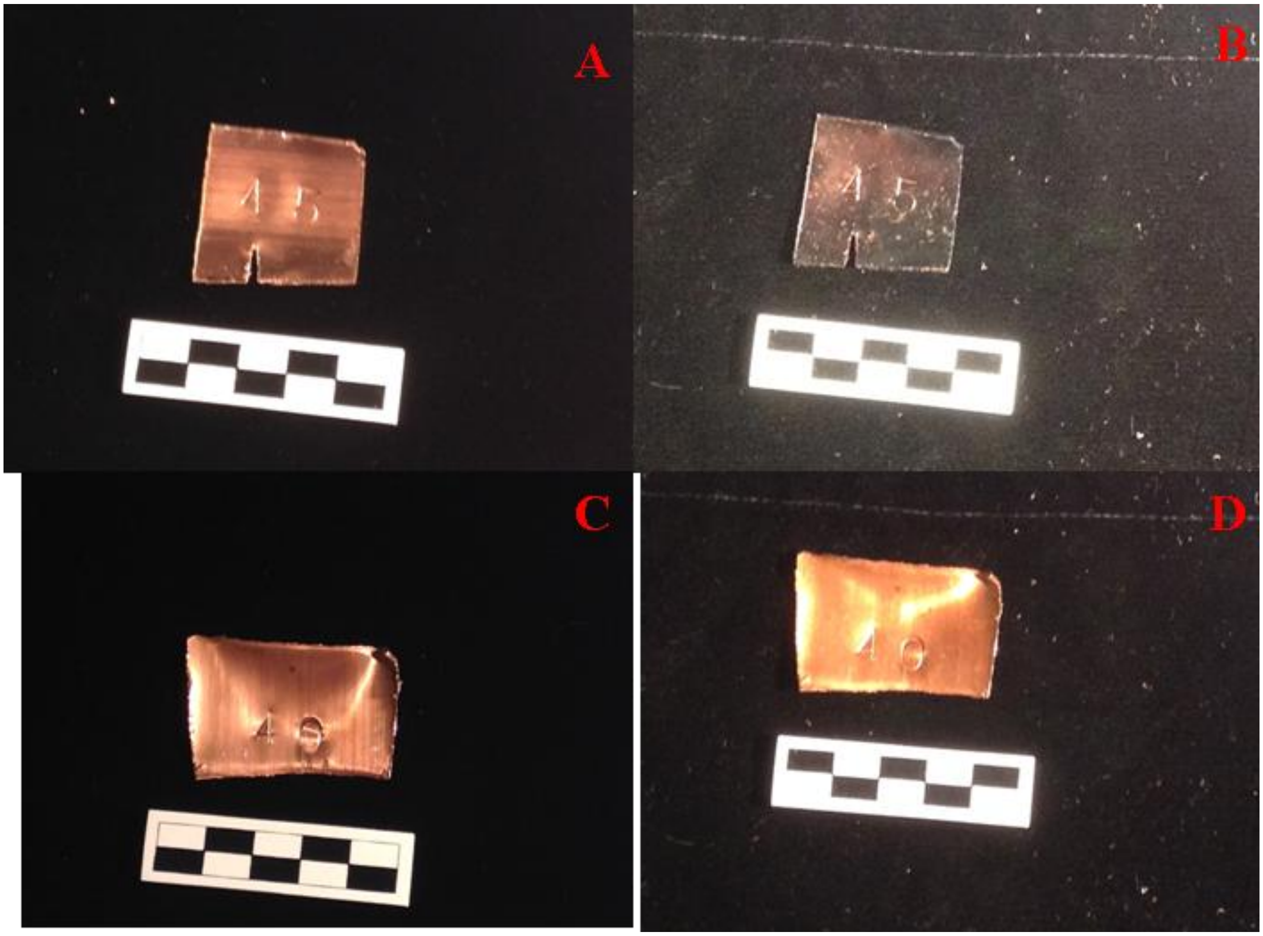

Figure 15. Example of range of how copper was affected by fire in woodland habitat. Piece 45 shows discoloration while piece 40 appears to be mostly unaltered.

Artifact physical changes (Grassland environment)

Chipped Stone Artifacts

The flakes in the grassland environment started with the same Munsell colors of brown (10 YR 3/2) and white (7.5YR 9.5/1) for the cortex on some pieces. For the most part the flakes in the grassland responded similarly to those in the woodland environment with no permanent color change but what appeared to be more darkening due to char residue. This could be because the finer grass fuels made more of a powdery substance which was easier to fill the small pores of the stone

Ground Stone Artifacts

The simulated stone axes on the grassland environment suffered even less damage than the ones in the woodland environment. Axe 1 had an unchanged Munsell color of Gley 1 5/10GY and axe 2 also had an unchanged color of 7.5 YR4/2. Like Axe 5, axe 2 was hafted using the same techniques and experienced the same insulating effect around the hafted portion of the head.

Copper

The copper artifacts also showed a range of discoloration but no evidence of significant damage (Figure 14). The temperature data from the grassland plot shows that the maximum temperature was nowhere near the melting point of copper and this fits the hypothesis that they would not be deformed, however, there were pieces that were unable to be cleaned back to their original state proving one prediction to be false. This was most evident in copper piece 15 as the surface had gone from the light red color 2.5YR 7/8 to a dark red 2.5YR 3/6.

Antler and Bone

The antlers and bones in the grassland plot were antlers 1 and 2 and bones 1 and 2. The antler Munsell colors were 2.5Y7/6 for antler 1 and 2.5Y8/4 for antler 2. Bones 1 and 2 were 2.5Y 9/2. Surprisingly, in the grassland plot the bones and antlers appeared to not be changed at all. These were dry brushed for cleaning and the minimal amount of soot was easily removed from their surfaces.

Leather

The elk hide in the grassland suffered similar patterns of damage as the woodland plot but to a lesser degree. The same shriveling, drying, and stiffening occurred but as mentioned in the earlier tables, lost only 12.5 percent of its weight.

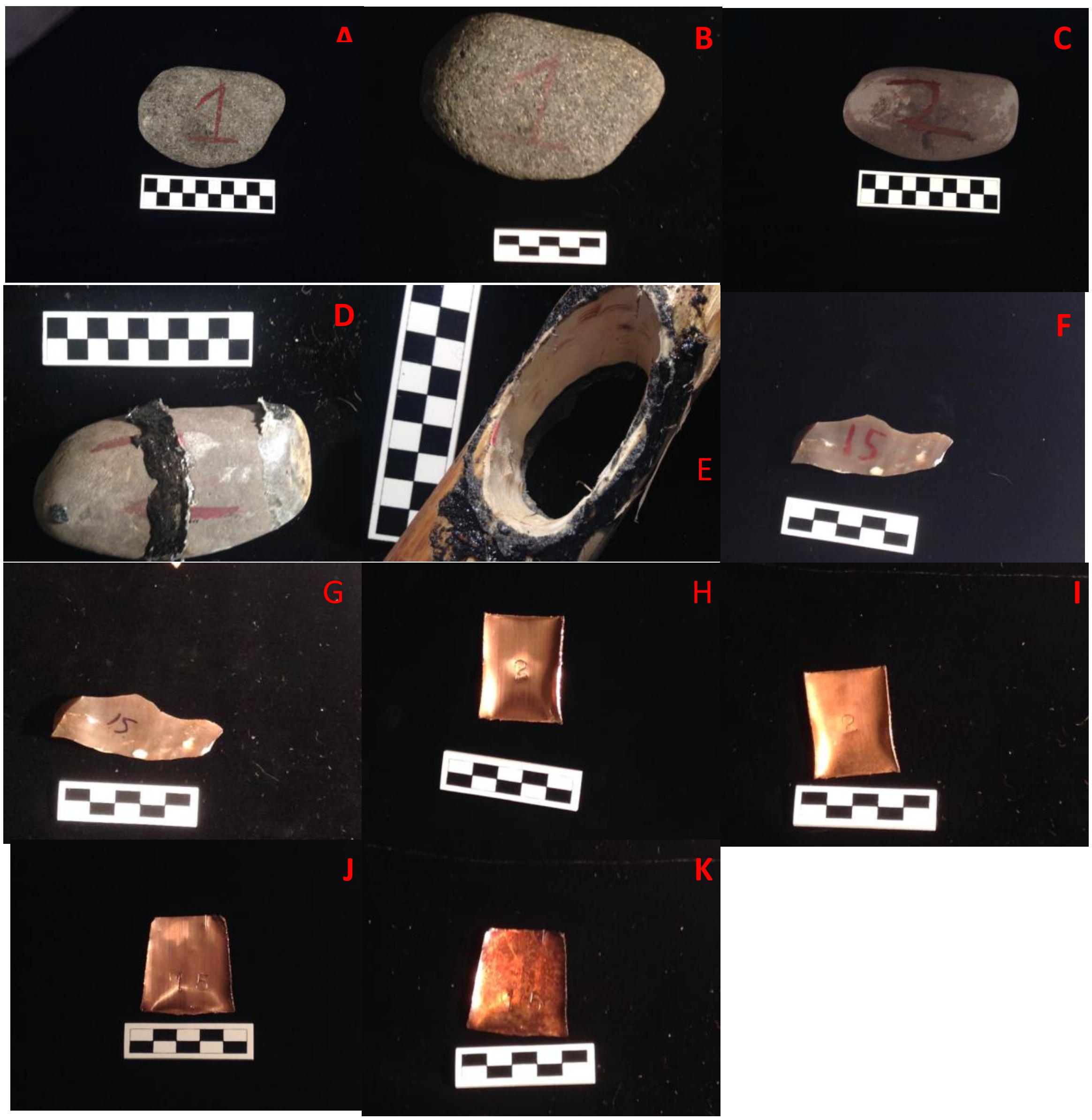

Figure 16. A. Axe 1 pre-burn. B. Axe 1 Post Burn. C. Axe 2 pre-burn D. Axe 2 Post Burn. E. Axe 2 Handle, note undamaged inside of haft similar to Axe 5. F. Flake 15 pre-burn G. Flake 15 post-burn. H. Copper 2 pre-burn. I. Copper 2 post-burn. J. Copper 15 pre-burn. K. Copper 15 Post-burn.

Figure 17. A. Hide 1 pre-burn. B. Hide 1 Post-Burn. C. Antler 2 pre-burn. D. Antler 2 post-burn. E. bone 2 Pre-burn. F. Bone 2 post-burn.

Chapter 5: Discussion and Conclusions

The experiment yielded some interesting results. The first contribution the experiment provides is that several classes of surface artifacts can undergo exposure to a prescribed burn reaching over 800° F and come out relatively unscathed while others sustain permanent alteration. The second contribution is that the experiment yielded a measurement of fire behavior as well as simulating a stage of site formation. While it is important to discuss what this experiment was it is perhaps more important to highlight what it was not. This experiment was not a long term study of site formation, but a simulation of what could happen under semi-unpredictable circumstances. This experiment was also not an exhaustive study of what fire can do to artifacts in all habitats in the state of Minnesota. The observations made in this experiment build on observations in previous studies (Buenger 2003, Sturdevant *et al* 2013).

Buenger (2003: Figure 2.1, 2.2, 2.3, 2.4) shows temperature data from grassland burns and while they produced slightly lower temperatures than this experiment, the graphs show one spike in temperature over a short period of time and yielded minimal changes to artifacts in the test plot. The temperatures in the grassland plot of this experiment achieved similar temperatures and burn durations to those seen in the Tallgrass Prairie National Preserve in Kansas from Sturdevant et al (2013) showing a short lived spike in temperature before returning back to ambient temperature (2013: Figure 26f). The authors note that out of the entire study, the artifacts in the grassland experienced the least amount of impact which is consistent with this experiment. In their recommendations for future research, Sturdevant et al (2013:71) wrote that data collected by land managers specific to the environment they preside over will help them make their decisions in management programs with respect to archaeology and fire. Expanding knowledge of how fire affects resources in their area may require additional partnerships with universities or archaeologists that are also qualified fire personnel.

Sturdevant et al (2013) also burned in an oak woodland setting at the Buffalo National River in Arkansas. The results from their woodland setting showed more significant impacts that this experiment. This is possibly due to a denser fuel load than what was burned in this experiment. Without the data to compare, it is unknown if the temperatures in the woodland setting of this experiment reached the same levels but burn durations were close to one of their woodland plots with 22 minutes 45 seconds while the woodland burn in this experiment lasted approximately 25 minutes. This suggests that similar environments across the United States can have similar expected results but testing the specific areas as mentioned by Sturdevant et al (2013) would be beneficial for land management decision making.

Additionally, this experiment shows what may have happened to sites that were burned in the past by indigenous people. The effects of the burns conducted for this experiment in general seem fairly minimal except for some location shift particularly in the woodland setting. If the artifacts hadn’t been recovered and subsequent burns had been conducted, those shifts in location from the fire in conjunction with other site formation processes might have changed the appearance of the site, but due to the amount of unburned material still on the ground surface it is likely that the effects would continue to be minimal on most of the artifacts. The potential severity of possible changes however will depend on factors like vegetation, slope, and fire severity. Johnson (2003) explains that fire can rapidly increase the speed of erosion allowing for artifacts to be carried away with sediment and debris. Since much of the Sherburne National Wildlife Refuge is flat, erosion may not be the as large a factor on archaeological sites. This also is likely due to the nature of prescribed burning and how the severity of the burns is intentionally less intense than in wildfires. In the past, Native Americans did not have access to the same equipment to manage an active fire but intentionally burning their landscape more frequently would allow for a similar control in the severity of wildfire.

Archaeological sites that were formed during Native American burns would likely experience the same effects as areas today that are managed with a regular pattern prescribed burning as long as the landscape had similar fuel loads. The differences are likely to come from Native Americans modifying heavier forested areas into landscapes we recognize today (e.g. deciduous woodland converted to oak savanna). Heavier fuel loads will produce larger fires which in turn would be expected to produce more severe effects. This is where it can be helpful to obtain paleobotanical samples on archaeological sites where fires in the past are suspected to have occurred in order to see how drastically the landscape may have been altered.

In this experiment, there appeared to be little to no effect on most of the replica artifacts. If they were subjected to the same conditions again in the context of intentional low intensity burns, it could take several burn seasons before any severe effects could be observed if at all. The question remains as to what can be said from sites that have obvious signs of burning such as potlidded chipped stone or calcined bones. The suggestion that can be made from this experiment is that artifacts displaying these effects would have been exposed to intense heat for longer periods of time. One source that can support this suggestion is Bennett (1998), in which researchers conducted an experiment that shows that thermal changes in bones can take hours to appear by burying bones at various depths and subjecting them to temperatures of up to 400 degrees Celsius. This would suggest that significantly altered bone found on sites was more likely to have been cooked intentionally or subjected to a long lasting wildfire rather than heated in a short lived prescribed fire.

This experiment acts as the first step towards understanding how site formation could have taken place on the Sherburne National Wildlife Refuge and what may have initially happened to sites left by Native Americans that were caught in a fire. As Johnson (2003:13) stated, "An awareness of how local materials and terrain respond to wildfire and the aftermath will usefully inform interpretation of fire history, prehistoric occupation, artifact distribution and excavated features." Another thing to consider from a land management perspective is that by continuing to manage lands with prescribed burning, land managers are continuing the cycle of cultural site formation while using what is considered by many to be a natural process. In areas like the Sherburne Refuge, this may not cause significant damage to sites as shown in this experiment. However, it is another reason why studies like this are important to show that these management practices could be adding to effects already imparted by anthropogenic burning from the past; or possibly causing effects not previously present on a site. This is why continued experimentation and study is necessary for understanding how fire has affected and continues to play a role in how sites are formed.

Recommendations for Future Research

Conducting experiments inside the organized chaos of a prescribed burn program are incredibly difficult to perform successfully from a logistical perspective. One of the largest challenges is fitting onto a program that is going to continue whether or not the experiment is set up correctly. In this case the cooperation wasn't only with refuge staff but additional fire resources and personnel brought in from other offices in the state. The amount of resources available dictates the size of burn that can be performed safely which in turn decides which established units can be worked. In the case of this experiment, the researcher was qualified as a wildland firefighter so they could participate in the burn as a fire resource once the test plots were placed. In the Sherburne National Wildlife Refuge there are over 20 of these established units and deciding where to place the experiment plots was a challenge. There were units that were on the refuge's priority list which helped narrow down the likely options but that left us to contend with another obstacle, weather. While forecasting weather can help decide which units will be available for burning that can cooperate with predicted wind patterns, the test plots had to be moved on multiple occasions and as a result, only two out of the three planned units were able to be burned.

To increase odds of a successful experiment, some strategies are presented. The first strategy would be to produce enough plots that can be placed in as many units as possible of varying habitats to increase the odds of getting them to be burned over. It would also be important to have plots placed in multiple units of the same fuel model so that in the event that more than one is burned they can be compared against each other. Another benefit to this strategy is that all of the location data can be obtained beforehand and not be rushed as experienced in this experiment. Another option would be to experiment with varying depths the artifacts can be placed at and compare damage and movement results of simulated underground sites. The only thing that would have to be deployed the day of the burn is the temperature tracking device if one is used. The downside to this strategy is that it could be more expensive and obtaining large amounts of raw materials may also be difficult. Another issue to consider is that even with enough preparation, there would still be a chance that weather or lack of resources would not allow for completion of all declared objectives. Another potential issue with burying replicated artifacts is the possibility of disturbing existing sites or losing the replica artifacts and creating a site unintentionally.

The second strategy is to have the resources for the plots ready to be placed the day of the burns as soon as the unit is confirmed. This had to be done with both of the plots in this experiment except all replica artifacts had to be moved from one location to another which took valuable time away from getting the plot ready before ignition. This strategy would allow for rapid deployment of the plots without as much of a rush allowing for more precise location data and plot placement depending on which kind of fire the investigator wants to expose the artifacts to.

The advantage to this plan is that researchers would not have to have as many plots prepared because they could place the sites at their discretion depending on the fuels model they want to experiment in. The disadvantage is the same as the other in that there is no guarantee of favorable burn conditions or that particular target habitats will be available due to weather patterns.

Other recommendations for further research would be to do a long term experiment where the sites aren't recovered after being burned but after multiple burn seasons with location data being collected multiple times during the process. This could act as a simulation of what Stewart *et al* (2009) wrote about how Native Americans regularly burned areas in their environments. This would allow researchers to view site formation in real time and to see if any patterns arise that are similar in archaeological deposits. One of the most likely patterns to notice would be the accumulation of charcoal in deposits. Snitker (2018) writes that humans actively transforming their environment using fire would cause more sedimentary charcoal accumulations than naturally occurring fires due to the frequency that humans burned. One common reason mentioned by Snitker is for agricultural purposes, but the other reasons outlined earlier like to improve hunting grounds would have had impacts on the fire regimes as well. With this in mind it would be likely that sites would be present within areas of increased sedimentary charcoal which may be observable on the Sherburne National Wildlife Refuge and in other areas of Minnesota.

Conclusion

The results of this experiment showed a mixture of falsified hypotheses with hypotheses that failed to be falsified. The first hypothesis was that the Knife River Flint in the woodland setting was expected to show signs of heat damage in the form of cracking or potlidding. In the grassland setting it was expected that there would be little to no observable damage but a heavier buildup of char residue. This hypothesis was falsified in both habitats as there was no observable damage and no discernible difference in the amount of charred residue between the habitats.

The second hypothesis was that the unhafted ground stone artifact in the woodland setting would suffer surface discoloration and possible heat spalling due to being collected on a shoreline and that they may have residual water retained in small cracks or pores in the rock. On the hafted stone axe it was expected that more surface damage underneath the hafted portion where the pitch glue and haft make contact with the stone would be observed. In the grassland setting, it was predicted that the duration of the burn would not be enough to cause surface damage to the unhafted stone. The hafted stone was thought to have a higher chance of damage for the same reason as the woodland setting if the pitch glue and handle were able to catch on fire. In both habitats, neither of the hafted axes experienced more damage in the area surrounded by the pitch glue, as the glue actually seemed protect the stone from damage so the hypothesis of the hafted axes and the potential spalling in the woodland setting was falsified. However, the hypothesis that the grassland burn would not be enough to cause damage to the unhafted stone was not falsified.

The third hypothesis was that the copper in the woodland setting was expected to show signs of color change and possible deformity. In the grassland setting, no damage was expected and it was hypothesized the pieces would be able to be cleaned to their original state in the laboratory portion of the experiment after the burns. The results showed that no deformity was present on pieces in the woodland setting and the grassland pieces did have some instances of color change that could not be cleaned so both portions of this hypothesis were falsified.

The fourth hypothesis was that the bones and antler pieces in both settings were predicted to experience permanent color change. It was not expected to observe any cracking or splitting in either setting because of what is written in Perez *et al* (2017). It was expected that the antlers would experience color change and react similarly to the way dry bone would without cracking or splitting. The bones and antlers in the woodland experienced slight darkening while the bones and antlers in the grassland setting appeared to be unaltered in color so this hypothesis was partially falsified.

The fifth hypothesis was that the elk hide was expected to be unrecoverable. In both settings, the hide was recovered but had experienced the highest amount of alteration of all the artifacts. It was still able to be recognized as hide and retained some hair so this hypothesis was falsified.

This experiment provided a unique perspective into how habitats are managed and how the management through the use of fire can impact archaeological resources. Starting with the woodland habitat it seems that the denser fuel load and difference in terrain incurred greater impacts on the experimental sites as the replica artifacts moved more and had more instances of physical alteration such as the elk hide losing a higher percentage of its weight and a higher degree of color change for the antler. The grassland plot showed that mild effects were present such as charred residue as well, but suffered less location disturbance. In both plots all artifacts were easily recovered and only the elk hide experienced total shape change and partial destruction in both plots where the expectation was that the hide would be completely destroyed. In both plots, the effects were less severe than the hypotheses expected. The grassland plot temperature data shows that in this instance, artifacts were able to be subjected to temperatures exceeding 800° F and be recovered relatively unscathed. While temperature data was not able to be collected for the woodland plot, the experiment showed that effects were still minimal even though the site burn duration was approximately five and a half times as long as the grassland. Analysis of the before and after locations of the artifacts suggests that several artifacts in the woodland did move a measurable amount and in some cases of the flakes and copper turned over completely while artifacts in the grassland stayed closer to their original locations. There was an issue with measuring elevation differences which is attributed to human error.

This experiment was a challenging but rewarding experience in experimental archaeology. The experiment allowed the researcher to view a site formation process on a small scale in two common habitats of central Minnesota. This baseline data is a stepping stone towards a greater understanding of fire and its interaction with cultural resources. Perhaps the most significant thing learned from this experiment is that while fire certainly has the potential to do damage to sites, in this region that potential may be the most likely in out of control wildfires. Their uncontrolled nature allows them to grow larger and more out of control than the prescribed fires that are used as prevention tools and actually can act as a form of protection. Many of the formation processes mentioned by Schiffer (1983) and others involve some level of potential data loss as their result. It is important to recognize that these processes have occurred repeatedly in the past and recognizing the patterns they generate may not replace that data but may allow researchers to design their research in a way that mitigates how much is lost. Hopefully future experiments involving fire and archaeology are conducted to increase baseline knowledge and allow land managers to adopt management practices that are beneficial to the lands they are stewards of, as well as the cultural resources within their jurisdictions.

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Appendix A- Pre and post burn location coordinates for woodland plot

	Artifact #	Easting	Northing	Elevation
KRF	61	95.659	94.459	10.431
	62	95.602	94.504	10.449
	63	95.537	94.557	10.444
	64	95.485	94.596	10.452
	65	95.448	94.623	10.452
	66	95.427	94.654	10.452
	67	95.389	94.673	10.447
	68	95.397	94.73	10.429
	69	95.297	94.763	10.422
	70	95.246	94.791	10.401
	71	95.73	94.536	10.451
	72	95.704	94.569	10.448
	73	95.641	94.605	10.437
	74	95.598	94.62	10.437
	75	95.557	94.648	10.436
	76	95.525	94.698	10.408
	77	95.495	94.74	10.438
	78	95.469	94.775	10.398
	79	95.39	94.835	10.438
	80	95.37	94.885	10.437
	81	95.906	94.665	10.388
	82	95.868	94.694	10.392
	83	95.813	94.724	10.401
	84	95.781	94.778	10.396
	85	95.756	94.796	10.392
	86	95.698	94.88	10.392
	87	95.686	94.923	10.382
	88	95.636	94.928	10.392
	89	95.602	94.957	10.396
	90	95.63	95.025	10.434
copper	31	94.712	93.728	10.476
	32	94.661	93.751	10.477
	33	94.614	93.76	10.443
	34	94.583	93.778	10.484
	35	94.555	93.834	10.483

	36	94.762	93.773	10.475
	38	94.648	93.862	10.468
	39	94.59	93.89	10.43
	40	94.54	93.963	10.421
	41	94.793	93.878	10.472
	42	94.753	93.907	10.473
	43	94.72	93.979	10.497
	44	94.653	94	10.468
	45	94.604	94.042	10.475
antler	5	96.085	92.765	10.62
	6	96.116	92.878	10.611
bone	5	96.482	94.042	10.468
	6	96.548	94.194	10.474
axes	5	93.55	94.779	10.482
	6	93.461	94.888	10.42
hide	3	94.919	95.549	10.33

Post Burn Woodland coordinates

	Artifact #	Easting	Northing	Elevation
KRF	61	95.661	94.481	10.429
	62	95.602	94.52	10.444
	63	95.531	94.576	10.442
	64	95.482	94.609	10.45
	65	95.453	94.644	10.45
	66	95.427	94.675	10.449
	67	95.387	94.694	10.445
	68	95.373	94.736	10.43
	69	95.298	94.788	10.432
	70	95.246	94.83	10.434
	71	95.72	94.527	10.44

	72	95.704	94.627	10.437	
	73	95.597	94.63	10.436	on top of 74
	74	95.589	94.641	10.436	
	75	95.556	94.669	10.437	
	76	95.519	94.715	10.413	
	77	95.47	94.727	10.433	flipped over
	78	95.471	94.788	10.402	
	79	95.391	94.879	10.439	
	80	95.361	94.901	10.432	
	81	95.92	94.704	10.409	
	82	95.885	94.732	10.416	
	83	95.844	94.825	10.403	
	84	95.78	94.813	10.41	
	85	95.782	94.837	10.42	
	86	95.708	94.925	10.409	
	87	95.691	94.931	10.411	touching 86
	88	95.681	94.933	10.415	flipped over
	89	95.626	94.974	10.417	
	90	95.631	95.037	10.431	
	31	94.701	93.749	10.47	
	32	94.651	93.762	10.473	
	33	94.623	93.797	10.457	
	34	94.6	93.817	10.459	on top of 33 partially
	35	94.559	93.847	10.473	
	36	94.76	93.8	10.475	
	38	94.633	93.878	10.46	
	39	94.599	93.904	10.455	rolled over onto 40
	40	94.535	94.002	10.453	
	41	94.792	93.889	10.472	
	42	94.747	93.919	10.479	
	43	94.718	94.016	10.488	
	44	94.659	94.005	10.469	flipped over
	45	94.532	94.01	10.459	
antler	5	96.085	92.774	10.602	
	6	96.088	92.894	10.615	

bone	5	96.501	94.048	10.466
	6	96.548	94.208	10.456
axes	5	93.553	94.801	10.477
	6	93.46	94.904	10.412
hide	3	94.878	95.961	10.347

Appendix B. Pre and post burn coordinates for grassland plot

Pre Burn

plot 1	KRF	Easting	Northing	elevation
grassland	1	103.602	104.096	9.77
	2	103.606	104.169	9.762
	3	103.601	104.258	9.764
	4	103.611	104.338	9.767
	5	103.604	104.389	9.76
	6	103.638	104.441	9.768
	7	103.634	104.503	9.773
	8	103.652	104.582	9.771
	9	103.647	104.632	9.773
	10	103.662	104.686	9.78
	11	103.728	104.085	9.761
	12	103.714	104.157	9.758
	13	103.726	104.218	9.781
	14	103.73	104.293	9.774
	15	103.73	104.352	9.778
	16	103.727	104.424	9.774
	17	103.736	104.469	9.777
	18	103.728	104.539	9.771
	19	103.752	104.601	9.771
	20	103.728	104.647	9.787
	21	103.836	104.092	9.772
	22	103.835	104.155	9.782
	23	103.824	104.201	9.777
	24	103.825	104.261	9.79
	25	103.823	104.336	9.782
	26	103.824	104.394	9.78
	27	103.827	104.458	9.786
	28	103.856	104.513	9.793
	29	103.858	104.469	9.789
	30	103.876	104.617	9.782
copper	1	104.549	106.434	9.799
	2	104.377	106.389	9.809
	3	104.223	106.423	9.837
	4	104.171	106.43	9.805
	5	104.075	106.433	9.808

	6	103.985	106.479	9.83
	7	103.9	106.495	9.826
	8	103.794	106.506	9.831
	9	103.709	106.524	9.829
	10	103.607	106.531	9.835
	11	104.331	106.618	9.865
	12	104.194	106.637	9.828
	13	104.062	106.682	9.845
	14	103.955	106.705	9.84
	15	103.827	106.733	9.857
antler	1	102.388	106.647	9.872
	2	102.342	106.511	9.873
bone	1	102.181	103.952	9.822
	2	102.189	104.094	9.857
axes	1	105.995	107.194	9.781
	2	106.231	107.258	9.808
hide	1	106.309	104.632	9.707

Post Burn

		E	N	el
KRF	1	103.591	104.11	9.794
	2	103.594	104.185	9.801
	3	103.596	104.267	9.798
	4	103.583	104.345	9.795
	5	103.594	104.395	9.806
	6	103.631	104.44	9.793
	7	103.627	104.517	9.807
	8	103.626	104.598	9.81
	9	103.638	104.634	9.803
	10	103.655	104.685	9.809
	11	103.724	104.103	9.794
	12	103.712	104.162	9.786

	13	103.718	104.218	9.81
	14	103.723	104.299	9.811
	15	103.717	104.36	9.812
	16	103.72	104.435	9.8
	17	103.728	104.476	9.807
	18	103.725	104.541	9.81
	19	103.744	104.608	9.806
	20	103.776	104.647	9.818
	21	103.822	104.13	9.807
	22	103.815	104.17	9.817
	23	103.823	104.212	9.81
	24	103.816	104.269	9.819
	25	103.8	104.355	9.808
	26	103.815	104.41	9.807
	27	103.833	104.461	9.815
	28	103.856	104.524	9.813
	29	103.854	104.567	9.828
	30	103.865	104.62	9.818
copper	1	104.544	106.444	9.82
	2	104.372	106.391	9.841
	3	104.217	106.441	9.848
	4	104.161	106.433	9.84
	5	104.096	106.43	9.846
	6	103.979	106.48	9.843
	7	103.9	106.496	9.847
	8	103.788	106.516	9.845
	9	103.703	106.528	9.849
	10	103.616	106.533	9.856
	11	104.336	106.637	9.842
	12	104.19	106.652	9.852
	13	104.058	106.693	9.861
	14	103.954	106.711	9.854
	15	103.823	106.745	9.866
antler	1	102.385	106.65	9.886
	2	102.352	106.52	9.887

bone	1	102.174	103.967	9.849
	2	102.173	104.107	9.859
axes	1	105.998	107.194	9.816
	2	106.18	107.259	9.812
hide	1	106.727	104.597	9.713

Appendix C. Pre and post burn measurements of maximum length, width, thickness, and weight

Pre-Burn

flake number	pre length	pre width (mm)	pre thickness (mm)	pre weight (g)
1	57.71	40.02	4.18	12
2	57.73	41.78	10.22	24
3	60.75	16.8	4.75	5
4	43.25	37.45	7.7	11
5	70.16	27.63	10.48	16
6	36.9	24.95	6.44	5
7	59.31	36.69	8.1	18
8	45.08	34.49	11.18	13
9	48.32	19.57	5.83	8
10	32.49	27.39	4.6	4
11	53.74	17.12	6.07	6
12	48.87	28.72	7.49	8
13	61.62	43.09	14.19	22
14	62.85	45.6	12.31	30
15	66.3	24.33	12.06	16
16	59.27	28.51	13.54	17
17	47.12	30.23	13.33	18
18	65.61	14.94	10.25	10
19	38.31	22.28	5.72	5
20	53.15	35.72	12.91	17
21	40.02	26.78	8.77	6
22	46.79	22.89	10.48	11
23	49.96	22.69	10.44	9
24	39.83	22.12	6.79	5
25	51.48	22.14	5.1	5
26	37.53	23.44	8.3	5
27	57.29	38.63	5.5	11
28	35.55	25.04	6.98	4
29	36.25	27.73	7.34	6
30	41.35	31.08	4.72	7
61	53.99	31.57	8.14	13
62	62.98	50.88	14.3	44
63	43.84	32.41	7.59	9
64	45.83	32.8	15.1	20
65	34.35	26.98	4.69	6
66	41.69	21.73	1.98	3

67	34.87	15.34	2.18	2
68	28.04	25.47	9.29	5
69	24.89	23.09	3.38	2
70	36.22	21.73	3.38	3
71	53.08	35.47	11.12	16
72	49.47	35.79	7.29	11
73	39.82	18.52	7.02	5
74	36.93	20.24	3.28	2
75	28.3	23.11	4.06	2
76	28.73	19.83	3.98	1
77	34.75	23.87	3.85	3
78	31.72	23.97	3.05	3
79	36.46	23.09	11.78	11
80	54.2	38.86	10.99	25
81	28.41	24.97	2.58	2
82	29.68	24.51	5.81	3
83	35.96	24.14	5.79	3
84	24.13	21.84	4.61	3
85	37.42	24.34	6.2	3
86	23.96	18.65	6.51	3
87	30.84	29.2	7.27	4
88	29.67	19.94	3.82	3
89	37.31	16.96	4.2	2
90	89.16	62.89	12.06	47

Copper number	length mm	width mm	thickness mm	weight g
1	35.35	33.18	0.84	9
2	40.84	31.5	0.94	10
3	30.82	29.17	1.09	6
4	34.07	26.12	0.98	6
5	35.72	24.54	0.93	5
6	31.97	26.01	0.97	6
7	33.95	32.39	0.85	8
8	34.13	32.86	0.91	9
9	35.04	24.39	1.1	5
10	35.04	24.97	0.88	6
11	32.46	30.29	0.8	6
12	31.95	25.29	0.9	6
13	33.35	28.22	0.95	7
14	43.3	26.48	1.01	8

15	41.35	40.32	0.89	11
31	38.29	24.47	0.96	7
32	30.26	24.56	1.04	5
33	32.78	29.43	0.99	7
34	34.13	28.34	0.9	8
35	29.68	26.68	1.06	6
36	35.85	29.69	0.81	7
38	32.09	32.77	1.01	9
39	36.28	32.46	0.84	8
40	43.47	27.68	1.01	9
41	37.89	25.52	0.95	7
42	29.46	25.29	1.02	5
43	44.9	24.2	1.04	8
44	31.05	25.16	0.84	6
45	32.2	31.33	0.86	7
antler number	Length mm	Width mm	Thickness mm	Weight g
1	232.63	26.54	20.01	103
2	183.32	22.67	19.1	67
5	130.57	37.11	24.52	102
6	115.56	54.62	33.02	137
1	220.59	19.95	18.3	107
2	245.35	21.36	16.86	106
5	250.5	20.74	18.06	112
6	215.01	20.03	18.72	106
Hide piece number	length	width	thickness	weight
1	380	311	1.11	76
3	520	275	1.38	113
axe number	length	width	thickness	weight
1	115.84	72.88	36.21	452
2	128.38	66.49	28.17	483
5	126.87	54.27	32.94	326
6	96.66	47.19	27.07	194

Post Burn

flake number	pb length mm	pb width mm	pb thickness mm	pb weight g
1	57.87	40.01	4.27	11.85
2	57.87	42.39	10.23	22.94
3	60.45	16.53	5.15	5.77

4	43.56	37.82	7.68	10.67
5	70.2	26.42	10.89	16.66
6	36.9	24.55	6.61	4.77
7	59.24	39.68	8.12	18.45
8	44.66	33.71	11.03	11.68
9	49.65	19.58	5.81	7.57
10	32.42	28	4.62	3.25
11	54.39	17.52	6.31	5.98
12	48.45	27.46	7.74	8.45
13	61.46	42.57	14.01	22.49
14	62.69	46.53	12.45	29.01
15	65.88	24.39	12.05	15.79
16	59.39	28.55	17.41	17.01
17	47.07	30.54	13.03	18.22
18	65.62	15.07	9.72	9.81
19	39.79	22.79	5.88	4.73
20	53.71	35.57	12.94	16.15
21	39.87	26.92	8.37	6.55
22	46.64	22.51	10.75	10.89
23	49.65	22.18	10.76	9.67
24	39.69	21.75	6.95	5.47
25	45.45	22.32	5.18	4.04
26	37.25	24.29	8.21	4.91
27	57.28	37.47	5.77	9.88
28	35.02	25.62	6.97	3.5
29	35.95	27.82	7.22	6.15
30	41.01	30.88	4.86	6.64
61	52.8	32	8.24	13.02
62	62.95	50.57	15.94	44.31
63	43.75	32.66	7.46	9.57
64	46.1	34.52	15.2	20.29
65	33.76	26.47	4.84	5.67
66	42.33	22.53	2.51	2.51
67	35.3	15.45	1.98	1.46
68	29	26.8	10.15	5.7
69	24.89	22.77	3.6	2.1
70	36.49	21.62	3.55	2.16
71	52.91	35.07	10.74	16.31
72	49.48	35.88	7.55	11.22
73	40.26	18.05	6.68	4.96
74	36.38	20.17	3.15	2.55

75	27.74	24.41	3.97	2.04
76	28.05	20.19	3.91	1.35
77	35.22	23.84	3.06	2.38
78	31.99	24.3	2.3	2.74
79	36.1	19.5	11.55	10.81
80	53.39	38.94	10.08	25.05
81	28.33	24.91	2.43	1.95
82	29.2	23.65	6.19	3.45
83	36.15	23.76	5.61	2.99
84	24.67	21.06	4.95	1.86
85	37.66	24.16	6.78	3.67
86	23.48	18.31	6.25	3.29
87	31.98	28.92	7.34	3.74
88	24.29	20.08	4.66	2.41
89	36.49	17.3	4.06	1.85
90	88.76	63.47	12.2	46.87
Copper number	pb length mm	pb width mm	pb thickness mm	pb weight g
1	35.36	33.23	0.85	8.76
2	40.84	31.58	0.91	9.87
3	30.56	29	1.05	6.69
4	34.56	26.2	0.92	6.32
5	35.77	24.71	0.96	6.61
6	32.07	26.15	0.94	6.12
7	33.78	32.48	0.85	7.99
8	33.92	33.02	0.9	8.22
9	35.23	24.2	1.05	6.3
10	35.02	24.99	0.88	6.4
11	32.57	30.12	0.83	6.03
12	32.06	25.33	0.91	5.98
13	33.25	28.26	0.95	6.94
14	43.53	26.54	0.97	8.51
15	41.58	41.32	0.89	11.31
31	25.35	0.92	7.47	7.5
32	25.58	1.03	5.29	5.28
33	30.38	0.93	6.78	6.75
34	28.27	0.87	7.21	7.23
35	27.61	0.96	5.97	5.99
36	29.02	0.97	7.13	7.15
38	32.77	1.01	7.95	7.95
39	32.67	0.84	8.14	8.15

40	27.75	1.05	9.15	9.15
41	25.79	1.02	7.01	7.01
42	25.46	1.05	5.2	5.2
43	24.48	0.96	8.45	8.46
44	24.6	0.88	5.53	5.52
45	30.85	0.91	7.6	7.6

antler number	pb length mm	pb width mm	pb thickness mm	pb weight g
1	228.85	25.57	20.1	103.61
2	184.55	22.44	18.8	68.48
5	133.24	37.18	24.74	103.37
6	114.45	54.66	31.38	139
Bone Number	pb length	pb width	pb thickness	pb weight
1	218.43	19.41	18.05	107.01
2	244.53	21.75	16.3	106.5
5	252.28	20.72	17.4	112.1
6	214.77	20.22	18.67	105.92

Hide number	pb length mm	pb width mm	pb thickness mm	pb weight g
1	136.24	122.35	1.78	66.52
3	250	140	2.79	82.6