



EXPLORING THE
WILDLAND FIRE AND
ARCHEOLOGY INTERFACE
IN THE MIDWEST: AN
EXPERIMENTAL PROGRAM
TO INVESTIGATE
IMPACTS FROM FIRE
ON ARCHEOLOGICAL
RESOURCES.

By
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United States Department of the Interior
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Midwest Archeological Center
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ABSTRACT

Today, public land managers must routinely balance the restoration needs of natural resources with the preservation of cultural resources. This project was designed to provide parks with scientific data on the interface between wildland fire and archeological resources at NPS units in the Midwest Region. Between 2006-2009 experimental research was conducted at six NPS units to record data on fire conditions (i.e., fuels, fire temperature, and burn duration) and the impacts on multiple classes of archeological materials routinely observed at sites within the region. The experimental study of fire conditions in different regional environments addresses questions regarding the threats or non-threats to multiple archeological resource types. By gaining a more thorough understanding of the fire/archeology interface at select parks in different ecosystems, park managers will be able to more effectively coordinate the needs of natural resource management with archeological resource preservation.

INTRODUCTION

Natural processes are never distant abstractions influencing the archeological record. As a natural and culturally induced landscape modifier and maintainer, fire has played a primary role in the evolution of North American ecosystems since humans first arrived during the last Ice Age (Pyne 1997; Vale 2002). Fire not only creates many of the archeological phenomena routinely investigated by archeologists (e.g., structural remnants, hearths, smudge pits, pottery, charcoal, etc.) but it also contributes to the ongoing modification of archeological sites and materials available for study.

The interface between wildland fire and archeological resources has become a crucial topic of study with ramifications for understanding the formation of the archeological record and archeological preservation. Considered a formal undertaking that requires an assessment of effect under Section 106 of the National Historic Preservation Act, wildland fire-use consistently has a direct linkage to questions of archeological site preservation. Today, park managers must routinely balance the restoration needs of natural resources with the preservation of cultural resources. The use of fire to achieve land management goals is becoming frequently employed by government land managers, non-profit organizations (e.g., The Nature Conservancy), and private land holders across the country. At the present time, many land managers are forced to make decisions about the use of fire and the preservation of archeological resources without the benefit of scientific data that would enhance the decision making process and allow a more effective use of fire without impairing the preservation of the archeological record. With more frequent and widespread applications of prescribed fire being used to achieve land management goals comes the need to determine the impacts to archeological resources and find ways to reduce or mitigate these impacts. There is also a need to begin to understand how, under certain conditions, fire-use may enhance archeological resource preservation over the long-term.

Previous studies have demonstrated that wildland/prescribed fire can have significant impacts on the archeological record and potentially lead to the loss or destruction of information about past cultural groups. Impacts to archeological resources, whether heavy or light, typically are a result of several factors including deposition context, burn duration and temperature, amount of fuel consumption, and artifact material type (Figure 1) (Buenger 2003). Burn duration and intensity are directly related to available fuels and firing technique used (i.e., backing, flanking, or head fire), and are a key indicator of potential impacts. Archeological studies on fire effects have ranged from pre- and post-burn archeological inventories used to assess the impacts or potential impacts on archeological resources (Buenger 2003; Cannon and Phillips 1993; Connor, Cannon, and Carlevato 1989; Haines and Schofer 2008; Hester 1989; Hough et al. 2005; Tratebas et al. 2004; Traylor et al. 1990) to materials studies that have provided baseline information on the specific impacts fire has on archeological materials (Bennett 1999; Buenger 2003; Cannon, and Carlevato 1989; Cavaioli 2002; Deal 2002; Haecker 2002; Lentz et al. 1996; Loyd et al. 2002; Picha et al. 1991; Scott 1979; Saylor, Seabloom, and Ahler 1989; Switzer 1974; Winthrop 2004). These studies provide useful and relevant information concerning fire conditions and effects observed in many areas throughout the country and have shown that impacts to the archeological record can range from

negligible to severe. However, most previous studies are based on fire conditions and archeological resources in areas of the United States where major wildland fires occur on an annual basis, primarily the Intermountain and Southwest regions. Most regions outside of the western United States have little or no baseline information that can be used to evaluate or predict the effects of fire on archeological resources. Prior to the current study, most Midwest Region parks lacked specific information concerning the local fire conditions and impacts to archeological resources.

Input Variables That Influence Fire Impacts

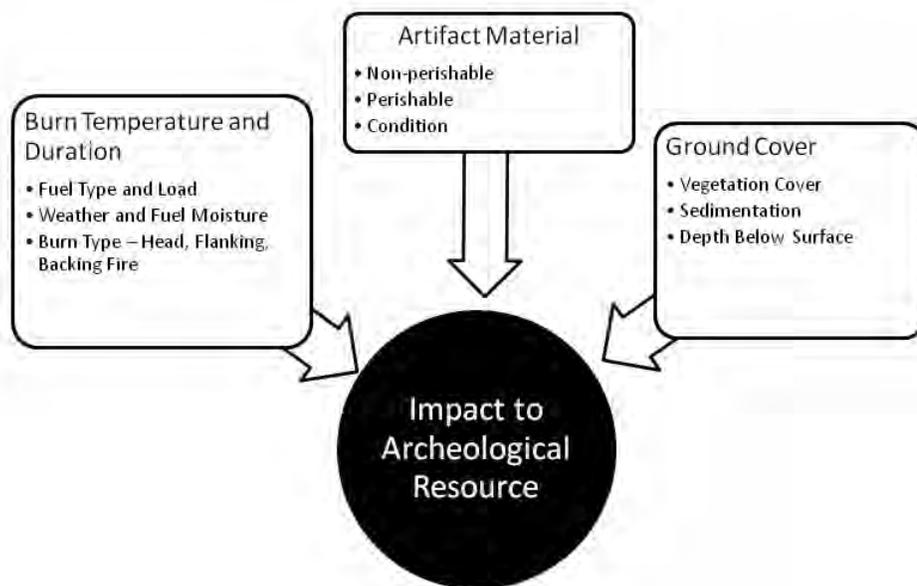


Figure 1. Variables that affect the outcome impacts from wildland fire on archeological materials.

GOALS AND OBJECTIVES

The objective of this project was to conduct experimental burns at six National Park Service (NPS) units in the Midwest Region (Figure 2). These experiments addressed questions regarding local fire conditions and the potential impacts to archeological resources. Each park contains a unique set of conditions and archeological resources from which data can be collected and modeled that will be widely applicable to other parks in the region. Two parks were selected from three environmental zones in the Midwest Region: (1) Great Plains; (2) Great Lakes/Eastern Woodlands; and (3) Ozark

Highlands. Experiments were designed to accurately model the typical fire conditions and archeological resources at each park. Outcomes from these experiments include (1) accurate data on the temperature and duration of fires, (2) a record of the macro-scale impacts on archeological resources, (3) an assessment of the impacts to archeological resources, and (4) recommended alternatives for mitigating the impairment of the archeological record.

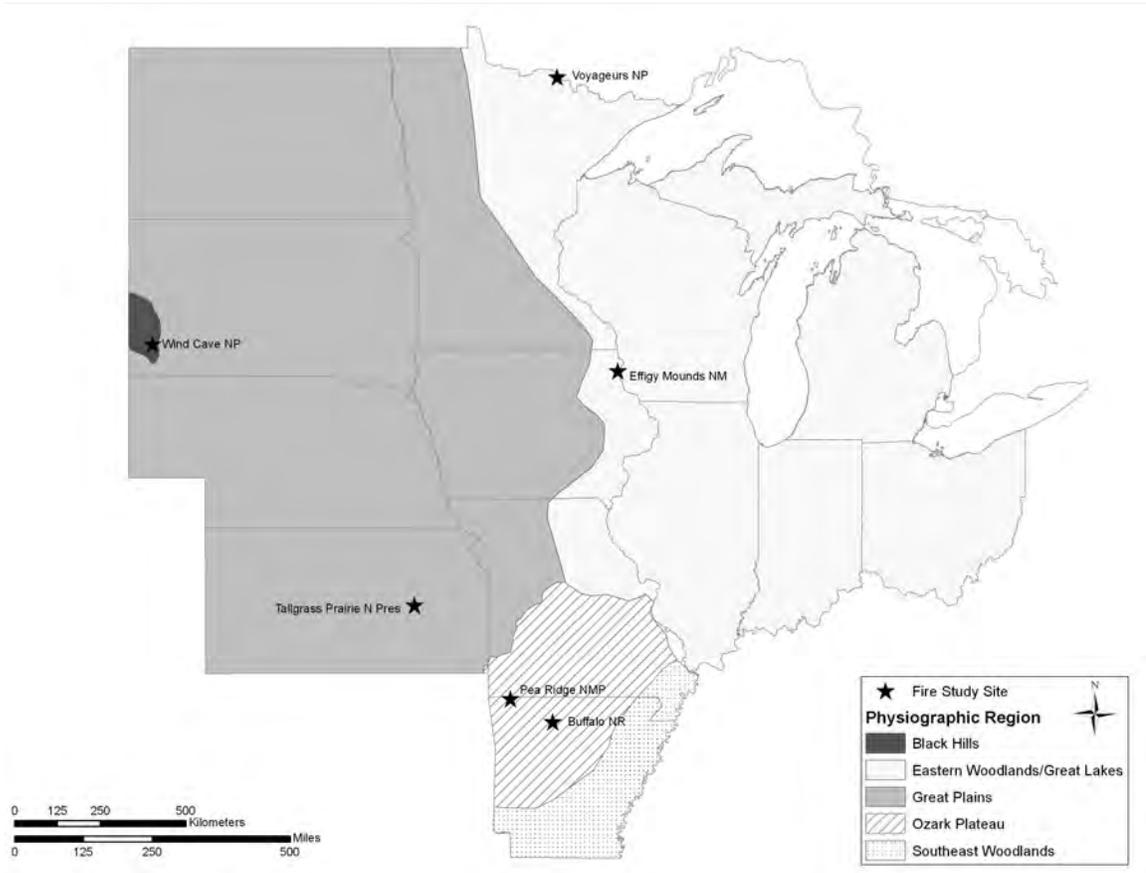


Figure 2. Map of the NPS Midwest Region illustrating the six parks included in this study.

Study parks were chosen to reflect the regional diversity of environmental zones, archeological resources, and burn programs throughout the Midwest Region. Experimental burn locations and times were chosen at each park with the following criteria: (1) experimental plots were placed at locations that reflect typical burn conditions (i.e., fuel types, fuel loads, moisture content, seasonality), (2) experiment plots utilized materials representative of archeological resources that are representative of each park, (3) experiments were undertaken in conjunction with prescribed burns already planned and scheduled by each park, hence meeting all the statutory and regulatory requirements of the NPS wildland fire program, (4) test plots were accessible and did not require extraordinary efforts to undertake the experimental burns and recording of archeological data.

The fire/archeology interface experiments addressed multiple questions relating to the fire conditions and archeological resources at each selected park. Research

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questions addressed during the experimental study include: (1) what are the fire conditions typical for environmental zones within each park, (2) what conditions are created when different firing techniques are used (head, backing, flanking), (3) what impacts (if any) can be observed on artifacts subjected to different firing techniques (head, flanking, backing fires), (4) what environmental/fire conditions produce changes in surface archeological materials, (5) what artifact classes are most and/or least impacted during the experimental burns, and (6) how permanent are the impacts from wildland fire and which impacts can be removed due to natural artifact weathering or by conservation cleaning in a laboratory?

This experimental project is directly related to a pilot study conducted by the Midwest Archeological Center (MWAC) in 2005 at Knife River Indian Villages National Historic Site (KNRI), North Dakota (Sturdevant 2006). The KNRI study was developed to address the prescribed burning of grasslands within medium density archeological sites. The 2005 experiments used local fire conditions at the park to evaluate multiple firing techniques (head, backing, and flanking) during two different burn seasons (Spring and Fall) in an effort to determine the types of burns and techniques with the least potential to impact surface archeological resources. The KNRI study benefited the park by addressing knowledge gaps regarding fire conditions (i.e. provided data on fire temperature/duration for multiple fire types) and the impacts to local archeological resources. The park now has current baseline information to move forward with a native prairie restoration program that will address issues of archeological resource preservation prior to prescribed burning by defining the fire techniques and burn season with minimal potential to impact surface archeological resources.

OVERVIEW OF NATIONAL PARK SERVICE STUDY SITES

The National Park Service's Midwest Region covers a vast area of thirteen states and includes several distinct regional ecosystems from the Great Lakes to the Central Great Plains. Midwest Region parks also include a diverse set of archeological resources from 12,000 year old prehistoric sites to homes of former U.S. Presidents, historic Euro-American farmsteads, prehistoric mound sites, Civil War battlefields, and 18th to 19th century Native American villages. This region-wide diversity of ecosystems and archeological resources makes a "one size fits all" approach to the fire/archeology interface problematic. Therefore, a region-wide, multi-park, multi-environment experimental project was developed to provide scientific data specifically relevant to the local fire management and archeological resource needs of a wide range of parks.

BUFFALO NATIONAL RIVER (BUFF), ARKANSAS

Located in the Ozark Highlands of north-central Arkansas, the Buffalo National River covers 135 miles of river encompassing 94,000 acres with numerous ecological zones including wooded uplands, riparian lowlands, springs, sinkholes, and small creeks and drainages (Figure 3). BUFF has an active prescribed burn program that is employed to promote and restore the Ozark woodland ecosystem. The park routinely conducts pre-burn archeological inventories prior to each burn in an attempt to locate, identify, record, and make recommendations for significant or potentially significant archeological resources that may be impacted or destroyed by fire. Currently, there are 650 known archeological sites recorded at BUFF. Examples of archeological resources include prehistoric bluffshelters and open village sites, historic Euroamerican homesteads, and late 19th century mining towns (Catton 2008; Sabo et al. 1990). Impacts of fire on the historic sites at BUFF are of particular interest since many have materials that can be damaged or destroyed by fire including wood, bone, shell, and leather. Prior to this study, there was scant scientific information available to evaluate fire conditions and the potential impacts at a local level in different ecozones (e.g., uplands vs. river terraces) and on multiple archeological resource types (e.g., prehistoric lithic scatters, historic farmsteads, etc.). Consequently, park managers have been forced to consider many types of archeological resources susceptible to impacts from fire without any scientific data to support their decision making and conclusions.

The vegetation of Buffalo River is composed mostly of variable (60 to 100% cover) canopy mixed-oak forests and dry woodlands which include oak, oak-hickory, oak-pine, and pine woodland communities with oak-hickory as the most predominant type. Typically the dominant species are white oak (*Quercus alba*), black oak (*Q. velutina*), mockernut hickory (*Carya alba*) and sweetgum (*Liquidambar styraciflua*). Some differences may be on cool moist sites dominated by American beech (*Fagus grandifolia*) or dryer sites with post oak (*Q. stellata*) and blackjack oak (*Q. marilandica*). South-facing slopes may be dominated by shortleaf pine (*Pinus echinata*) while species such as eastern red cedar (*Juniperus virginiana*) and honey locust (*Gleditsia triacanthos*) may be present in areas recently cleared or having experienced an absence of fire (Johnson and Schnell 1988).

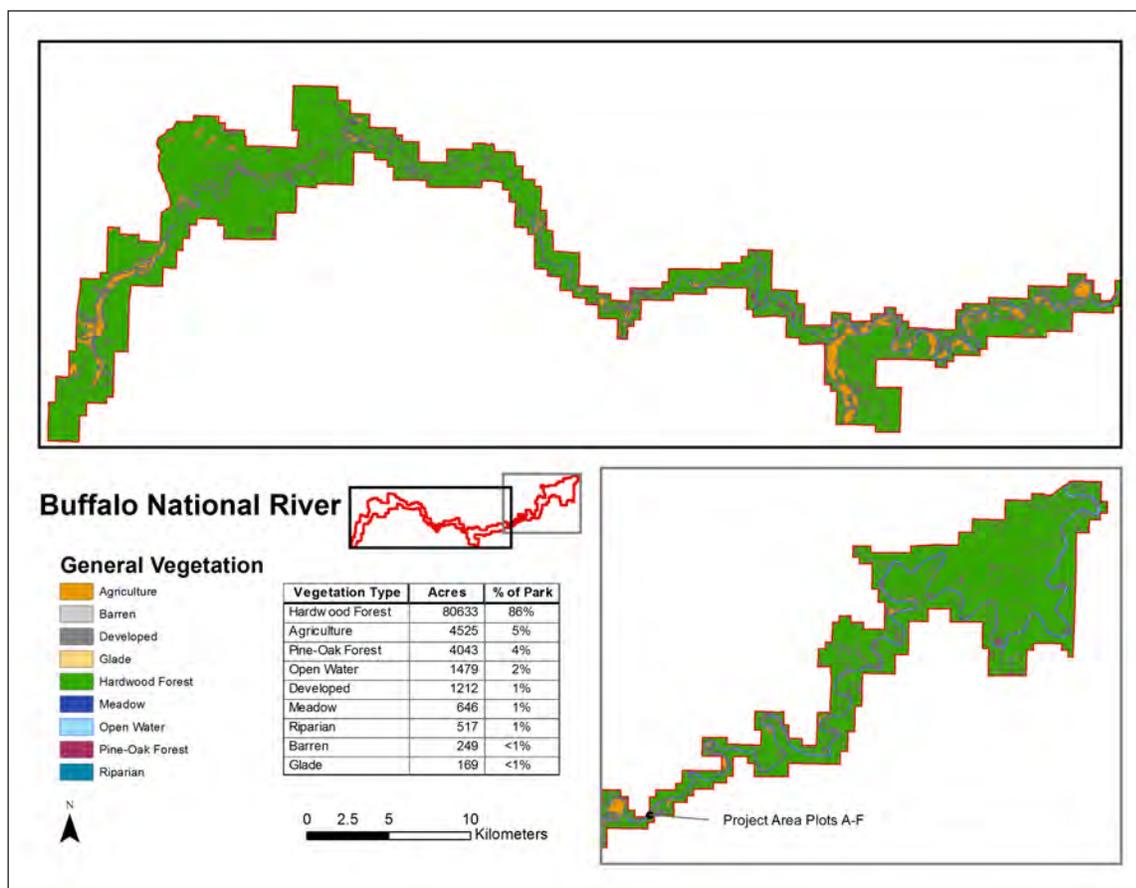


Figure 3. Map of general vegetation types within Buffalo National River.

Savannas, or barrens, are grasslands interspersed with trees and maintained by fire. They are usually distinguished by a tree canopy cover of 10 to 30 percent, the almost complete absence of a shrub layer, and the dominance of prairie grasses and herbs (Nelson 2005, R.C. Anderson 1982). This vegetation community comprises a very small portion of the park (< 1%).

The glades of Buffalo River are small and predominantly found on exposed, variable-depth soils over sedimentary (limestone) substrates (Hinterthuer 1977, Logan 1992). Often they will have patches of exposed bedrock or variously sized boulders. Generally, the glades (<1% of park) are dominated by grasses, including little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), and Indiangrass (*Sorghastrum nutans*) with a rich mixture of forbs. The glades are surrounded by transition woodlands which are characterized by a short (to 50'), sparse canopy of overstory or understory woody species over sparse to dense grass/herbaceous ground cover dominated by post oak, eastern red cedar, winged elm (*Ulmus alata*), and winged sumac (*Rhus copallina*).

Old field sites are heavily dominated by tall fescue (*Schedonorus phoenix*), sericea lespedeza (*Lespedeza cuneata*) and Kentucky bluegrass (*Poa pratensis*) (Johnson and Schnell 1988). Beginning in 1995, the park undertook a program to identify and manage field openings through a combination of prescribed fire, native grass restoration, and mechanical treatment. During 1999 fifty-eight of the 125 identified openings along

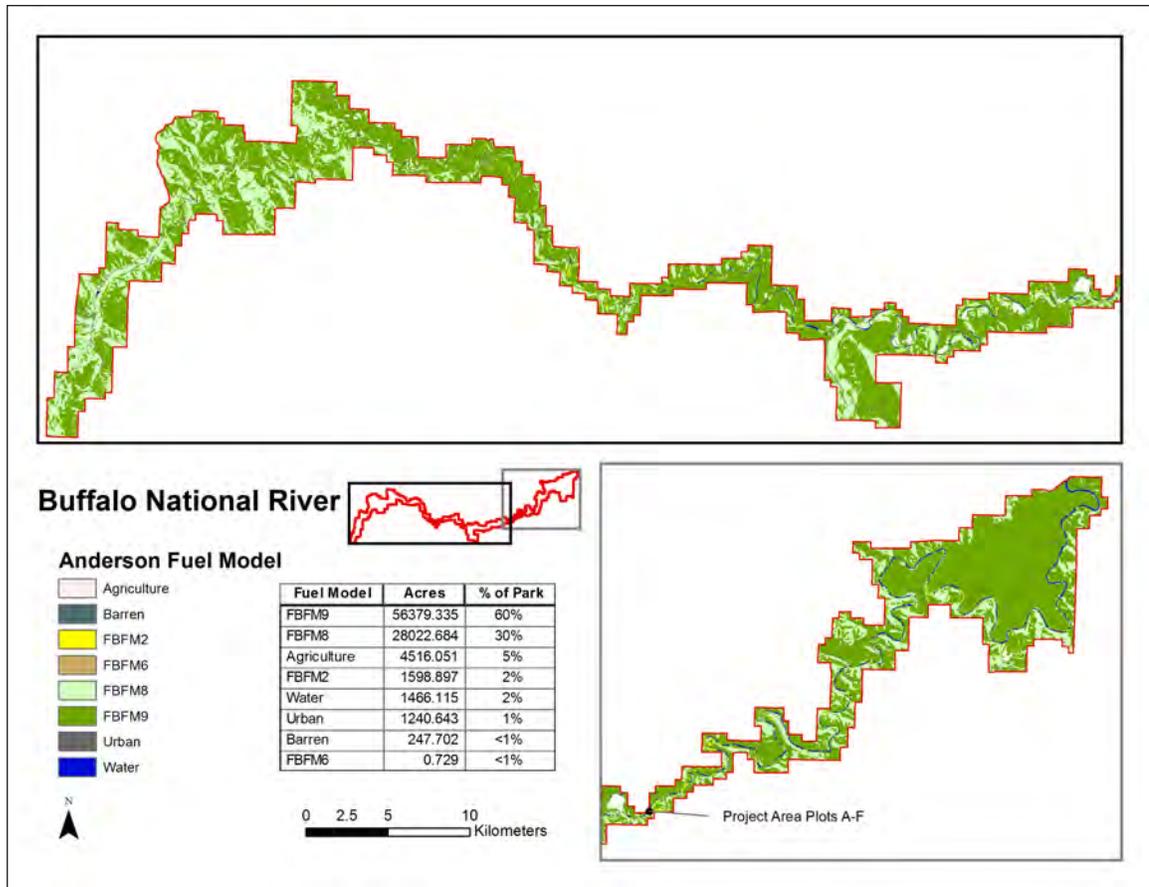


Figure 4. Fire fuel models within Buffalo National River.

the river corridor were qualitatively surveyed for vegetation. Twenty-nine of the units contained little bluestem and it was found to be the dominant or subdominant species within 5 of the units. Additionally, seven of the units were found to have “glade-like” qualities and the final recommendation of the survey was for “controlled burns for all of those fields surveyed (Logan 1999).

Buffalo National River fuels fall into Fire Behavior Fuel Models 2, 3, 6, 8, and 9 (H.E. Anderson 1982, Figure 4). Oak, oak-hickory, oak-pine, and pine woodlands are best characterized as fuel models 8 and 9 (90% of the park). These mixed oak forest and dry woodlands typically have fuel loads around 14 tons/acre. Glades and transition woodlands are characterized as fuel model 2 with fuel loads around 10 tons/acre. Old and managed field sites are characterized as fuel model 3.

EFFIGY MOUNDS NATIONAL MONUMENT (EFMO), IOWA

Located in the Paleozoic Plateau region of northeastern Iowa, Effigy Mounds National Monument lies along the western edge of the Mississippi River. The park contains 2,526 acres of high Mississippi River Bluffs, valleys including the Yellow River, upland prairie, and wooded hillslopes. EFMO has a prescribed burn program and a fire management plan, as well as a program designed to address the Wildland Urban Interface by the removal of some trees and brush in interface areas. There are 52 known

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and recorded archeological sites in the park (Benn 2004). These sites include at least 198 prehistoric Native American mounds. The animal effigy, conical, and linear mounds are the main features of the park; however, various prehistoric and historic habitation sites also exist and surround some of the mound groups. Other site types within the park include rock shelters, petroglyphs, and historic Euroamerican settlements.

Over 80% of the vegetation cover at EFMO is hardwood forest, with another 10% in wetlands and marshes, and the remainder in prairie and shrubland (Figure 5). Sugar maple (*Acer saccharum*) and basswood (*Tilia americana*) dominate some of the remaining North-Central Interior Dry Oak Forest with scattered prairie openings on the ridge tops and bluff edges. Sugar maple-basswood stands represent climax community forests for this area, but historically, prairie openings may have been actively maintained by American Indians. Current prairie openings have a recent history of farming activities. These old field areas have been restored to prairie through the use of fire or by seeding native prairie species. The small goat prairies existing on bluff edges show signs of encroachment by woody species.

Vegetation on the wooded hills consists of a mix of hardwoods, such as oak (*Quercus* spp.), maple (*Acer* spp.), hickory (*Carya* spp.) and basswood. White oak (*Q. alba*) grows on ridge tops in drier sites. Red oak (*Q. borealis*) grows on slopes with moist soil and can reach impressive sizes. Black oaks (*Q. velutina*) grow along the bluff edge while

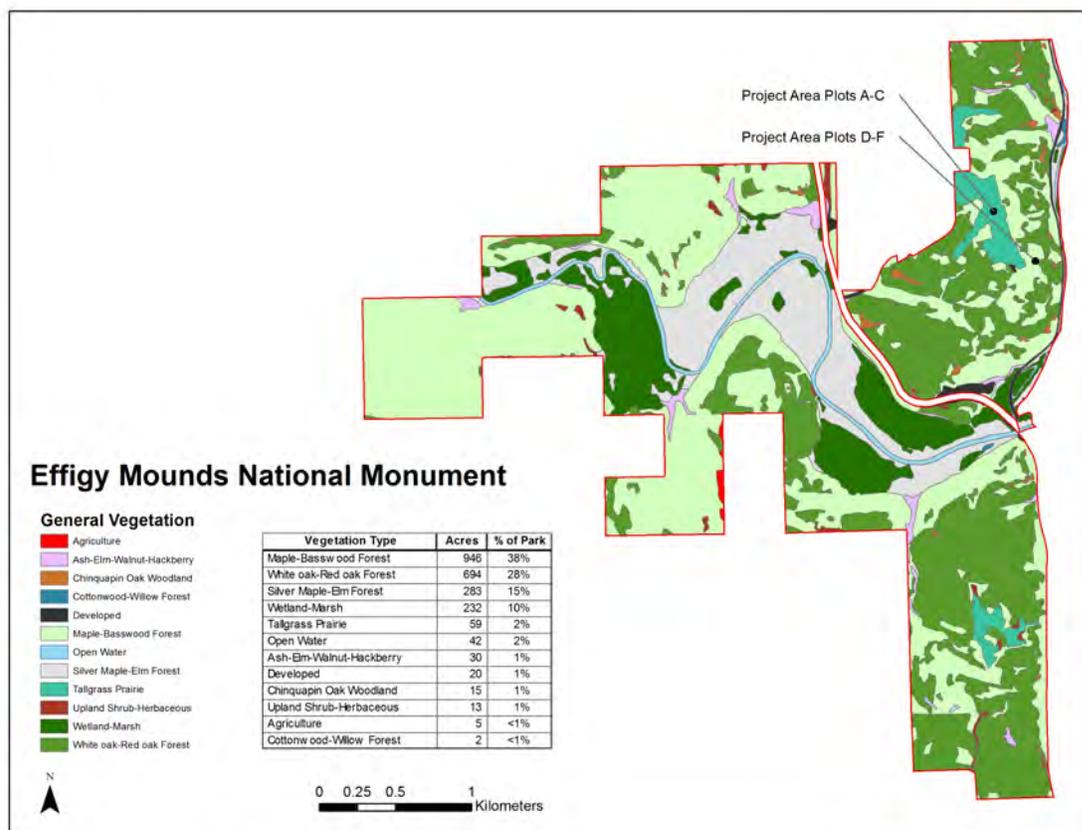


Figure 5. Map of general vegetation types within Effigy Mounds National Monument. Sny Magill unit not included.

chinkapin oak (*Q. muehlenbergii*) can be found among the limestone outcroppings. Interspersed throughout the area are a variety of less-common species, including ironwood (*Ostrya virginiana*), American hornbeam (*Carpinus caroliniana*), and eastern red cedar (*Juniperus virginiana*). Many shrubs grow in the uplands, including American hazelnut (*Corylus americana*), gray dogwood (*Cornus racemosa*), and common pricklyash (*Zanthoxylum americanum*). In areas previously cleared, maturing stands of trembling (*Populus tremuloides*) and bigtooth aspen (*P. grandidentata*) are found. Sumac (*Rhus* spp.) is found in the forest-prairie ecotone.

Indian grass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*) are the dominant grass species of the tallgrass prairie. Compassplant (*Silphium laciniatum*), butterfly milkweed (*Asclepias tuberosa*), blazing star (*Liatris aspera*), goldenrods (*Solidago* spp.), asters (*Aster* spp.), and purple coneflower (*Echinacea pallida*) add color to the open grasslands.

Various species of pondweed along with water milfoil, elodea, watershield, duckweed, arrowhead, bulrush, cattail, and wild rice populate the quiet backwaters and ponds. When present, filamentous and plankton algae are bio-indicators that identify areas polluted with excessive nutrients. The Sny Magill Unit is in the Mississippi River/Sny Magill Creek floodplain and inundated annually by spring floods. The vegetation in this unit is dominated by silver maple, elm (*Ulmus* spp.), and green ash (*Fraxinus pennsylvanica*). Swamp white oak (*Q. bicolor*) is well represented.

The combination of topography, longitude, latitude and the climate of northeast Iowa have produced unique microhabitats that support island populations of flora and fauna. These microenvironments include north-facing algific talus slopes and “goat prairies”. The plant communities of the algific talus slopes are remnants of plant populations associated with more northern climates. Goat prairies, on the other hand, are small prairie remnants found on bluff faces associated with shallow soil, south-facing slopes, and rock outcrops. Although the south aspect, shallow soil, and drier conditions give drought tolerant prairie species a competitive advantage, fire is needed to discourage invasion by trees and shrubs.

In the maple-basswood forest, disturbances are expected infrequently with windthrows occurring every 600-700 years and stand replacing fires every 1000 years. By contrast, stand replacing fire in the mature North-Central interior Dry Oak Forest and Woodland, are likely to occur every 35-200 years while savannas could have burned 4-7 years on average. Upland prairie openings and goat prairies may have burned every 5-10 years historically (LANDFIRE).

The fuel models at EFMO are primarily Fuel Model 3 (tallgrass prairie), and Fuel Model 8 (closed timber litter, Figure 6). The closed timber litter (Model 8) is typical of the timber fuels found here during most of the year. The exception occurs in the fall during leaf drop (Model 9). During this period the leaves are light and fluffy, subject to rapid wind movement, especially in areas of high relief. Other fuel models that are used include Fuel Model 1 (short grass prairie) for goat prairies, and Fuel Model 9 (hardwood litter) for fall timber conditions (Anderson 1982). The shortgrass (Model 1)

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and tallgrass (Model 3) fuel models are typical of the prairie and wetland fuels found in this area of Iowa.

Community type substantially affects fire intensity, fuel and fire continuity, and fire severity. For example, maple and basswood leaves provide a poor fuel bed in that the leaves compact and degrade rapidly resulting in low fire intensity and continuity. By contrast, fuel beds in oak dominated stands are substantially more flammable and sustain more intense fires. As succession continues and maple and basswood trees gain dominance, fire becomes a less effective tool to maintain oak stands. Slope and aspect play an important role in affecting fuel moisture and fuels accumulations. Slopes range from 6% to 70%, which can have a significant impact on fire behavior as the slopes become more exposed with the loss of leaf cover. Many of the Monument's slopes face south, west, or east, which results in greater drying of the fuels during the day, especially with prevailing south and southwest winds.

Recent fuel loads at Effigy Mounds vary by community type and burn history. On average, white oak-red oak forests have 18-21 tons/acre. The maple-basswood forests have a wider range of fuel loadings with approximately 13 tons/acre in the disturbed

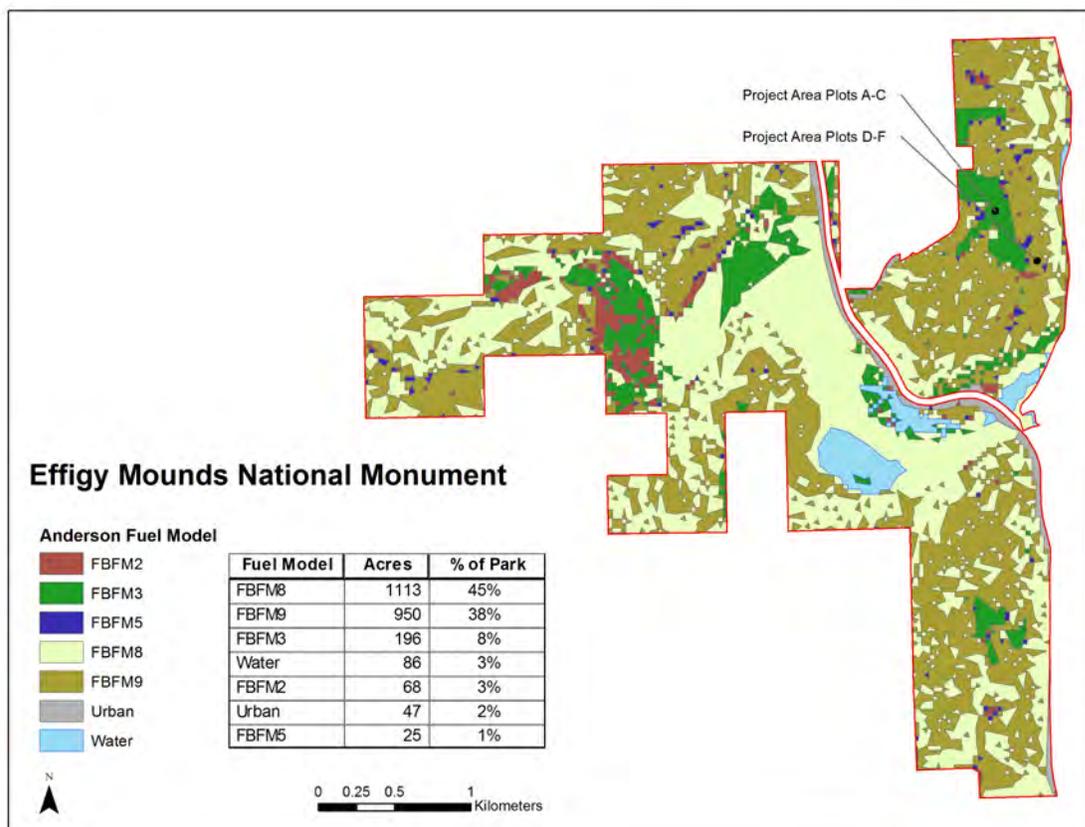


Figure 6. Fire fuel models within Effigy Mounds National Monument. Sny Magill unit not included.

hardwoods phase, but the disturbed oak phase has 36 tons/acre (unpublished data, Heartland Inventory and Monitoring Network).

PEA RIDGE NATIONAL MILITARY PARK (PERI), ARKANSAS

Pea Ridge National Military Park is located in the Ozark Highlands of northwest Arkansas. The park was established to preserve the 4,300-acre site of the 1862 Civil War battle between Confederate and Union forces (Carlson-Drexler et al. 2008). The landscape is diverse with rolling grassland prairies set in a mixed oak-hickory forest. The landforms range from rolling prairies to forested areas with shallow and steep-walled ravines rising to steep rocky hills. In addition to the archeological record of the 1862 Civil War battle, there are numerous prehistoric Native American sites and historic Euroamerican farmsteads that have also been documented at PERI. PERI conducts routine prescribed fires for natural resource management purposes. Previous studies (Buenger 2003; Saylor, Seabloom, and Ahler 1989) have indicated that, under certain fire conditions, battlefield materials, such as lead, can be extensively damaged or destroyed. Therefore, it is necessary for PERI land managers to have information available that addresses the specific local fire conditions that are encountered during prescribed or wildland fires.

Paramount to the park's mission is to restore and preserve the landscape and cultural features that existed at the time of the Battle of Pea Ridge in March of 1862. The sharply contrasting geology and landforms, and a wide range of soil conditions within the park, provide an excellent illustration of the prairie-forest transition of the western Ozark region. This contrast historically brought together a vegetation assemblage that included oak-hickory woodland/forest, pure tallgrass prairie, upland oak savanna, and limestone glade. These plant communities, while largely products of climate and soils, are all dependent upon large-scale disturbance regimes (fire, drought, and herbivory) for maintenance of structural, functional, and compositional characteristics (Nelson 2005, Ladd 1991). Fire of anthropogenic origin has existed in the region since humans first arrived, around 10-12,000 years ago, and was a key ecological process in the development and maintenance of these vegetation associations (O'Brien and Wood 1998).

The vegetation communities within Pea Ridge National Military Park consist of four major types: oak-hickory forests, oak woodlands, cultivated fields, and cedar forests (Figure 7). Approximately 75% of the park is in the oak woodland or oak-hickory forest vegetation type with about 19% in pasture. Approximately 600 acres of open fields are maintained in their historic appearance by haying, under special use permit to local farmers for agricultural use, and/or prescribed fire.

In the absence of fire during much of the 20th century, the oak woodland community has developed more of a forest structure, with a dense overstory (>300 trees/ha) and a well-developed midstory of pole-sized trees. It is still possible to distinguish the degraded oak woodland communities from the oak-hickory forests since they have different species assemblages. Elkhorn Mountain and Round Top support tree species similar to those present at the time of the battle. Historical evidence suggests that the

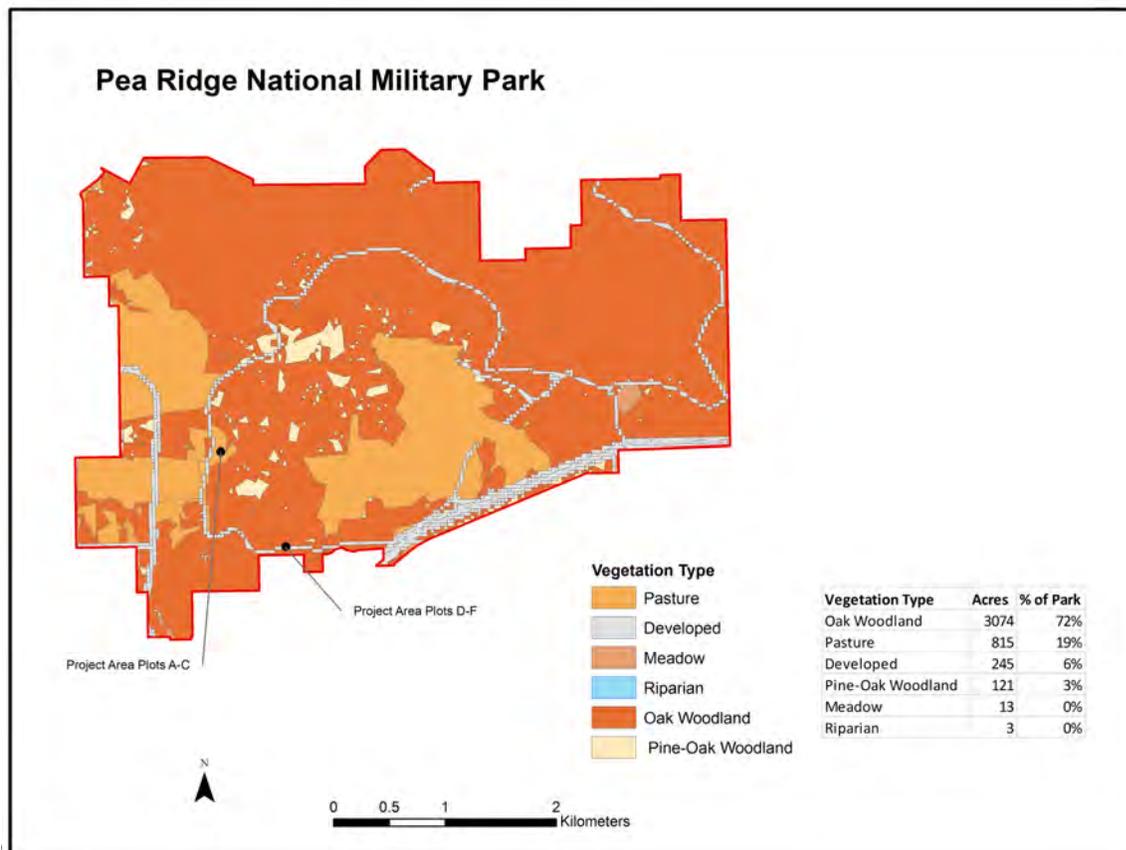


Figure 7. Map of general vegetation types within Pea Ridge National Military Park.

use and the suppression of fire. The remainder of the battlefield is less forested today. Tallgrass prairies were once present in the western quarter of the park and attempts are being made to reestablish some prairie.

The park’s oak woodland and hardwood forest vegetation varies with site conditions. Distinct forest and woodland types include post oak-blackjack oak woodlands and oak-hickory forests. Abandoned field vegetation includes tall grasses and mixed shrubs. Eastern red cedar (*Juniperus virginiana*) is a native, invasive species which now dominates old fields that were abandoned at the time of the park’s establishment. Areas now dominated by this cedar forest represent the driest sites in the park that formerly supported oak savanna and limestone glade. Cedar trees were mostly absent at the time of the battle, and were not a significant part of the historic landscape. Many areas of the park have stands with a red cedar component heavy enough to affect the movement of fire and the effectiveness of prescribed fires. Treatment of these areas will include cutting, physical removal and burning as appropriate.

PERI fuels fall into Fire Behavior Fuel Models 2, 3, 8, and 9 (Anderson 1982, figure 8). Oak woodlands/forests are best characterized as fuel model 9 (62% of the park). The

cultivated fields are characterized as fuel model 3 (19% of the park). Oak woodlands typically have fuel loads around 10 tons/acre with oak-hickory forests at 15 tons/acre. Typically, the period from late September through early April exhibits the greatest fire occurrence on or adjacent to the unit. While most fires occur in grassy fuels, leaf litter in the forest lands contributes to an increased potential during the winter. Another fuel problem that occurs occasionally results from ice storm damage. This causes an additional load of 10 and 100-hour fuels which in turn increases the resistance to control

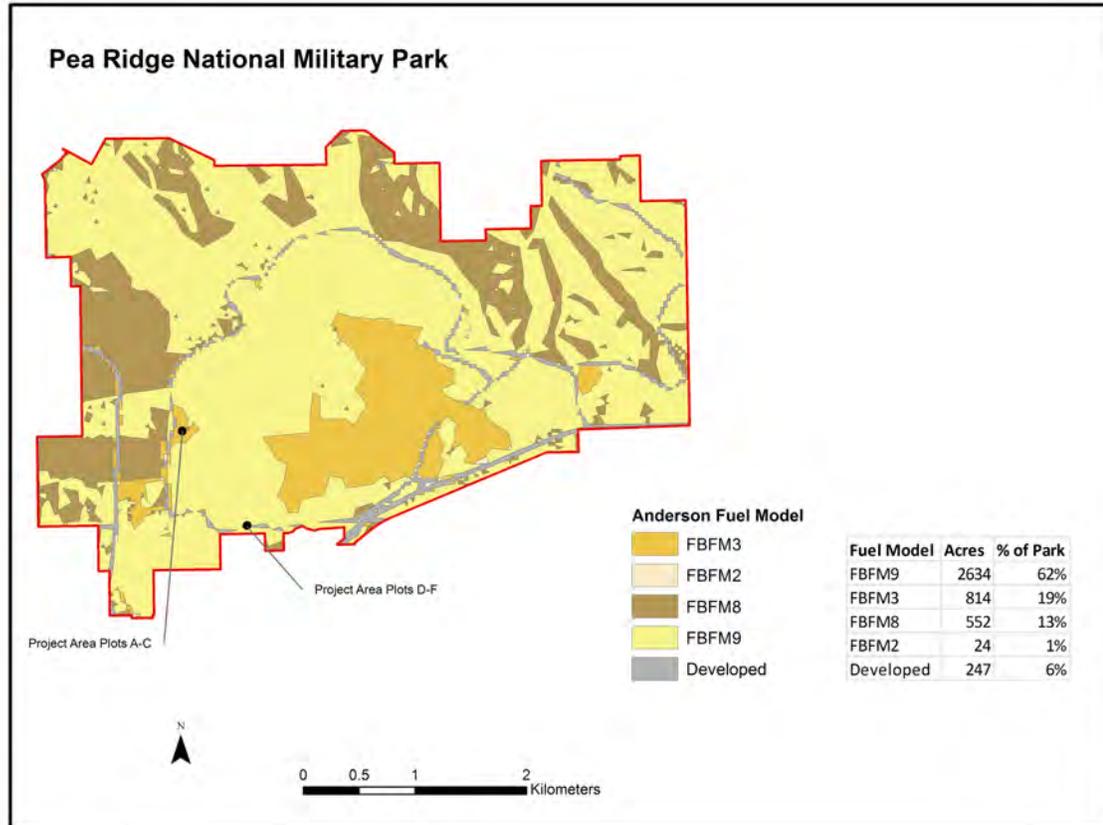


Figure 8. Fire fuel models within Pea Ridge National Military Park.

and mop-up problems. Fires in fuel model 9 generally consume leaf litter and top-kill small trees up to five inches in diameter. During extreme weather, most of the overstory trees can also be killed, particularly with the large accumulation of 100-hour fuels that have developed from years of fire protection.

TALLGRASS PRAIRIE NATIONAL PRESERVE (TAPR), KANSAS

Tallgrass Prairie National Preserve covers roughly 11,000 acres of rolling grassland in the Flint Hills of east-central Kansas. A small amount of the Preserve is actually owned by the National Park Service, with the majority of land now owned by The Nature Conservancy (TNC). The park is managed jointly by the NPS and TNC. Until recently, much of the land owned by the prior owner, the National Park Trust, had

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been leased for cattle grazing, with the leased lands intentionally burned each spring to stimulate new grass growth, a traditional activity that occurs throughout much of the Kansas Flint Hills. It is likely that some of the Tallgrass pastures have been intentionally burned upwards of 70 times over the past 100 years. Archeological resources within TAPR include abundant prehistoric quarry sites where chert was obtained for stone tool manufacture, together with a number of historic farmsteads dating to the late nineteenth century (Jones 1999).

The preserve contains a nationally significant remnant of the once vast tallgrass ecosystem (Figure 9). Nearly 500 species of vascular plants have been identified within the Preserve as of 2007. The unplowed upland tallgrass prairie is dominated by big

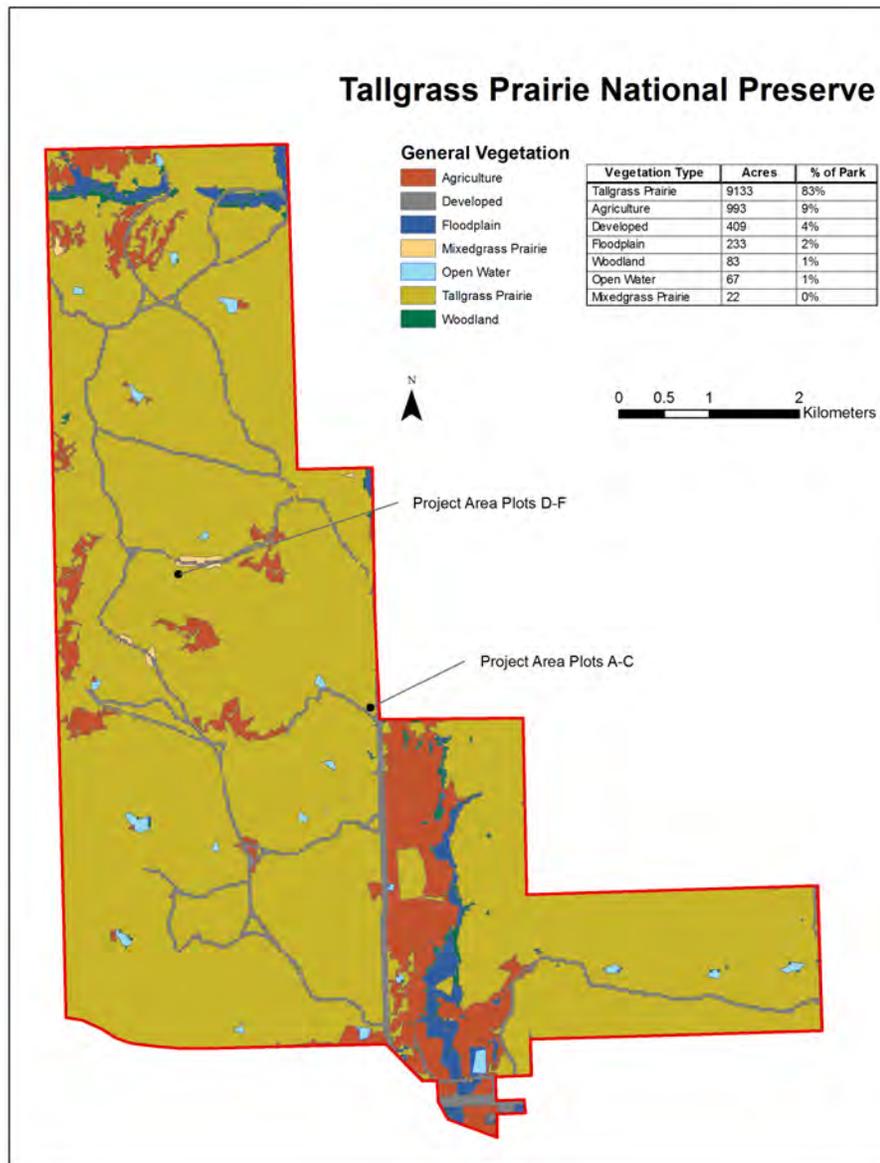


Figure 9. Map of general vegetation types within Tallgrass Prairie National Preserve.

bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*Bouteloua curtipendula*), buffalograss (*Buchloe dactyloides*), ironweed (*Vernonia baldwinii*), and leadplant (*Amorpha canescens*). Other common species include ragweed (*Ambrosia psilostachya*), white heath aster (*Symphotrichum ericoides*), light poppymallow (*Callirhoe alcaeoides*), and sedges (*Carex* spp.). Other community types such as the Bulrush-Spikerush Marsh and Limestone outcrops are very narrow and found in small patches (Lauver 1998). Riparian forests are found along Palmer and Fox Creeks.

Prairie occupies most of the acreage of the Preserve (39 km²) and is found in all of the pastures and on gentle rolling slopes, terraces, and some stream drainages. From 1995 to 2006, the prairie vegetation was burned every spring, usually around April 1st as a condition of the 35-year grazing lease. During that period, intensive early stocking was applied as the grazing system. Cattle were stocked at an average of two acres per 550-pound steer for approximately 90 days (April 15th and July 31st). The cattle were then removed allowing a period of regrowth until the next spring. In 2006 the preserve began to shift management towards reduced disturbance intensity. Pastures have been periodically rested from grazing or fire and stocking rates were reduced. Furthermore, one pasture has been devoted to a novel grazing system called patch burn grazing (3813 ac). This system builds in rest from grazing and fire while meeting ecological and production goals.

The riparian forests along Fox and Palmer creeks are characterized by nearly level bottoms and terraces along the creeks (Lauver 1998). This floodplain community has been called the rarest in the state of Kansas because of the tendency, historically, to plow these deeper soils and to replace native vegetation with agricultural or grazing crops (National Park Service, 1998 Enhancement Report). The bottomland along Fox Creek was planted in smooth brome (*Bromus inermis*) and was cut for hay annually. Park staff has been working to restore these brome fields to native prairie. The riparian forests are a mixture of oak (*Quercus* spp.), plains cottonwood (*Populus deltoides*), American sycamore (*Platanus occidentalis*), and eastern red cedar (*Juniperus virginiana*) with other shrubs as a minor component. Understory species include coralberry (*Symphoricarpos orbiculatus*), eastern woodland sedge (*Carex blanda*), Canada wildrye (*Elymus canadensis*), rice cutgrass (*Leersia oryzoides*), and Kentucky bluegrass (*Poa pratensis*).

TAPR is predominantly tallgrass prairie, FBPS (Fire Behavior Prediction System) models 1 and 3 (Figure 10). Short grass species, model 1, tend to dominate in areas of shallow soil often found on ridge tops while tallgrass species, model 3, are more dominant on low lands and deeper soils. Intense fire and grazing practices applied in the past may have encouraged expansion of short and mid-grass species over time. Along the stream bottoms and near springs, woody plant communities represent FBPS fuel models 8 and 9.

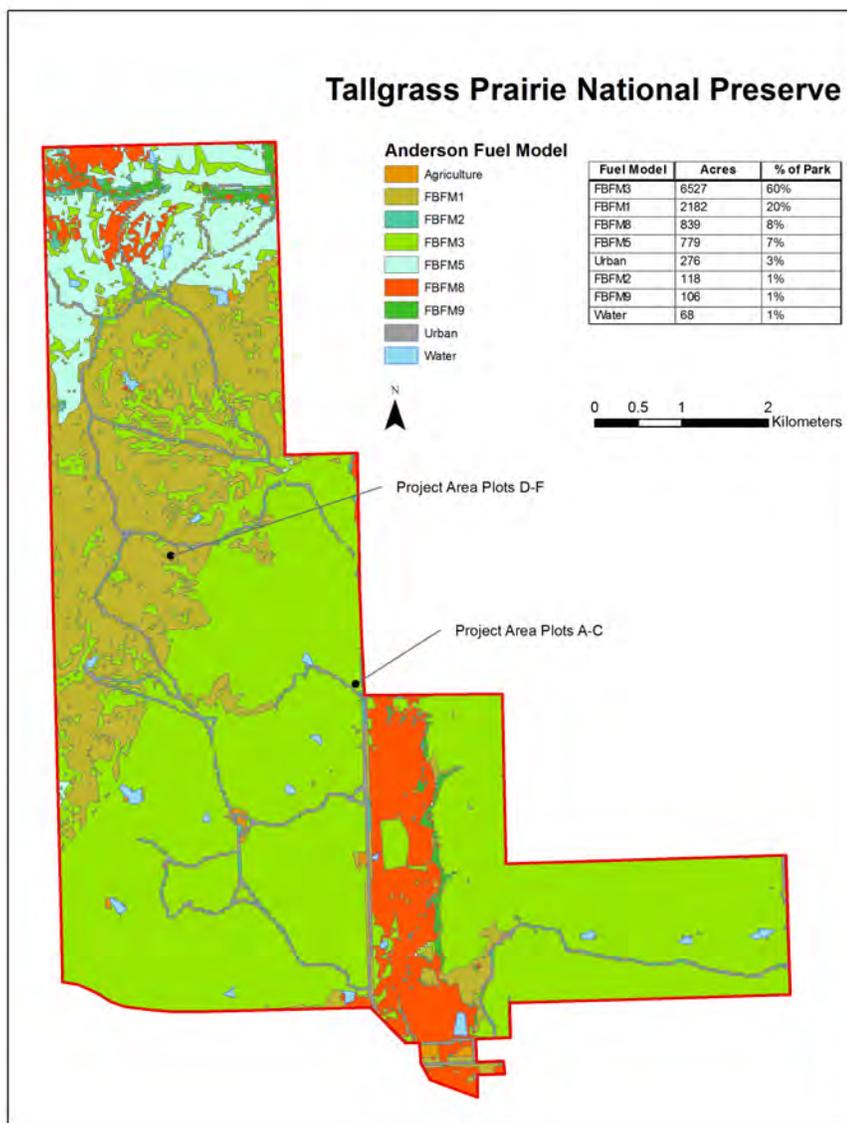


Figure 10. Fire fuel models within Tallgrass Prairie National Preserve.

VOYAGERS NATIONAL PARK (VOYA), MINNESOTA

Voyageurs National Park is positioned in the Border Lakes Region along the U.S./Canadian border where the northern hardwood forest merges into the northern boreal forest. The park is within the vast (18,000 square mile) Rainy River drainage system and consists of over 218,000 acres of forests and lakes. Characteristics of both forest types are visible in the park, although boreal species predominate in about 70% of park lands (Figure 11). The park area has been subject to the effects of fire since the end of the Pleistocene and fire continues to shape the character of the park’s vegetation. The effects of natural ignitions and prescribed burns on park vegetation have been intensively studied for many years, but the impacts of these frequent and numerous fires on archeological resources remain largely unknown.

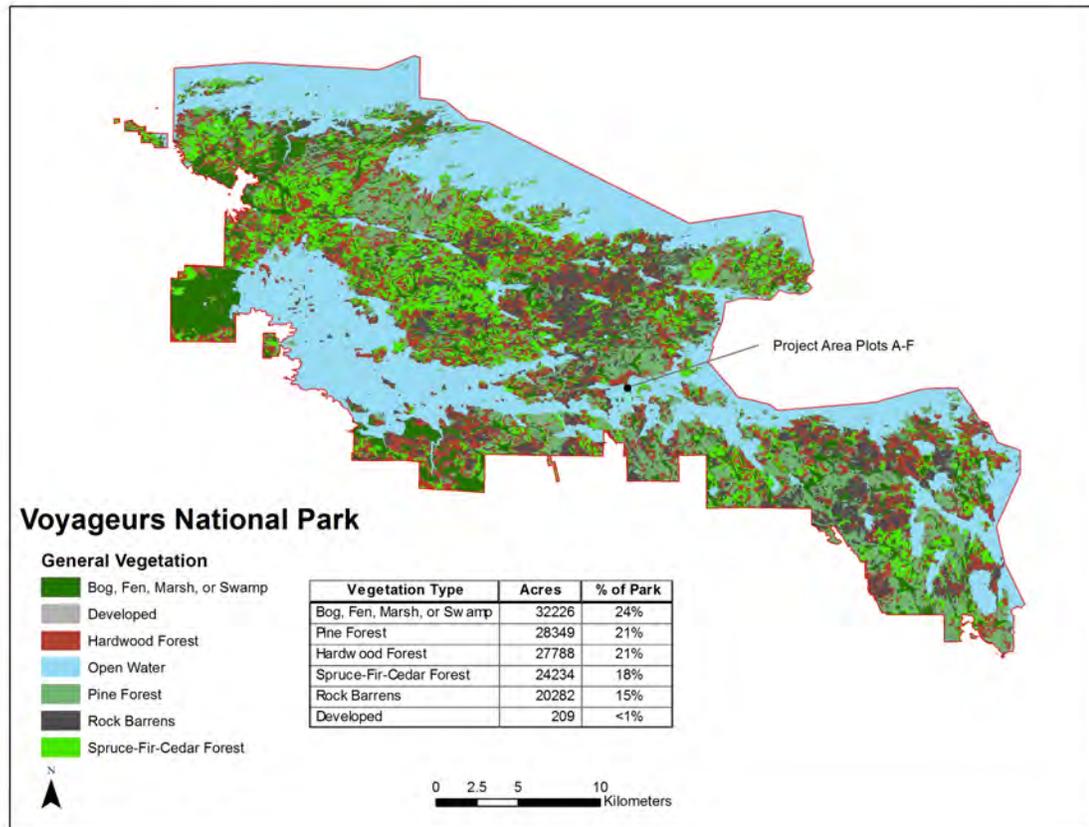


Figure 11. Map of general vegetation types within Voyageurs National Park.

Over 400 archeological sites are formally recorded within the park and many more remain to be discovered (Richner 2008). They range in age from Late Paleoindian (circa 10,500 BP) through the early 20th century. Prehistoric sites contain rich artifact deposits, usually including numerous prehistoric pottery sherds and faunal elements in addition to large numbers of chipped stone artifacts. The park’s numerous historic sites include more than four dozen Ojibwe occupation and special use sites and a variety of Euroamerican sites ranging from logging and fishing camps to gold mines and homesteads. Due to the typically shallow soil conditions encountered in the bedrock-dominated landscapes of VOYA, most archeological deposits occur within 50 centimeters of the ground surface, and in many cases the artifacts are positioned immediately under the forest duff zone. At the historic sites, artifacts are typically exposed on the ground surface and/or incorporated into the forest humus zone.

Voyageurs National Park encompasses 218,055 ac (88,247 ha), of which 84,000 ac (34,000 ha, 38%) are water in the form of lakes and ponds, and 134,000 ac (54,000 ha, 62%) are burnable vegetation (Hop et al. 2001). The park is on the western extent of the Canadian Shield and soils are thin and overlie bedrock. The climate is continental with approximately 100 frost-free days a year and 24 inches of annual precipitation. The forests are considered sub-boreal and major tree species include red pine (*Pinus resinosa*), eastern white pine (*Pinus strobus*), jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), red maple

(*Acer rubrum*), paper birch (*Betula papyrifera*), arborvitae (*Thuja occidentalis*), and aspen (*Populus tremuloides* and *P. grandidentata*).

Approximately 20,500 ac (8,300 ha) of the park's forests and woodlands are classified as jack pine. At Voyageurs this type is common on dry to very dry, nutrient poor sites, particularly on ridges having shallow soils. Jack pine is a pioneer species and typically grows in monotypic, even-aged stands. It is considered a short-lived species typically living as intact stands for 100 – 200 years. It regenerates by seed only and can store viable seeds in its serotinous cones for approximately 20 years. Being very shade intolerant, exposed mineral soil and a high light environment are necessary for seed germination and seedling survival (Ahlgren 1960, Chrosiewicz 1974, Carroll and Bliss 1982, Carey 2007). Fire provides these conditions by opening serotinous cones, removing litter and duff, and eliminating the overstory.

Red and white pine species covers approximately 15,902 ac (6,440 ha) at Voyageurs. Within the park, red and white pines often occur together and pure stands of these species are uncommon. They are often found on islands and along the north, east, and southeast shores of lakes, streams, and wetlands, where they are protected from severe fires commonly approaching from the southwest (Heinselman 1973, Swain 1973). Generally, this stand type is more common to the south and eastern portions of the park where soils are shallower.

The mixedwood community described for Voyageurs encompasses a variety of communities including aspen-birch, aspen-birch-boreal conifer, birch-fir, maple-aspen-birch, spruce-fir-aspen, and spruce-fir-birch-cedar. Many stands in these types once contained scattered super-canopy and canopy white, red, or jack pines prior to logging. Whether these stands were once dominated by pine and underwent conversion via removal of the pine seed source and succession, or were always mixedwood stands containing scattered pines, is debatable.

Aspen-birch and spruce-fir-aspen community types are the most abundant types in the park due in part to soil type, the park's logging history, and the lack of recent fire on the landscape. Together they cover approximately 51,000 acres (20,500 ha) in the park, occurring under nearly all site conditions except for the very driest and wettest. Both types have similar species assemblages. Major deciduous species are trembling and big-tooth aspen, paper birch and red maple. Trembling aspen is often the most abundant species in early successional stages while big-tooth aspen, paper birch, and red maple are common minor associates. Species considered late successional such as balsam fir, northern white cedar, and black and white spruce are usually present, though not abundant, during the early successional stages. By the later successional stage, stands consist mainly of balsam fir with lesser components of aspen, birch, spruce, and sometimes cedar. White pines naturally occurred as isolated super-canopy trees, though their presence is now quite rare. Isolated red and jack pines may also occur in the overstory as remnants of previously logged stands. Shrub cover is often dense, especially on rich sites, with beaked hazel (*Corylus cornuta*) being the most abundant tall shrub followed by mountain maple (*Acer spicatum*), round-leaf dogwood (*Cornus rugosa*), and green alder (*Alnus viridis*). Low shrubs are not always abundant and consist of northern bush honeysuckle (*Diervilla lonicera*), blueberry (*Vaccinium* spp.), and dewberry (*Rubus*

spp.). Depending on shading and site physiography, the ground layer varies in abundance and diversity. Moist and more open sites are more abundant, containing numerous herbs. Bigleaf aster (*Eurybia macrophylla*) is normally most abundant with wild sarsaparilla (*Aralia nudicaulis*), bluebead (*Clintonia borealis*), star flower (*Trientalis borealis*), twisted stalk (*Streptopus lanceolatus*), threeleaf false lily of the valley (*Maianthemum trifolium*), ground pine (*Lycopodium dendroideum*), and club moss (*Lycopodium* spp.) being very common. As conditions become drier and more nutrient poor, blueberry, western brackenfern (*Pteridium aquilinum*), veiny pea (*Lathyrus venous*), and bunchberry dogwood (*Cornus canadensis*) become the most abundant species.

Six wetland groups have been identified at Voyageurs (Hop et al. 2001). These include bogs, northern shrub and graminoid fens, wet meadows, marshes, and northern conifer and hardwood swamps. These wetland groups cover approximately 32,000 acres in the park.

Fuels in the park can best be divided into four broad categories: conifer, mixed conifer/hardwood, hardwood, and wetland species (Figure 12). Live fuel flammability in the park is generally limited to conifer species. These species affect fire spread by torching, spotting, and crowning.

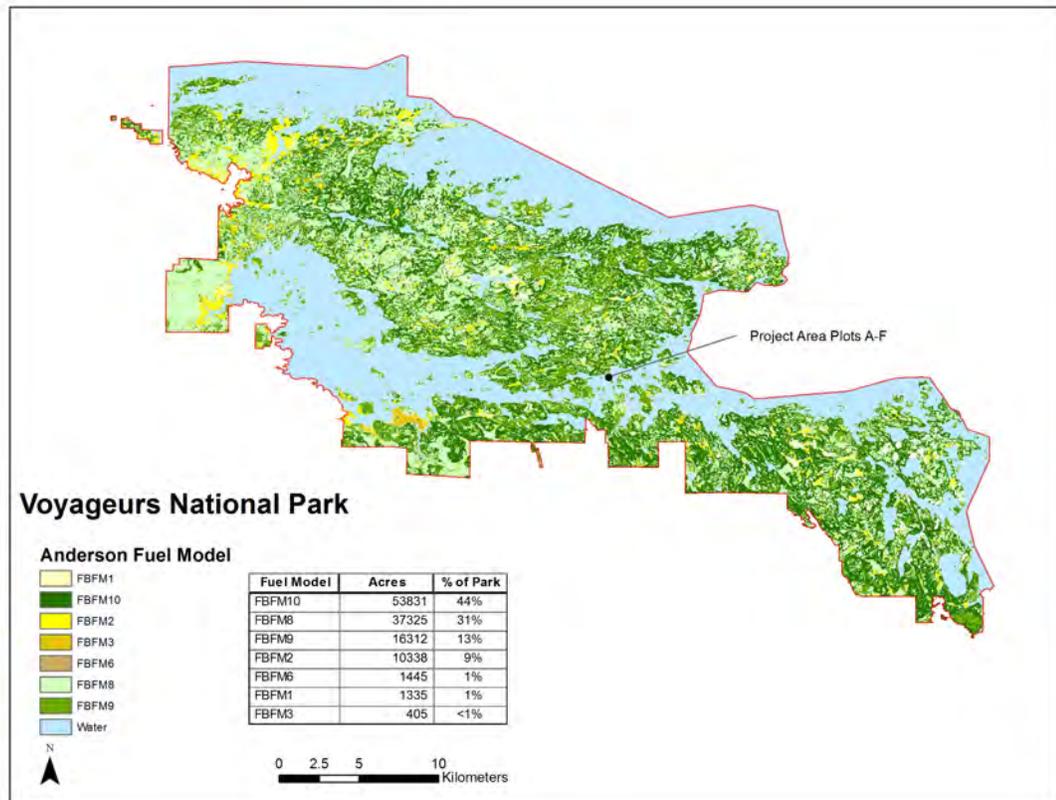


Figure 12. Fire fuel models within Voyageurs National Park.

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Conifer stands found in lowland sites (generally black spruce, balsam fir and white cedar) are best described by fuel model 8 and normally act as a fuelbreak. During very dry years, however, fire spread can occur and organic soils can pose a mop-up problem as well as add to fuel availability. Upland stands of jack pine, red and white pine, and spruce-fir are most flammable while in immature stands. High flammability and the presence of ladder fuels can cause torching and intense crowning, better represented by fuel model 4. In well-stocked mature stands, however, needle litter is the main carrier of fire with less of a fuel ladder in the pine species to carry fire to the crowns; fuel models 8 and 9 are representative. Older stands and stands damaged by windthrow or insect infestations can contain large amounts of dead and down fuels and when present on shallow soil sites or during dry years can be susceptible to high intensity fires, best described by fuel model 10.

Mixed conifer/hardwood stands include aspen, birch, spruce, and fir in any combination. Depending upon fuel loading, stands of mixed conifer/hardwood are represented by fuel models 8 or 10. Surface and/or crown fires can occur in any of these types. Spruce-fir areas provide ladder fuels with low-hanging branches and birch bark provides the ideal vehicle for spotting long distances. Periodic insect infestations create jackpots of dead aerial and surface fuels. Mop-up efforts can be hampered by the heavy fuels and soil conditions.

During the leaf-off period, dead grass, leaf litter and other surface fuels provide the primary means for fire spread in hardwood stands. Increased solar radiation and unrestricted wind movement accelerate the drying of dead and down fuels. Fires are normally surface fires better represented by fuel model 2. When hardwood leaves are present, however, surface fuels are generally unavailable due to shading and the resultant higher fuel moistures. At this time, fuel model 8 is more representative.

Wetland includes such areas as marsh, meadow, slough, stream course, leatherleaf bog, shrub carr, and black spruce bog. Fires rarely occur during the summer unless the water table is low, thus allowing ground fire in the organic soil or surface fire in fine fuels. Cured marsh grasses can support fire throughout the snow-free season. For fires burning in marsh, meadow, slough, stream course, leatherleaf bog, or shrub carr communities, fuel models 2 or 3 will be used. Black spruce sphagnum bog is generally too wet to burn except during extreme drought when fire is essentially a ground fire burning slowly through the organic soil. However, under the right circumstances, an independent crown fire can carry through a lowland black spruce stand if there is no break between the canopy of upland conifer and the lowland black spruce. Where there is significant leatherleaf and/or feather mosses present under the black spruce, fuel model 5 would be used.

WIND CAVE NATIONAL PARK (WICA), SOUTH DAKOTA

Wind Cave National Park was created on January 3, 1903, as the seventh national park and the first to protect a cave. While the original legislation applied only to the cave and surface developments needed for its management and care, the purpose of Wind Cave National Park has since evolved to protection of both subsurface and surface ecosystems and has grown to encompass 28,295 acres. The park is located in the Black

Hills of western South Dakota. WICA incorporates four major topographic features (the Hogback Ridge, the Red Valley, the Limestone Plateau, and the Central area), each with its characteristic vegetation, fauna, and natural resources. The Black Hills are also a sacred place for most Northern Plains Native American tribes (Galindo 2004; Spence 2010). Wind Cave itself is of major cultural significance for the Lakota whose traditions and oral history identify the park area and the cave in particular as their place of origin.

The vegetation communities within Wind Cave National Park consist of four major types with approximately 57% mixed-grass prairie, 28% ponderosa pine forest, 8% shrublands, and 5% prairie dog towns (Cogen et al. 1999, Figure 13). These major types can be further divided into several plant communities or association types which include upland grasslands, riparian/wet meadows, shrublands, coniferous forests, hardwood forests, rocky outcrops/sparse vegetation, landscaped areas and other types.

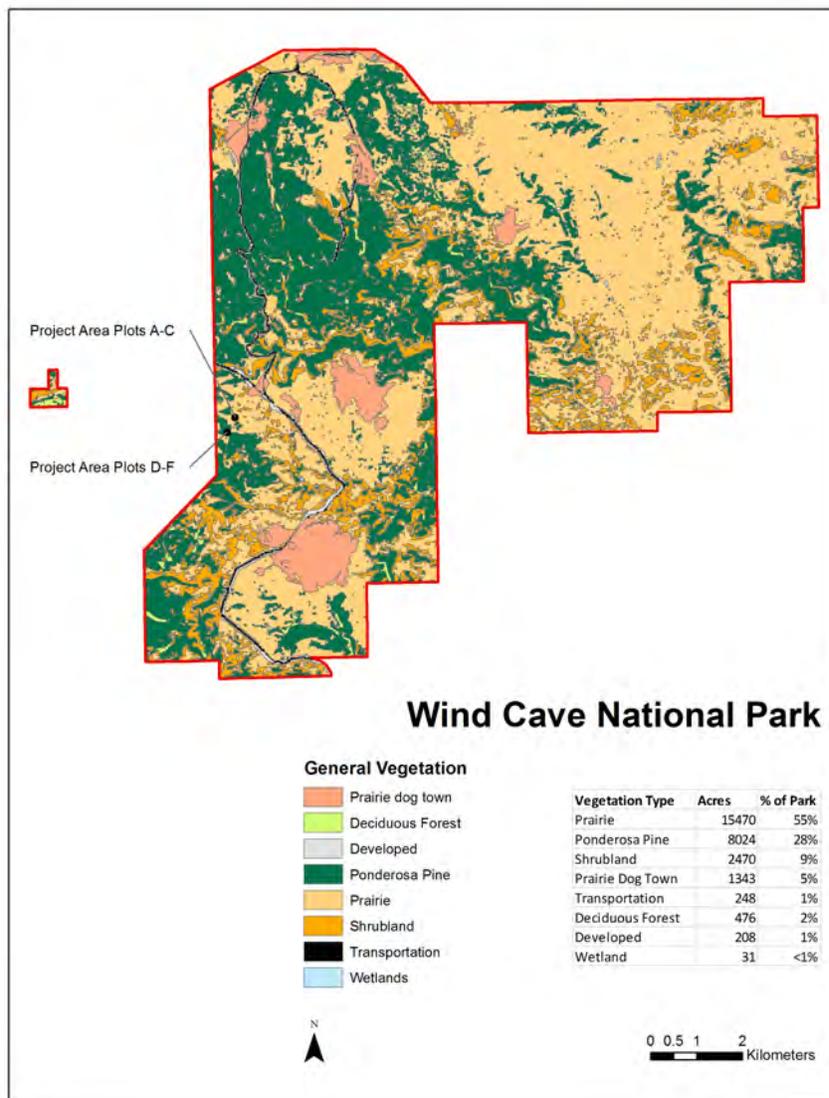


Figure 13. Map of general vegetation types within Wind Cave National Park.

Mixed-grass prairie is the dominant vegetation community and occurs in a mosaic with other communities, including ponderosa pine, shrubland, riparian, and woodland communities. The mixed-grass prairie is dominated by species such as western wheatgrass (*Pascopyrum smithii*), little bluestem (*Schizachyrium scoparium*), and blue grama (*Bouteloua gracilis*). These species are interspersed with short grass species such as buffalo grass (*Buchloe dactyloides*) and tallgrass species such as big bluestem (*Andropogon gerardii*), Indian ricegrass (*Oryzopsis hymenoides*) and switchgrass (*Panicum virgatum*). Threadleaf sedge (*Carex filifolia*) is common to dry open prairies and rolling hills. A wide variety of forbs and shrubs are interspersed throughout the park.

Ponderosa pine forest comprises about 28% of the vegetation communities. The overstory is nearly a ponderosa pine monoculture, although Rocky Mountain juniper (*Juniperus scopulorum*) and bur oak (*Quercus macrocarpa*) are occasionally found in the mid-story. The understory is largely made up of grass and forbs species found in the mixed-grass prairie with the addition of shrubs such as chokecherry (*Prunus virginiana*), raspberry (*Rubus idaeus*), common juniper (*Juniperus communis*) and currants (*Ribes* spp.).

Deciduous trees grow along stream courses and canyon bottoms, and include green ash (*Fraxinus pennsylvanica*), boxelder (*Acer negundo*), bur oak, plains cottonwood (*Populus deltoides*), American elm (*Ulmus americana*), and paper birch (*Betula papyrifera*).

In addition, the park has approximately 8% of its lands in shrublands, these being dominated by mountain mahogany (*Cercocarpus montanus*), creeping juniper (*Juniperus horizontalis*), chokecherry, and serviceberry (*Amelanchier alnifolia*).

Finally, about 5% of the park is covered with prairie dog towns. These tend to be dominated by purple threeawn (*Aristida purpurea*) and fetid marigold (*Dyssodia papposa*), while bigbract verbena (*Verbena bracteata*) is also common. Many other mixed-grass species occur, but tend to be very short in stature because of the constant grazing by prairie dogs.

Many exotic plants have established in the park and pose a threat to native vegetation. Starting in 2002, horehound (*Marrubium vulgare*) became established in some of the prairie dog towns within the park. It has since increased in abundance and is outcompeting many of the native prairie grasses. To date, over 100 species of exotic plants have been identified within park boundaries. These include, but are not limited to: Canada thistle (*Cirsium arvense*), bull thistle (*Cirsium vulgare*), scotch thistle (*Onopordum acanthium*), spotted knapweed (*Centaurea maculosa*), common mullein (*Verbascum thapsus*), and field bindweed (*Convolvulus arvensis*).

Wind Cave's fuels fall into Fire Behavior Fuel Models 1, 2, 6, 8, and 9 (Anderson 1982, Figure 14). Nearly 90% of the park can be characterized as fuel model 1, 2, or 9. Mixed-grass prairie is generally described as fuel model 1 (59% of the park). Fuel loads tend to range from 1 to 4 tons per acre in this fuel type, depending on precipitation, time since last fire, and level of bison grazing.

The ponderosa pine forests of Wind Cave are characterized as fuel model 2 (26% of the park) or model 9 (4% of the park); model 2 if the primary carrier of fire is grass fuel and model 9 if the primary carrier is pine needles and small-diameter woody fuels. This distribution between fuel models 2 and 9 may be weighted too heavily toward model 2,

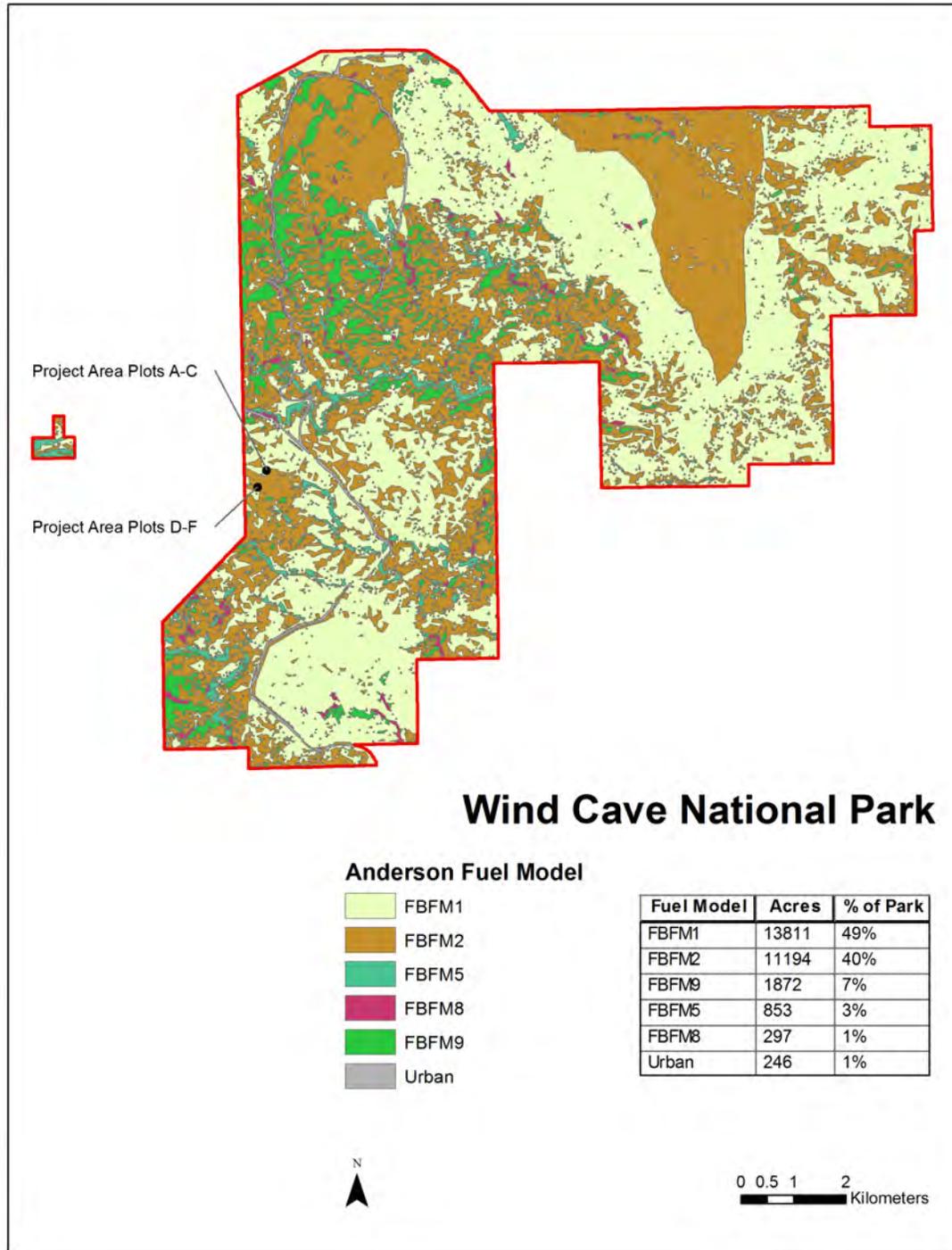


Figure 14. Fire fuel models within Wind Cave National Park.

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but that could be debated. Fuel loads in ponderosa pine stands range from fewer than 2 tons per acre in a recently burned open stand to more than 34 tons per acre in a dense, unburned stand. In dense stands that have not burned in many years, more than half the fuel load can consist of litter and duff. Prescribed fire has on average reduced fuel load by slightly more than 50% in burn units of the park.

The remainder of the park has been described as fuel model 6 (shrublands) or fuel model 8 (prairie dog towns and deciduous forest). Fuel model 6 occurs on about 4% of the park and generally is interspersed within fuel model 1 or 2. Even though prairie dog towns are modeled as fuel model 8, they tend to carry fire only under extreme conditions and even then not particularly well.

ANALYTICAL METHODS AND PRESCRIBED FIRE EXPERIMENTS

In order to address questions regarding the fire and archeology interface, researchers developed methods to assess the condition of archeological materials and measure burn conditions typical of Midwest Region ecosystems. The experimental fire effects study utilized a multi-step comparative analytical approach to identify and assess macro-scale impacts to archeological resources. Information on fuel types, fuel loads, fire temperatures, and burn durations provided a measure of fire conditions that could be linked to individual artifacts and impacts observed on each item. By employing these experimental techniques, the qualitative artifact analysis was linked to burn conditions that would assist in assessing the impacts from a prescribed burn.

Experimental “replica” artifact assemblages were compiled to approximate prehistoric and historic archeological resources at each study park. Each study assemblage contained a sample of both prehistoric and historic objects that may be found at each park. Prehistoric artifacts included stone tools (both flaked and ground stone), prehistoric pottery, bone, and shell. The sample of historic objects was typically much more diverse and includes whiteware ceramics, stoneware, kaolin tobacco pipe fragments, bottle glass, lead munitions, buttons, cans, leather, metal tools, domestic wares, and other objects that may be unique to a particular park or site type. Artifact assemblages at each park typically contained a mix of items obtained via de-accessioned collections, replica manufacture, or purchased replica items that are a close approximation of actual archeological objects such as brass Civil War belt buckles, kaolin tobacco pipe fragments, and lead munitions.

PRE-BURN ANALYSIS

The initial task for researchers was to procure an assemblage of replica and un-provenienced or de-accessioned artifacts that could be subjected to prescribed fire. It was acknowledged in the initial planning stages of this study that all NPS units involved have separate cultural resource needs. Some units have higher proportions of prehistoric sites; others have higher proportions of historical sites. This research project was designed to customize artifact assemblages to reflect the cultural resources of each park. This meant that observations needed to span a wide range of materials (i.e., prehistoric to historic) and characteristics (e.g., cracking on prehistoric bones to crazing on historic ceramics). These artifacts were used to assess the impacts of prescribed fire on material items that have not been affected by weathering or the impacts of previous fires. A key component of analysis was making the pre-burn observations on the artifacts that would be subjected to fire experiments in the field.

Identifying the qualitative and quantitative characteristics of each artifact was a critical task that was completed before any artifacts were placed into test plots. The pre-burn analysis was necessary in order to describe all the changes observed on artifacts after they had been burned by prescribed fire. A representative assemblage of 192 artifacts was accumulated for each park. This allowed for an arrangement of four artifacts per thermocouple or 32 artifacts per plot (Figure 15). A recent study on fire effects (Buenger 2003) had outlined similar methodologies for assessing the impacts to

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archeological resources and provided a basis for analytical methods used during this project. All artifacts were analyzed for previous wear, damage, and condition prior to being subjected to prescribed fire experiments. Artifacts were also measured, weighed, and photographed with a digital camera prior to burning.

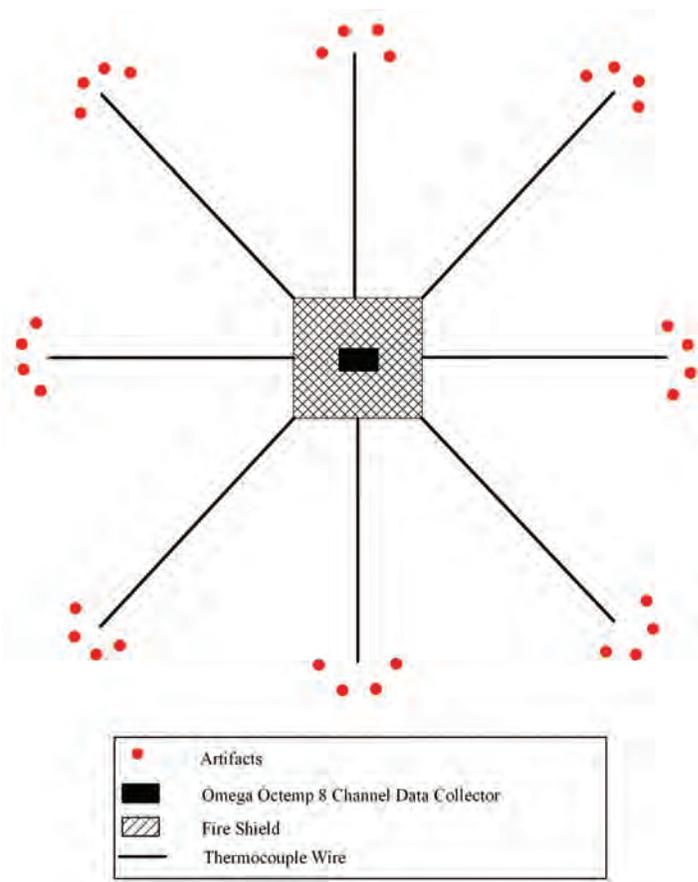


Figure 15. Illustration showing the arrangement of the electronic data logger, thermocouple wires, and artifacts used during the experimental burns.

WILDLAND FIRE EXPERIMENTS

Between 2006 and 2009, the Midwest Region project team conducted the wildland fire experiments at all the parks participating in this study. Experimental plots were established in sets of three at two locations representative of typical archeological and environmental conditions for each individual park. Prior to each experimental burn, weather, soil moisture, fuel type, and fuel load data were collected (Figure 16). Data on fire temperature and burn duration was recorded from the center of each plot using an Omega OM_CP_OMTTEMP eight channel thermocouple data logger with Type K thermocouples. The eight-channel data loggers collect simultaneous readings for each of the eight thermocouples at five second intervals. The collection points for each data logger were located at the ends of eight 12-foot thermocouple wires arranged in a radial pattern from the center of the plot (Figure 17). Ignition of individual experimental plots (head, flanking and backing) allowed fire monitoring data such as flame length, flame depth, and rate of spread to be calculated.



Figure 16. Research team collecting pre-burn fuel samples at Tallgrass Prairie National Preserve.



Figure 17. Pre-burn grassland plot at Effigy Mounds National Monument.

Each plot was ignited to simulate the burn conditions of a head, flanking, or backing fire (Figure 18). A head fire is one that is traveling with the wind and can generate intense fires with large flames driven by the increased air/wind effect. A backing fire generally produces small flames and low intensity fires relative to a head fire. The backing fire burns into or “backs” into the wind. A flanking fire incorporates two flame fronts that essentially converge at a point and burns against or perpendicular to the prevailing wind direction. Flanking fires can create a mix of fire behaviors that mirror both backing and head fires. The direction of each burn was based on the situational wind conditions that were needed to produce the particular type of firing within each unit. Generally, fires were ignited outside the experimental plots and allowed to burn through the plot, thus exposing the artifacts and thermocouples to the desired fire type (Figure 19).

POST-BURN ANALYSIS

Post-burn analysis was conducted using similar methods and analytical categories that were used during the pre-burn analysis (Figure 20). An initial recording and photographs were made in the field when artifacts were collected from the burn plots (Figure 21). All materials were then re-analyzed in the laboratory and compared against the pre-burn analysis. Impacts such as cracking, charring, sooting, combustive residue, fracture, scorching, and melting were recorded for artifacts where changes occurred during the burn experiments (Figure 22 a-b). Artifact weight, dimensions, and color change were also measured and samples of items were photographed to document the impacts sustained during a burn. The post-burn analysis created a comparative data set that would demonstrate the amount and types of changes that were introduced to artifacts during a prescribed burn (Figure 23 a-b). Linking these variables with the data on burn temperature and duration will allow researchers to assess the impacts on the replica artifact assemblages under multiple burn conditions.

Table 1 lists the major categories used to describe individual artifact impacts and conditions. Several of the terms have been adapted for this study from Sayler et al. (1989) and Buenger (2003:105-106). Due to the subjective nature of these terms, a listing and definition of each usage is necessary. Each descriptive term was viewed as independent of the others, hence individual artifacts could have multiple impacts listed in order to describe its condition.



Figure 18. Fire passing through a grassland experimental plot at Effigy Mounds National Monument.



Figure 19. Research team members recording observations on fire behavior during the experimental burn at Voyageurs National Park.



Figure 20. Team member conducting post burn-data collection at Voyageurs National Park.



Figure 21. Experimental artifacts in-situ following the grasslands burn at Effigy Mounds National Monument.



Figure 22a. Pre-burn photograph of a kaolin pipe bowl and stem.



Figure 22b. Post-burn photograph of the same kaolin pipe bowl and stem after being subjected to the Voyageurs National Park burn.

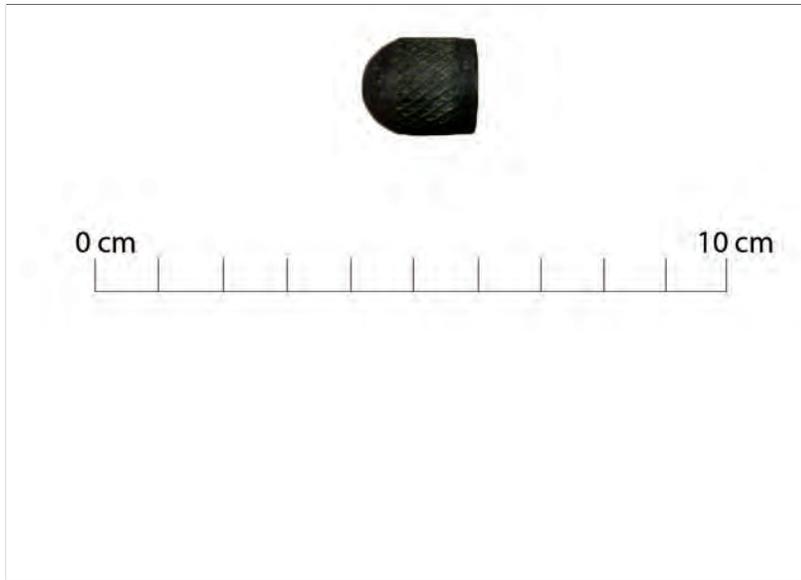


Figure 23a. Pre-burn photograph of a lead replica minié ball.



Figure 23b. Post-burn photograph of the same lead minié ball following the burn at Pea Ridge National Military Park.

RESULTS OF EXPERIMENTAL BURNS

BUFFALO NATIONAL RIVER (BUFF)

All six of the BUFF experimental plots were successfully burned on March 20, 2009. Experimental burns at BUFF were conducted exclusively in woodland fuel types typical of Ozark upland landforms. One set of archeology plots (A, B, C) was located in an oak woodland community type and had an average fuel load of 10 tons/acre. The other three plots (D, E, F) were located in pine-oak woodland with a fuel load of 25 tons/acre. All plots were located in fuels that are characterized as fuel model 9 (Anderson 1982).

Burn durations ranged between 22 minutes 45 seconds to 83 minutes 45 seconds (Figure 24 a-f, Table 2). Maximum temperatures recorded ranged between 833°C and 545°C with average plot temperatures between 102°C and 116°C (Table 2). BUFF experimental plots exhibited some of the highest maximum temperatures and average temperatures recorded for any parks included in this study.

The adherence of combustible residue and minor scorching on objects accounts for the majority of impacts observed on the BUFF collection (Table 3). Significant impacts including fracturing, cracking, spalling, melting, and color change were observed on less than a quarter of the collection (Table 3). Bone and shell objects were most susceptible to significant impacts and generally did not withstand the effects of fire as well as non-perishable materials such as ceramics, metal, and glass.

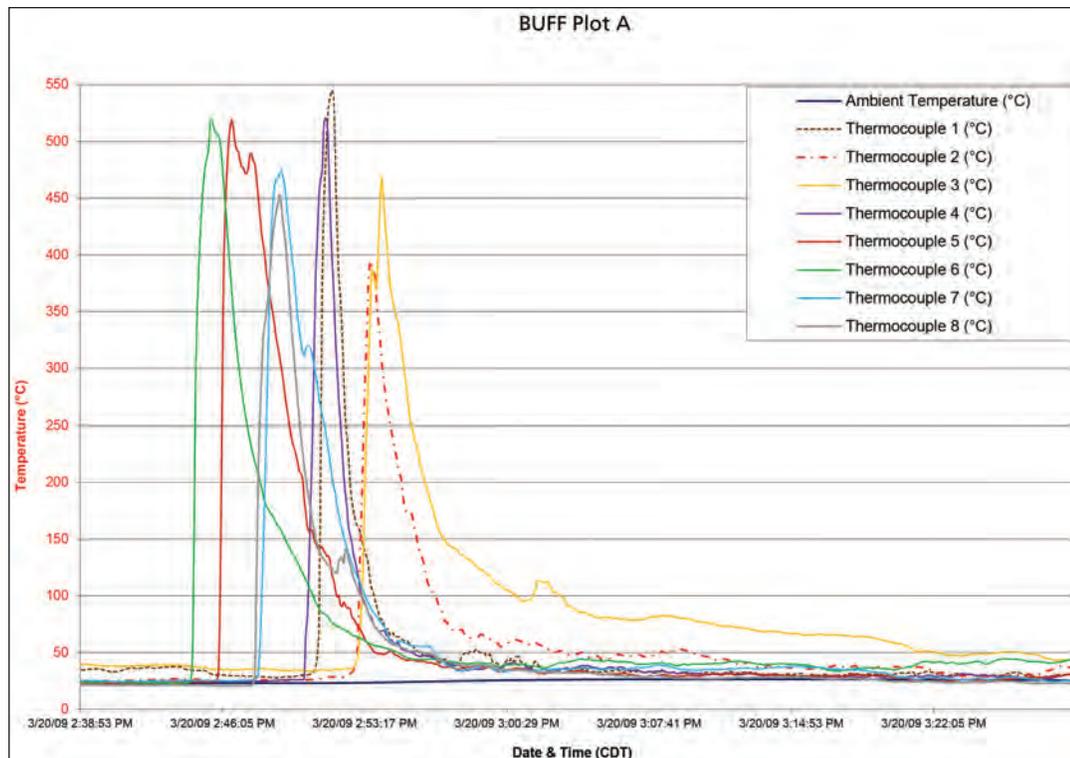


Figure 24a. BUFF Experimental Plot A, Oak Woodland, flanking fire.

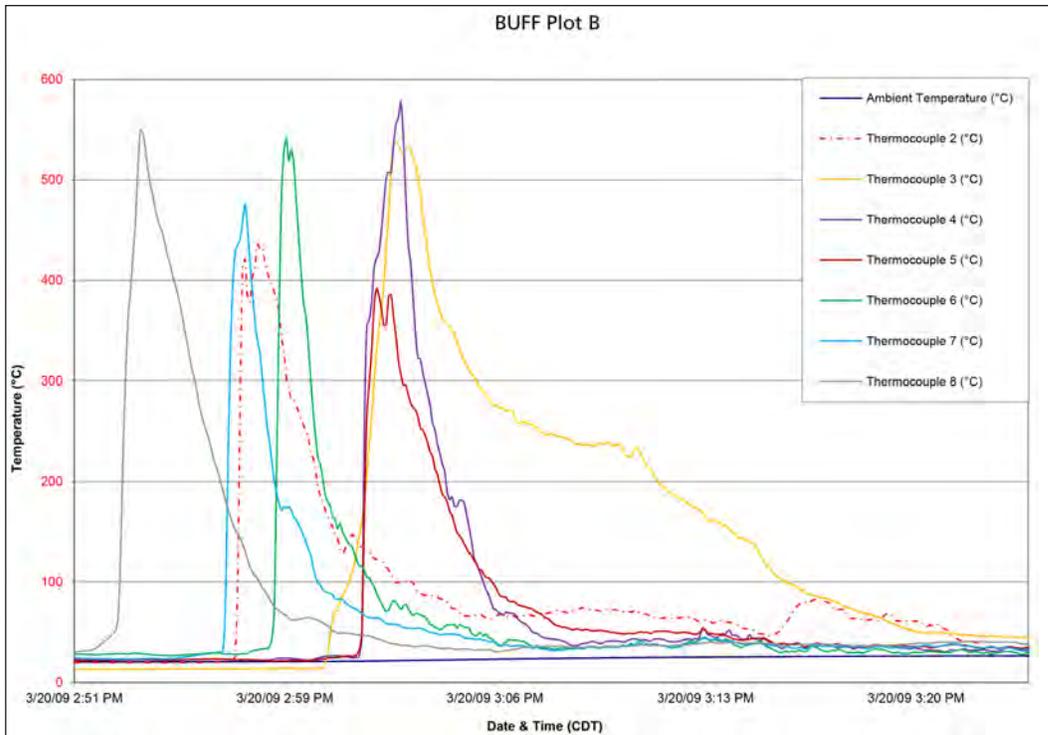


Figure 24b. BUFF Experimental Plot B, Oak Woodland, head fire.

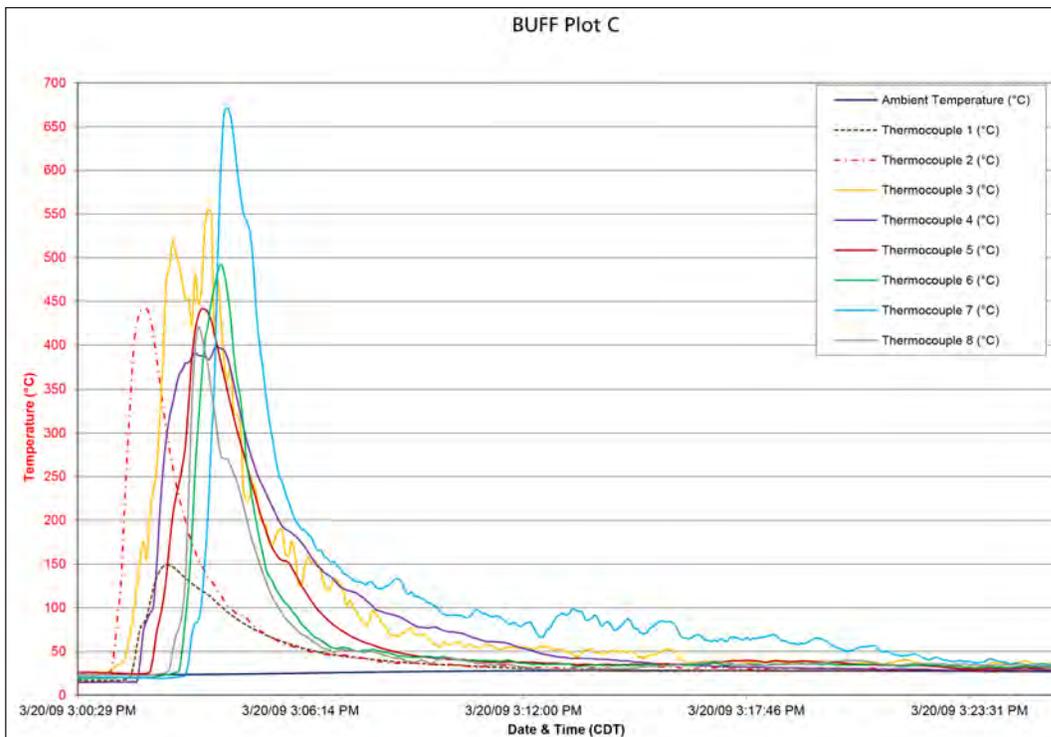


Figure 24c. BUFF Experimental Plot C, Oak Woodland, backing fire.

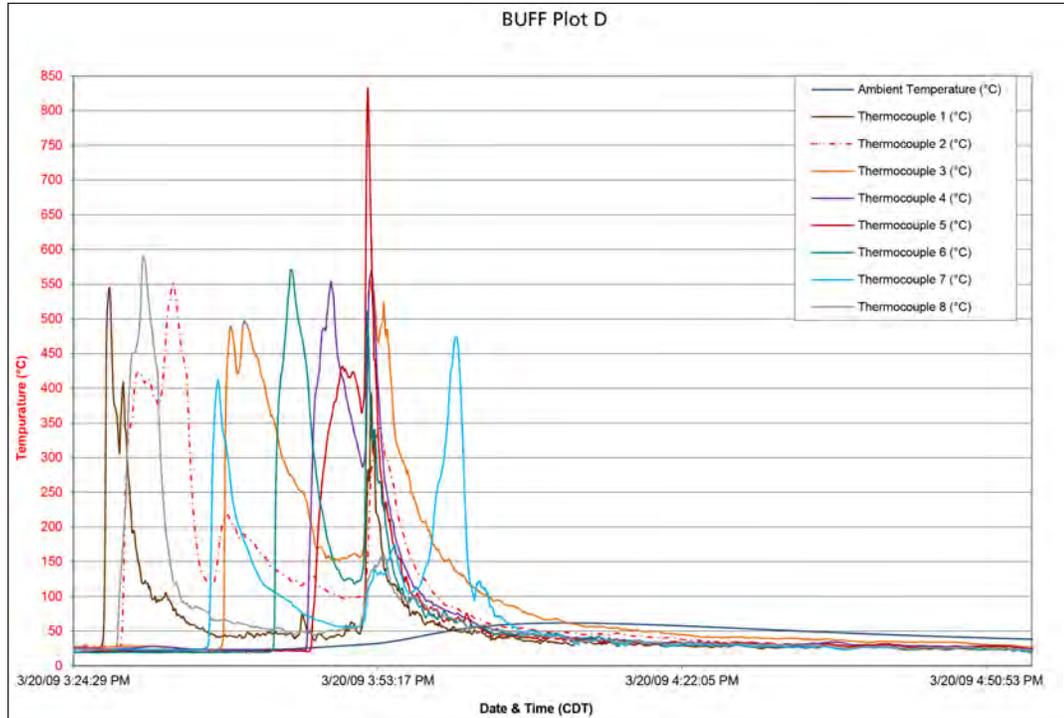


Figure 24d. BUFF Experimental Plot D, Pine/Oak Woodland, backing fire.

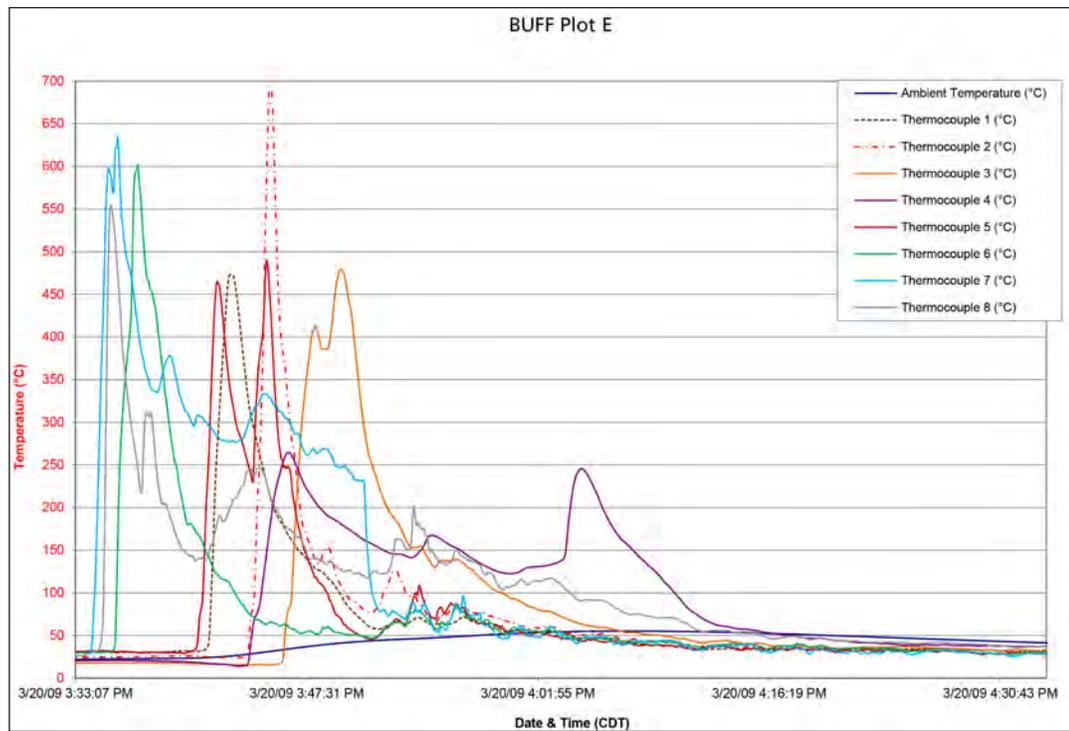


Figure 24e. BUFF Experimental Plot E, Pine/Oak Woodland, flanking fire.

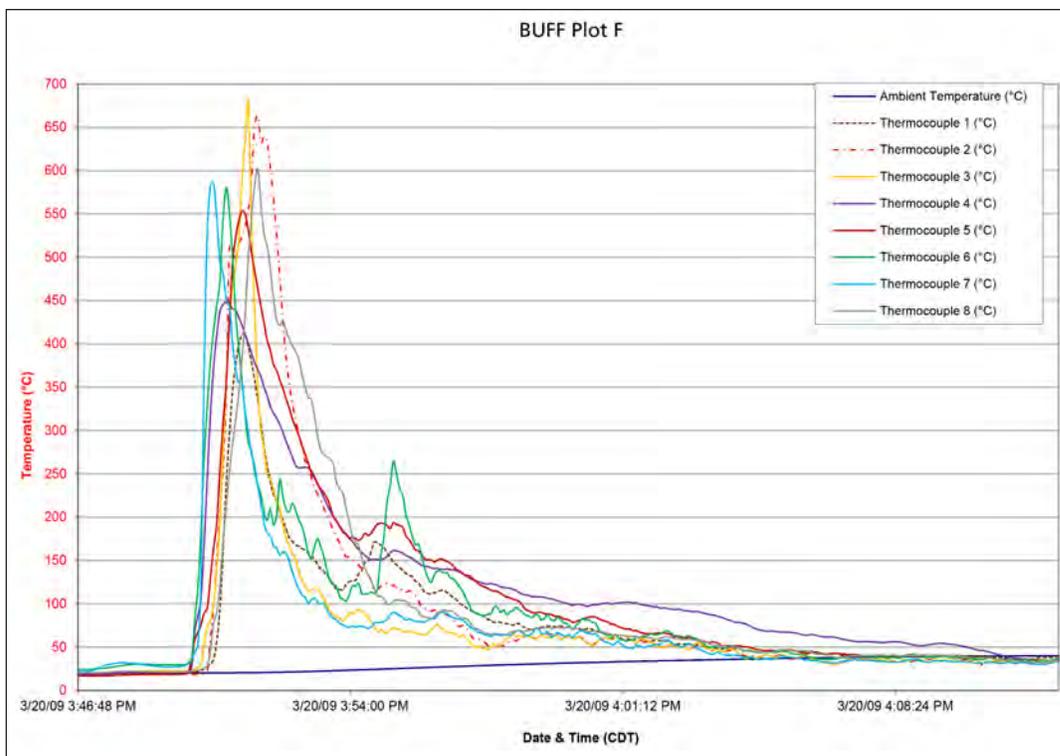


Figure 24f. BUFF Experimental Plot F, Pine/Oak Woodland, head fire.

Based on the summary of impacts from BUFF, the higher fuel loads did increase the occurrence of significant impacts when compared to experimental units in lower fuel load experiment plots. The successful burning of all six experimental plots at BUFF provided a good measure of impacts for an upland fuel setting in the Ozark Highlands. However, this baseline sample does not address the numerous other fuel types and landscape settings that may contain archeological resources. Additional sampling of other fuel types is needed to address impacts in other areas of the park, particularly lowland river terraces and open-field settings.

EFFIGY MOUNDS NATIONAL MONUMENT (EFMO)

The three grassland and one woodland fuels plots at EFMO were successfully burned on April 19, 2007. The fuel models at Effigy Mounds National Monument are primarily Fuel Model 3 (tallgrass prairie), and Fuel Model 8 (closed timber litter) (Anderson 1982). Burn durations for the EFMO grassland fuels plots ranged between 17 minutes 30 seconds and 31 minutes 25 seconds (Figure 25 a-c, Table 2). Maximum temperatures recorded within grassland fuels plots ranged between 536°C and 649°C with average temperatures of 81°C to 91°C (Figure 25 a-c, Table 2). The single woodland fuels plot was fired using a head fire that would sustain the burn across the plot. The woodland fuels plot recorded a burn of 14 minutes fifty seconds with a maximum temperature of 368°C and average temperature of 53°C (Figure 25 d, Table 2).

The adherence of combustive residue to the archeological objects accounts for nearly half (48%) of observed impacts at EFMO (Table 4). There were also high

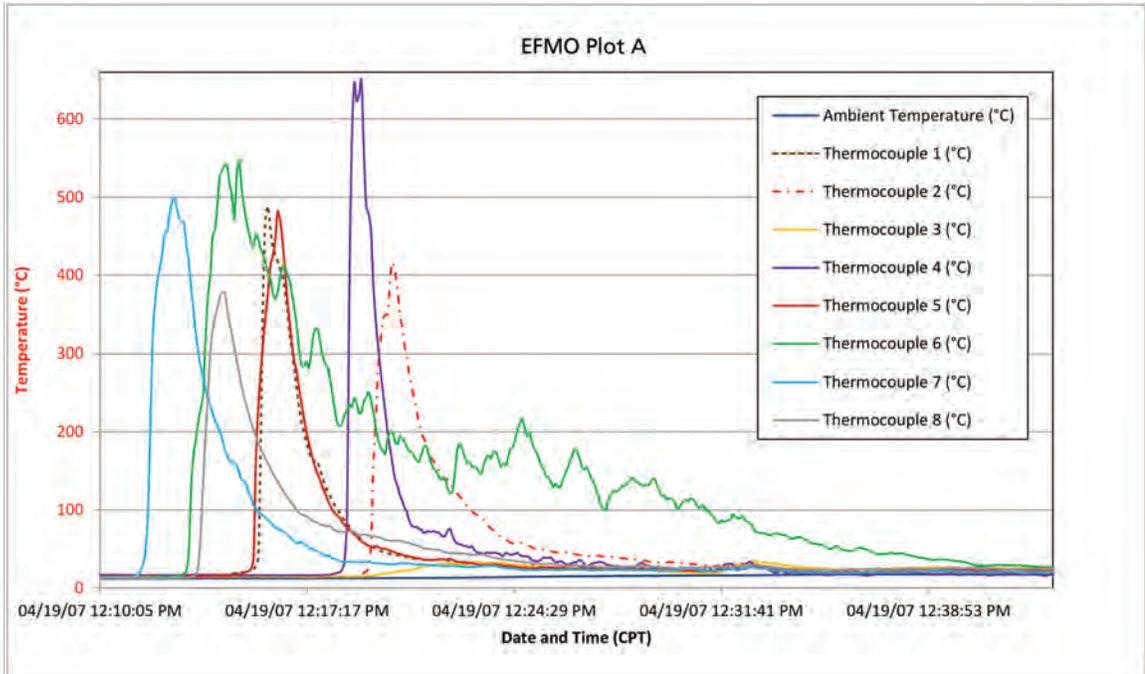


Figure 25a. EFMO Experimental Plot A, Grassland, backing fire.

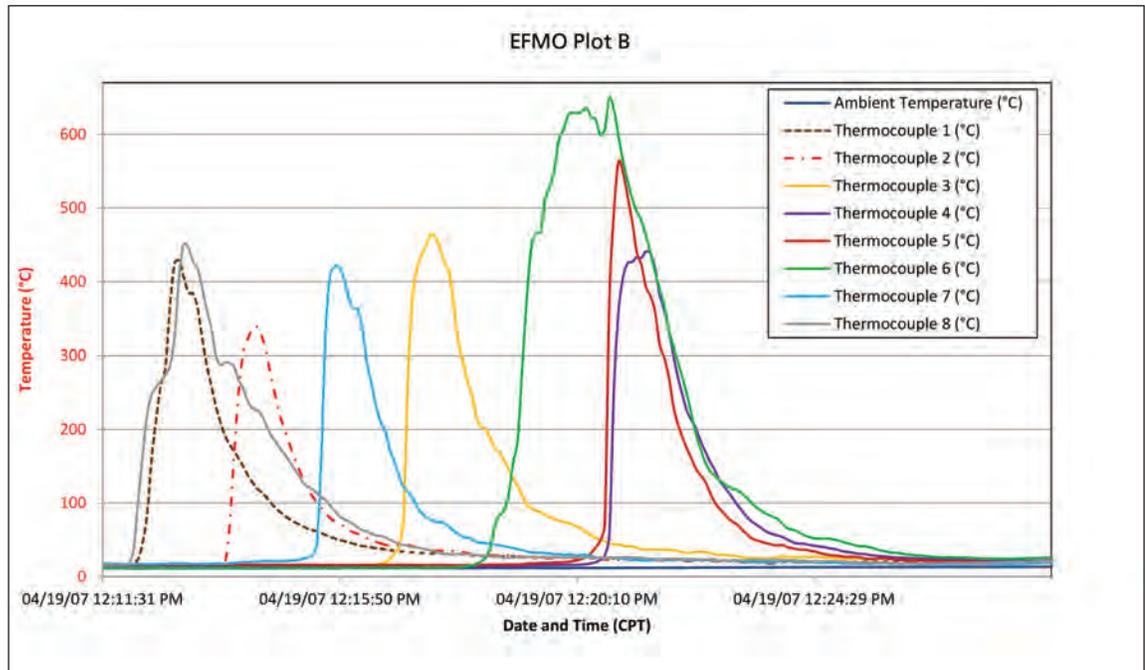


Figure 25b. EFMO Experimental Plot B, Grassland, flanking fire.

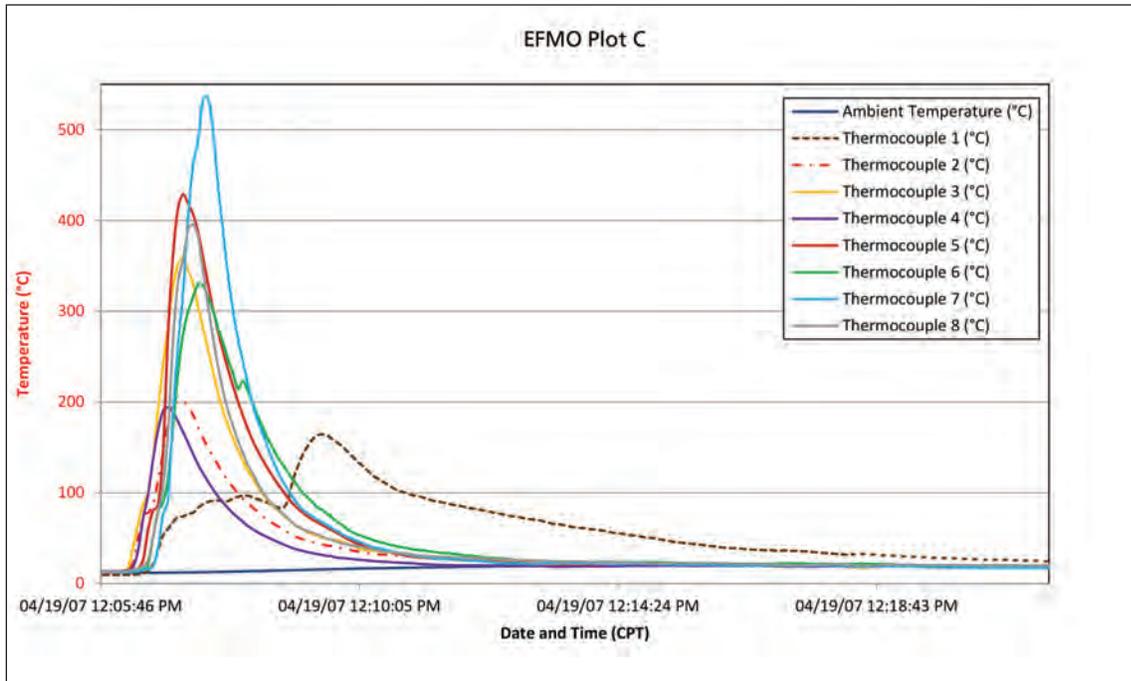


Figure 25c. EFMO Experimental Plot C, Grassland, head fire.

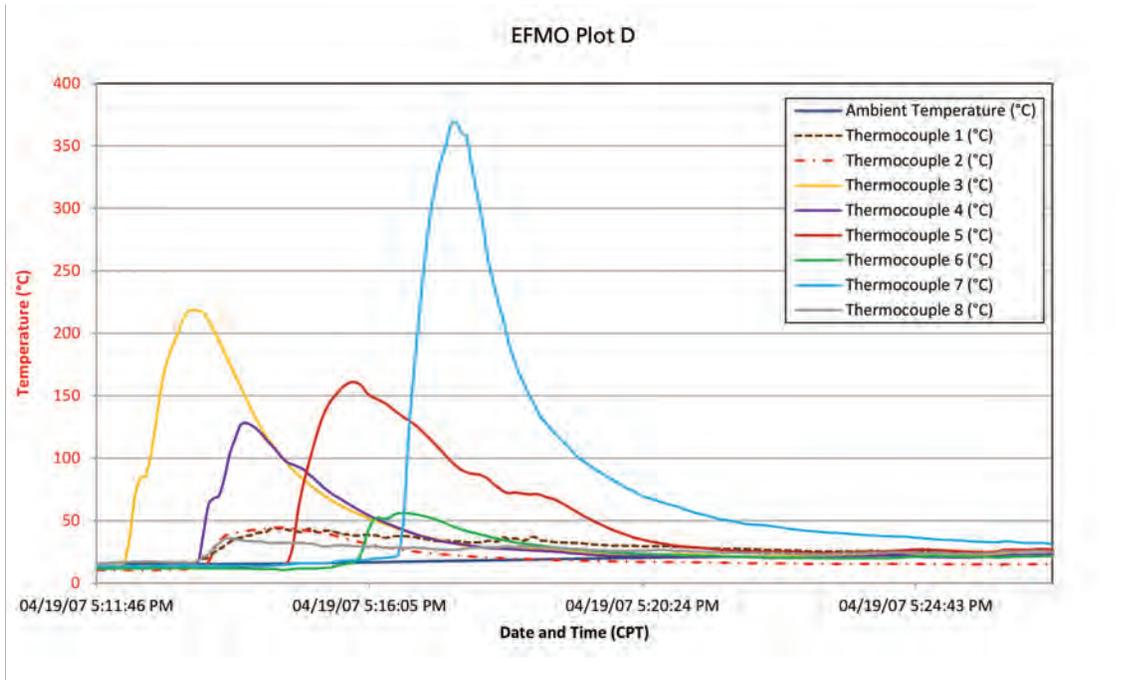


Figure 25d. EFMO Experimental Plot D, Woodland, head fire.

incidences of scorching and color change recorded for the EFMO experiments (Table 4). Significant impacts were confined to cracking and fracturing but represent only 1% of the total impacts observed.

Conclusions based on the results of the experimental burns at EFMO are considered tentative since burn conditions did not facilitate the successful burns of two out of three woodland fuels plots. Because of a paucity and thinness of leaf litter in the woodland zone, the backing and flanking fire plots did not burn and yielded no results. The head fired woodland plot did burn and was included in our analysis. All three grassland plots were completed and provided data to evaluate grassland fuels within the park.

PEA RIDGE NATIONAL MILITARY PARK (PERI)

Experimental burns at PERI utilized two distinct Ozark Highland contexts and are a good representation of the Ozark old-field grassland and woodland fuel types. Oak woodlands/forests are best characterized as fuel model 9 (62% of the park). The cultivated fields are characterized as fuel model 3 (19% of the park) (Anderson 1982). The grassland plots did contain some woody brush vegetation. The woodland plots included a uniform cover of hardwood leaf litter and woody vegetation.

All six PERI experimental plots were burned on March 18, 2007. Grassland fuels plots recorded relatively uniform burn durations of between 26 minutes 50 seconds and 31 minutes 45 seconds (Figure 26 a-c, Table 2). In comparison, woodland fuels plots burned relatively quickly with burn times of 7 minutes 5 seconds to 15 minutes 55 seconds (Figure 26 d-f, Table 2). Woodland fuels plots also exhibited lower maximum temperatures ranging between 254°C to 383°C with the grassland fuels ranging between 459°C to 630°C (Figure 8 d-f, Table 2).

Non-permanent impacts dominated the effects recorded on artifacts from PERI (Table 5). Combustive residue accounted for 75% of the observed changes in the PERI collection. More significant impacts such as fracturing, melting, and spalling together accounted for 8% of the total impacts observed (Table 5). The dominance of non-permanent, less significant impacts at PERI suggest that its relatively short burn durations reduced the incidence of significant impacts observed on the PERI materials.

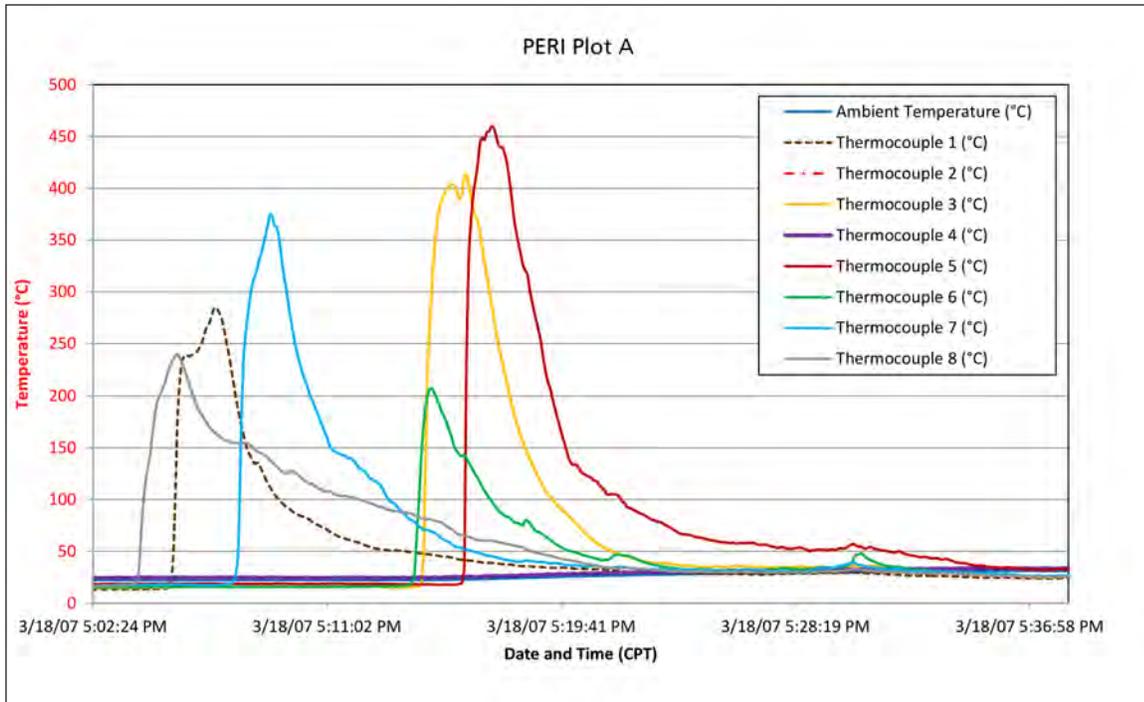


Figure 26a. PERI Experimental Plot A, Grassland, flanking fire.

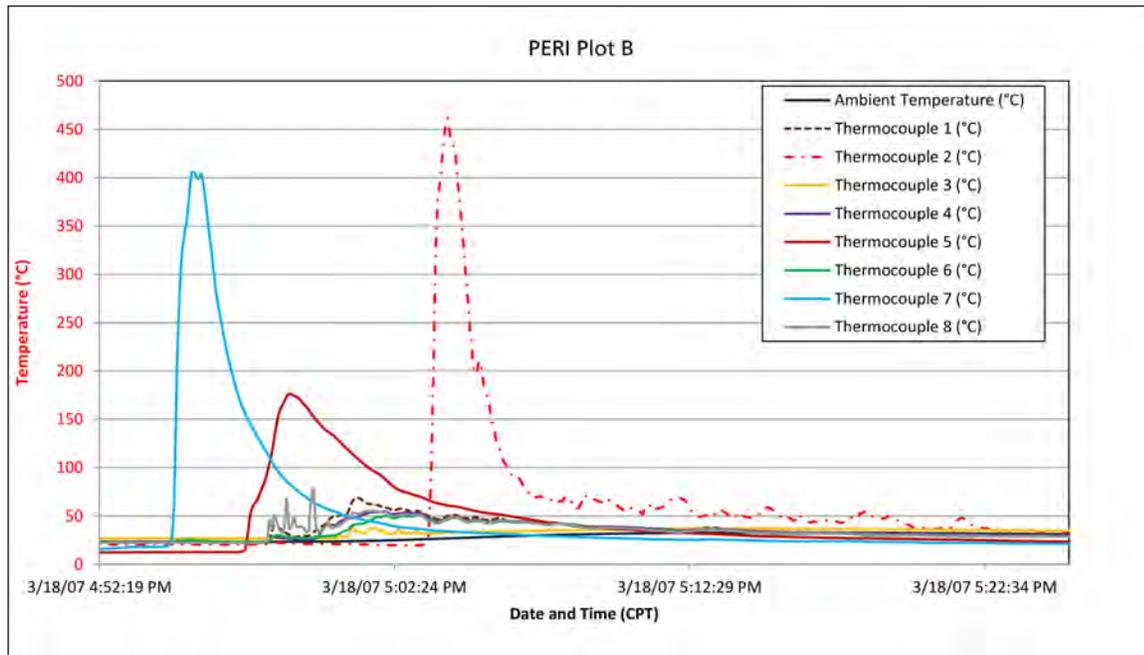


Figure 26b. PERI Experimental Plot B, Grassland, backing fire.

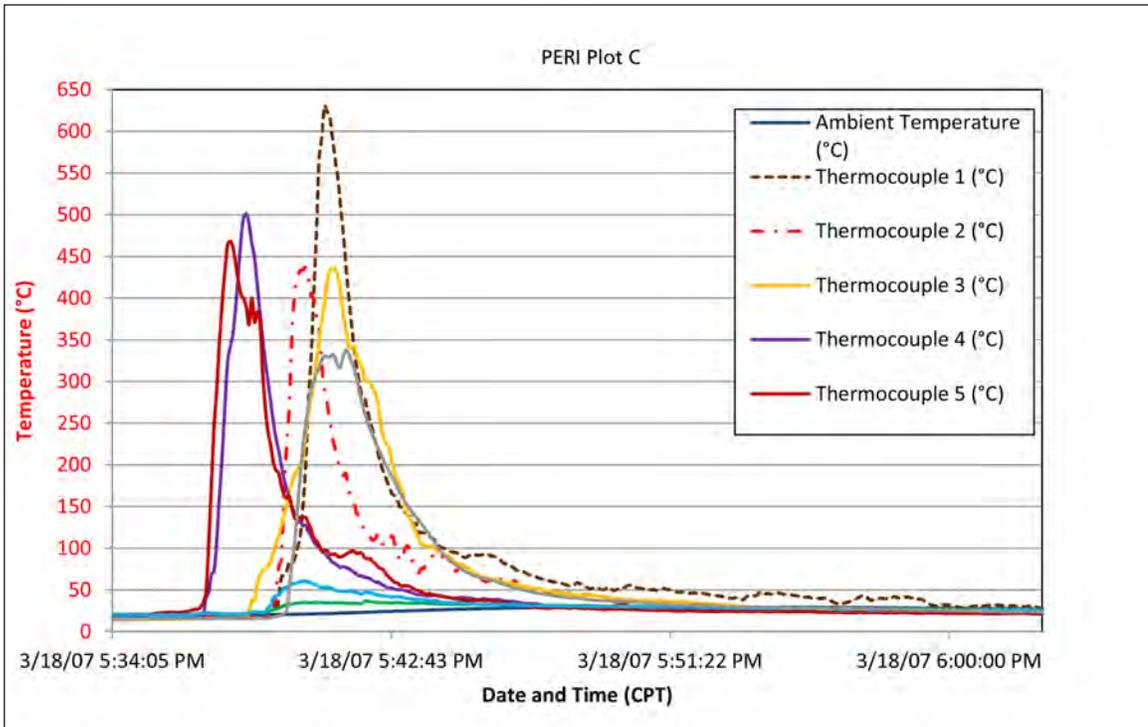


Figure 26c. PERI Experimental Plot C, Grassland, head fire.

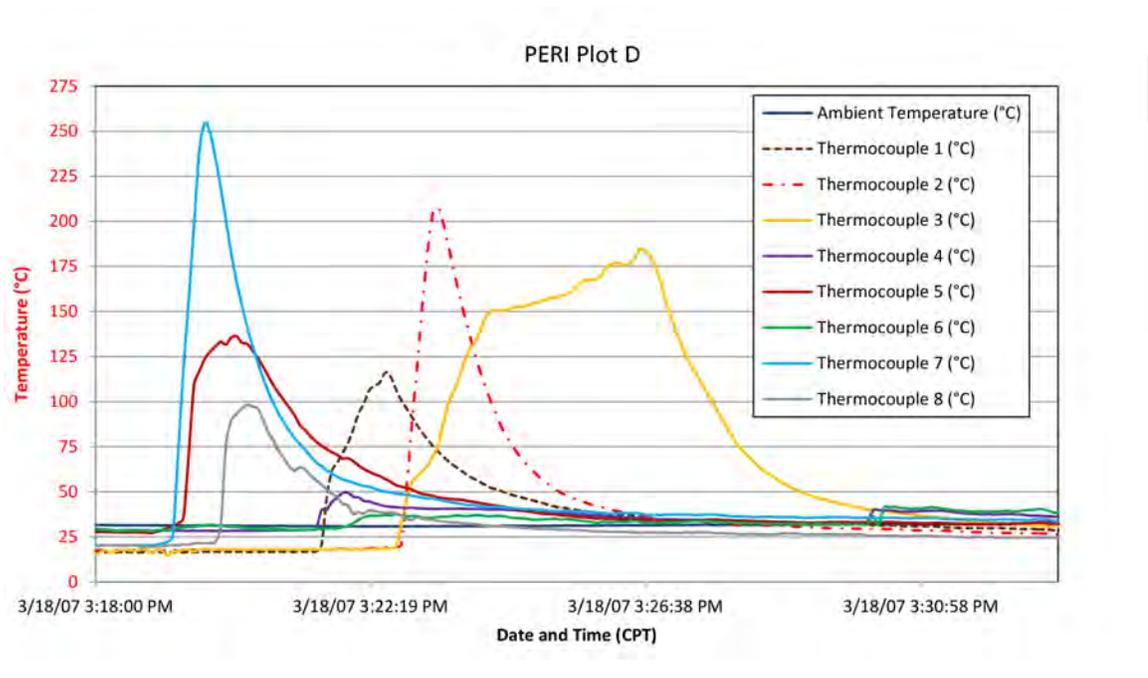


Figure 26d. PERI Experimental Plot D, Woodland, backing fire.

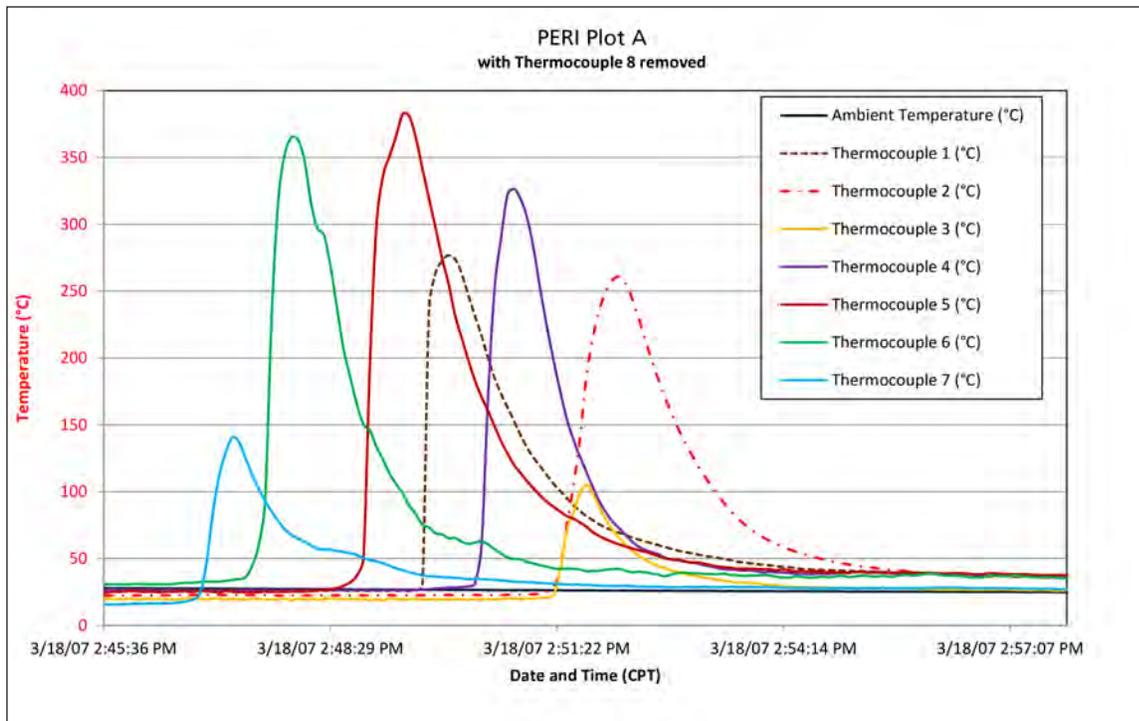


Figure 26e. PERI Experimental Plot E, Woodland, flanking fire.

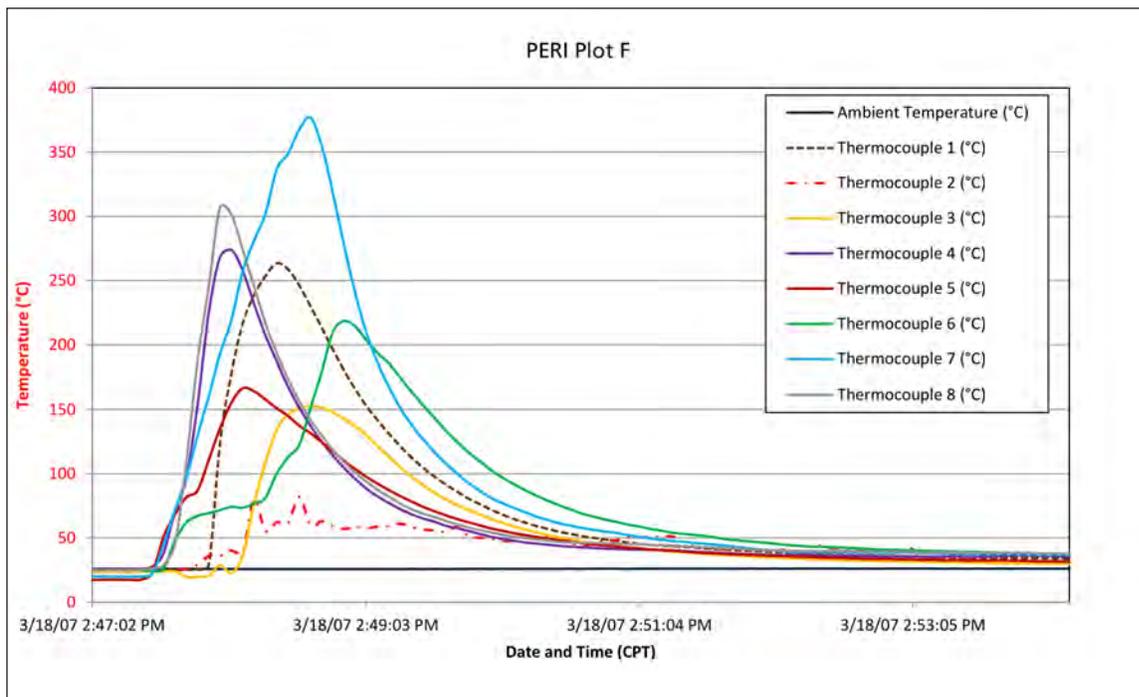


Figure 26f. PERI Experimental Plot F, Woodland, head fire.

TALLGRASS PRAIRIE NATIONAL PRESERVE (TAPR)

The grassland fuels at TAPR are a very uniform fuel type with less variability than woodland plots in other parks and consist primarily of fuel models 1 and 3. The TAPR grasslands are characterized by a frequent burn schedule and intensive cattle grazing, both of which tend to reduce fuel loading in a grassland environment. One backing fire plot did not produce any results because fire did not carry across the plot during the burn.

Experimental plots at TAPR were burned on March 26, 2007. Grassland fuels at TAPR exhibited the lowest burn durations of the parks included in this study. Burn durations between 4 minutes 20 seconds and 9 minutes 25 seconds produced maximum temperatures of 208°C to 492°C (Figure 27 a-e, Table 2). Average temperatures across all TAPR plots varied between 47°C and 106°C (Figure 27 a-e, Table 2).

Impacts observed at TAPR were the most minimal of the experimental program (Table 6). No change was recorded on 22% of the objects subjected to the prescribed burn. Combustive residue and scorching account for 58% and 7% respectively of the total impacts observed (Table 6). A small percentage of objects (11%) did exhibit some color change following the prescribed burn (Table 6).

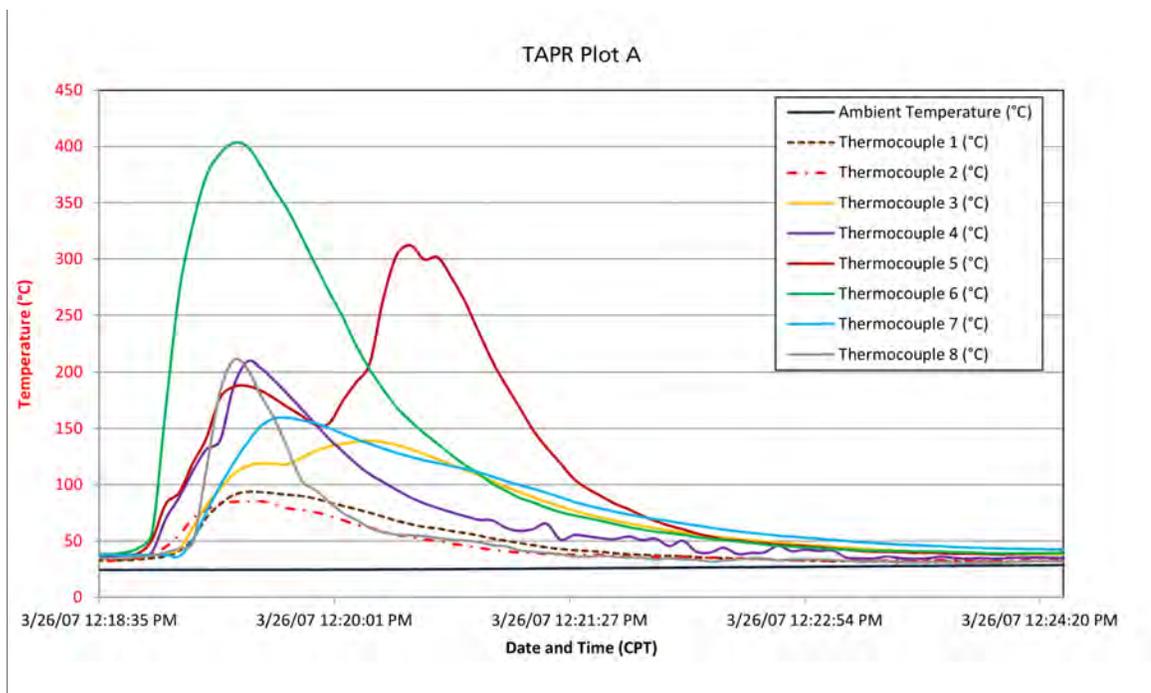


Figure 27a. TAPR Experimental Plot A, Grassland, head fire.

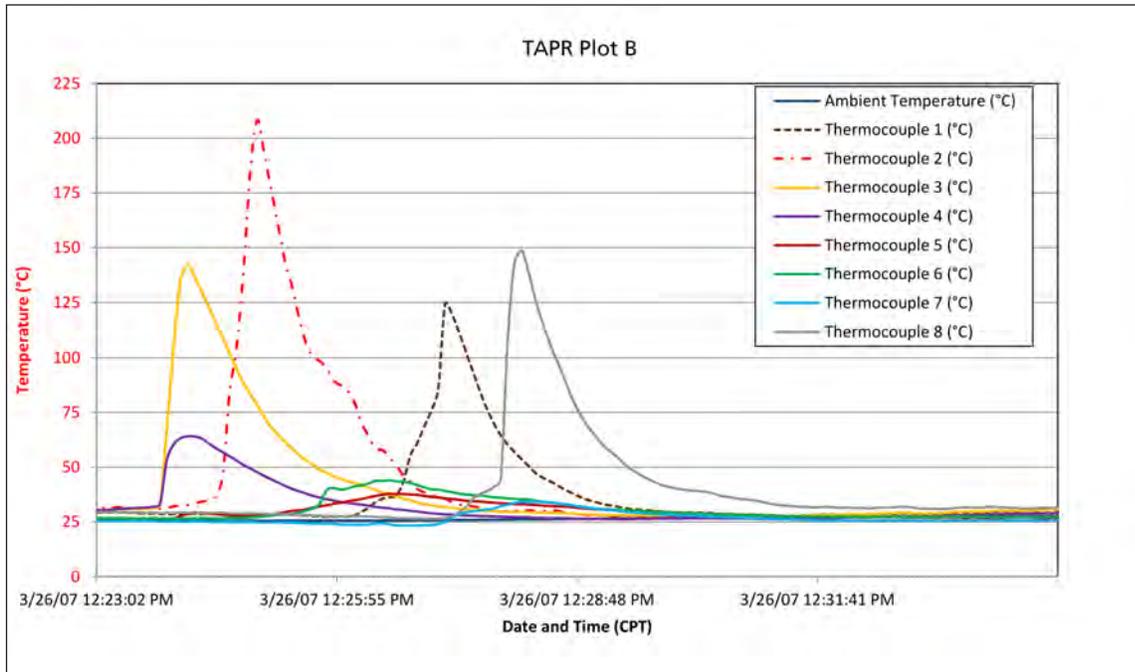


Figure 27b. TAPR Experimental Plot B, Grassland, flanking fire.

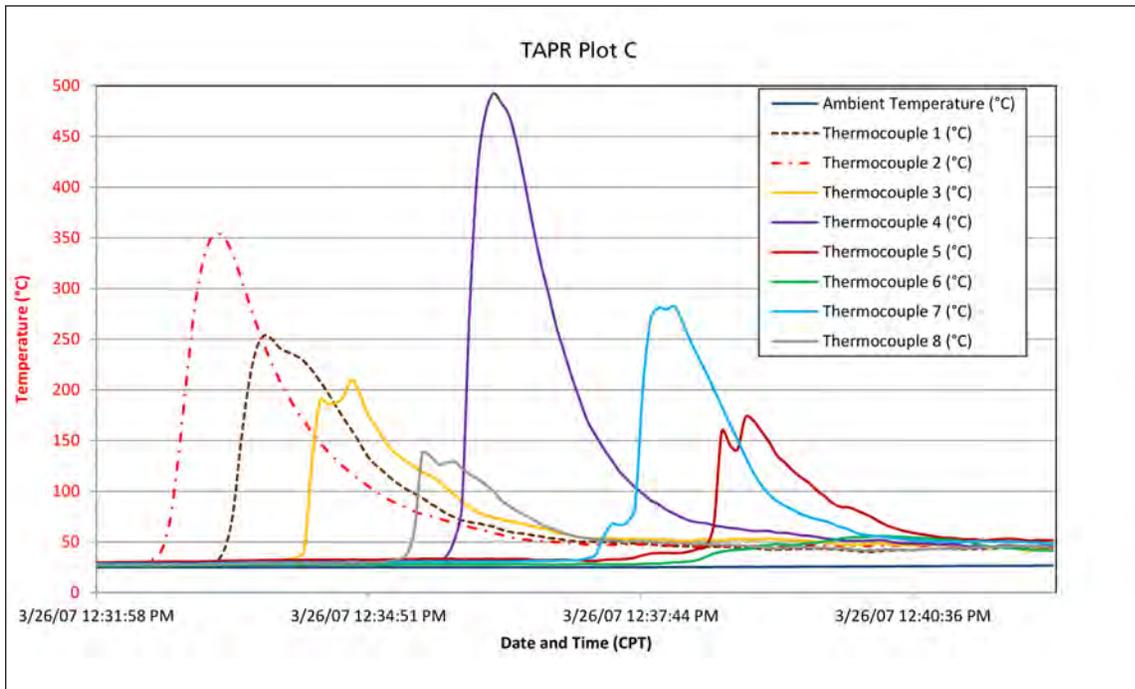


Figure 27c. TAPR Experimental Plot C, Grassland, backing fire.

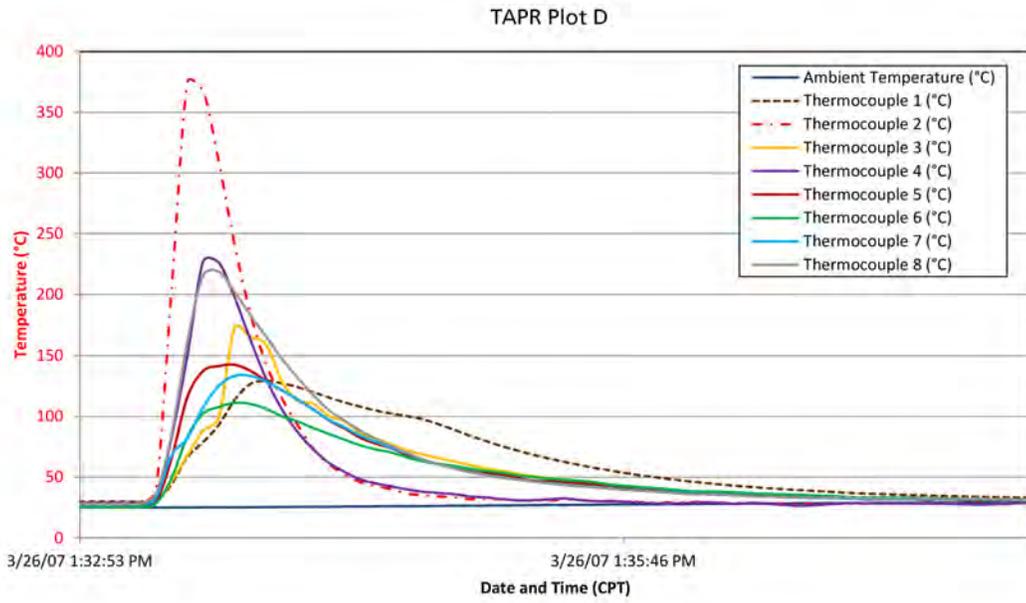


Figure 27d. TAPR Experimental Plot D, Grassland, head fire.

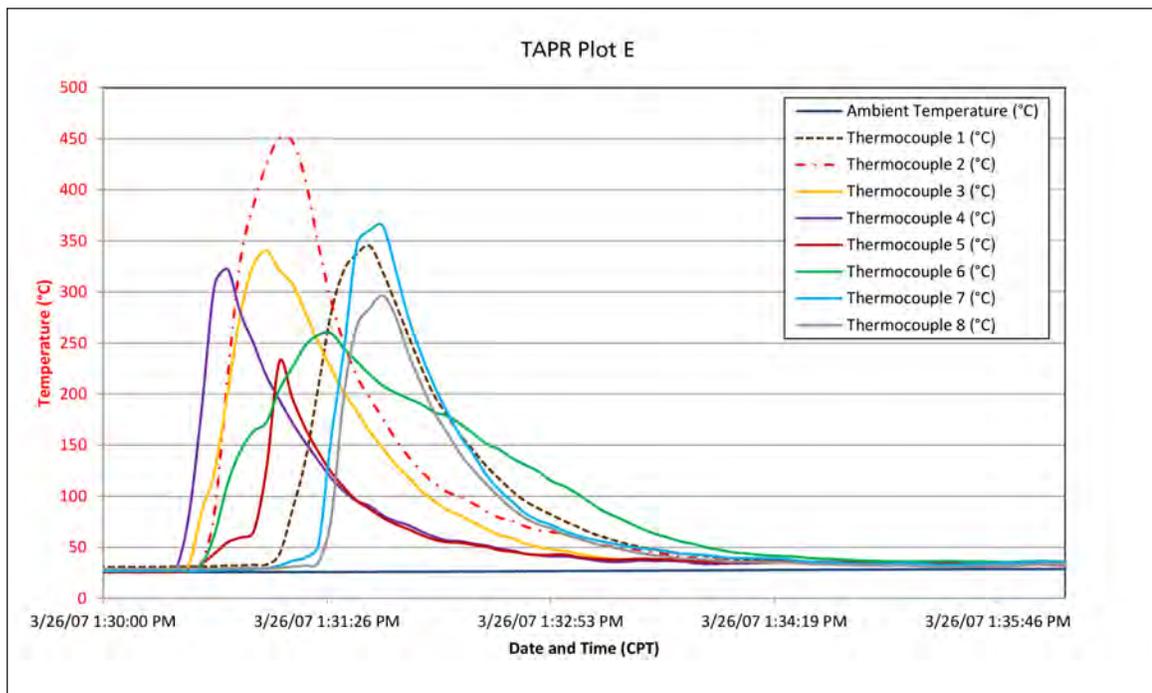


Figure 27e. TAPR Experimental Plot E, Grassland, flanking fire.

VOYAGEURS NATIONAL PARK (VOYA)

The prescribed burns at VOYA were logistically the most difficult of the project. Coordination of the VOYA prescribed burn experiments was complicated by the fact that the VOYA fire program tends to have narrowly defined prescribed burn parameters and is remote enough that achieving a successful burn at the park took multiple attempts during a three-year period.

VOYA experimental plots were placed in a 200 year-old red and white pines stand. Except for a prescribed burn conducted by VOYA in 2004, the site had not burned since the early 1900s. As a result, there was a dense growth of beaked hazel and round-leafed dogwood. The coarse woody debris on the site consists of scattered jackpots from wind thrown trees, with a low to moderate fuel load across the majority of the site. Although the overstory is mostly pine, it is sparse in areas and the litter is often dominated by leaf litter rather than needle cast. The duff layer ranges widely in depth from near zero on the exposed ridges and openings to nearly 15 cm in the dense brush. The site is best described as fuel models 8 and 9 (Anderson 1982).

The experimental plots were placed in two areas, one of dense brush that had been cut the year prior (fuel model 8) and one in an exposed area with scattered woody fuels (fuel model 9). The litter layer was composed of mainly needle cast with a mix of leaf litter from the surrounding brush. The duff layer was up to 10 cm thick in the former brushy area and was minimal in the latter exposed area.

All VOYA plots were successfully burned on August 13, 2009. Because of the variability in fuels at VOYA, two plots burned as a combination backing and flanking fire (Table 2). VOYA exhibited the longest burn durations of the project and a high degree of variability with the maximum recorded burn temperatures. Burn durations were as long as 188 minutes with none under 70 minutes (Figure 28 a-f, Table 2). Maximum temperatures ranged between 47°C and 622°C with average temperatures recorded between a project low of 26°C and 109°C (Figure 28 a-f, Table 2). Fire data from VOYA underscore the highly variable nature of the fuel types and loads contained within the park.

Similar to the other woodland fuels plots at other parks, the VOYA collection exhibited a higher incidence of significant impacts to certain material types. Bone and shell items were found to be more susceptible to fracturing, cracking and spalling (Table 7). Combustive residue accounted for 55% of the impacts observed at VOYA (Table 7). Scorching (15%) and color change (14%) combined for nearly 30% of the total impacts. One lead object did show evidence of melting during the burn. Prehistoric stone tools and pottery exhibited incidences of combustive residue, minor-medium scorching, and some color change after the prescribed burn.

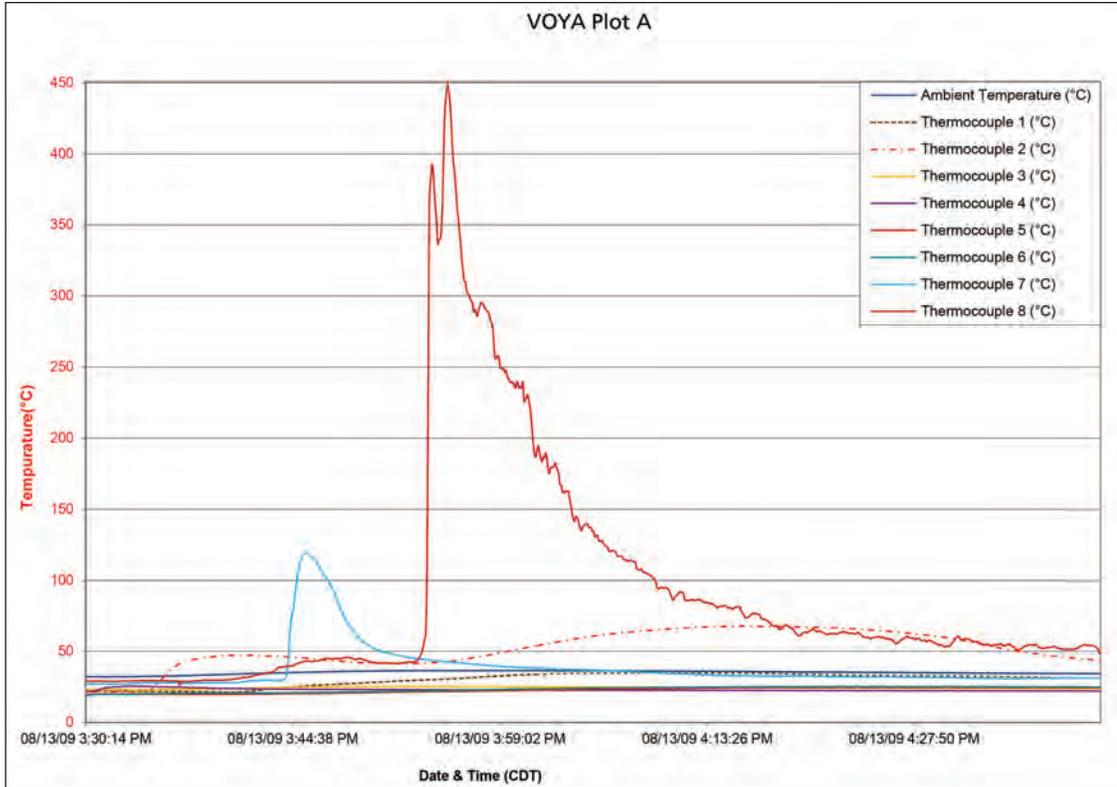


Figure 28a. VOYA Experimental Plot A, Woodland, flanking fire.

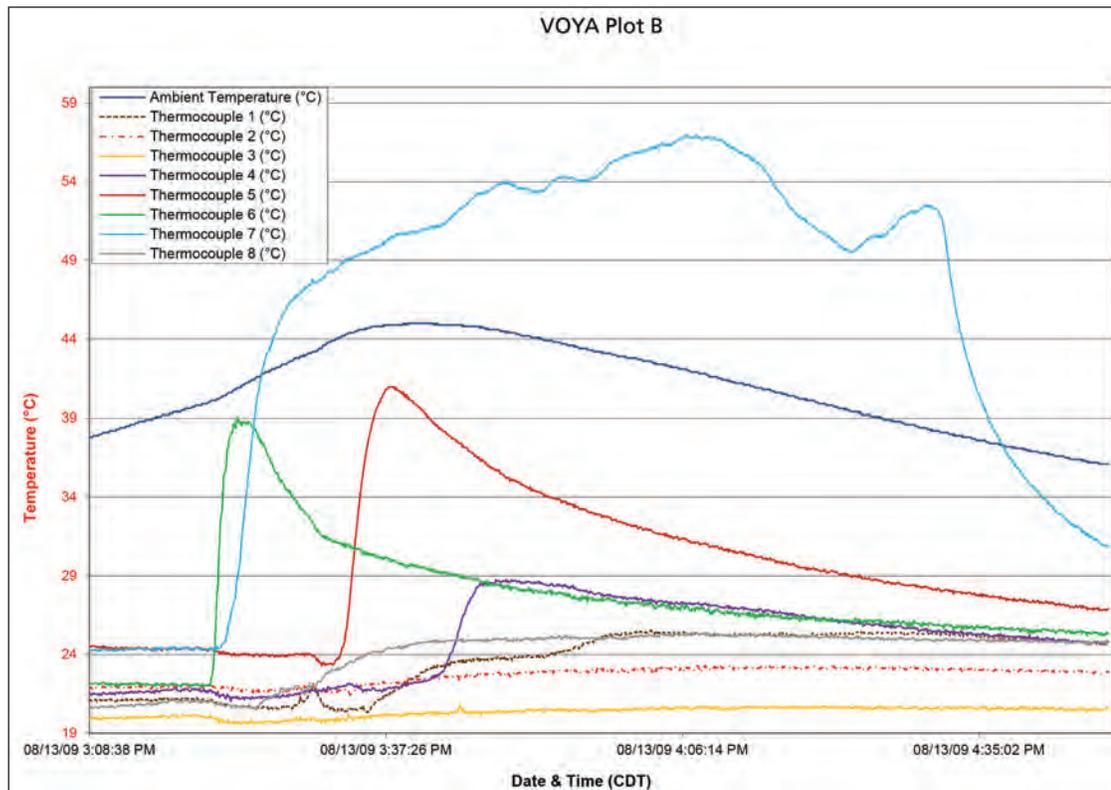


Figure 28b. VOYA Experimental Plot B, Woodland, head fire.

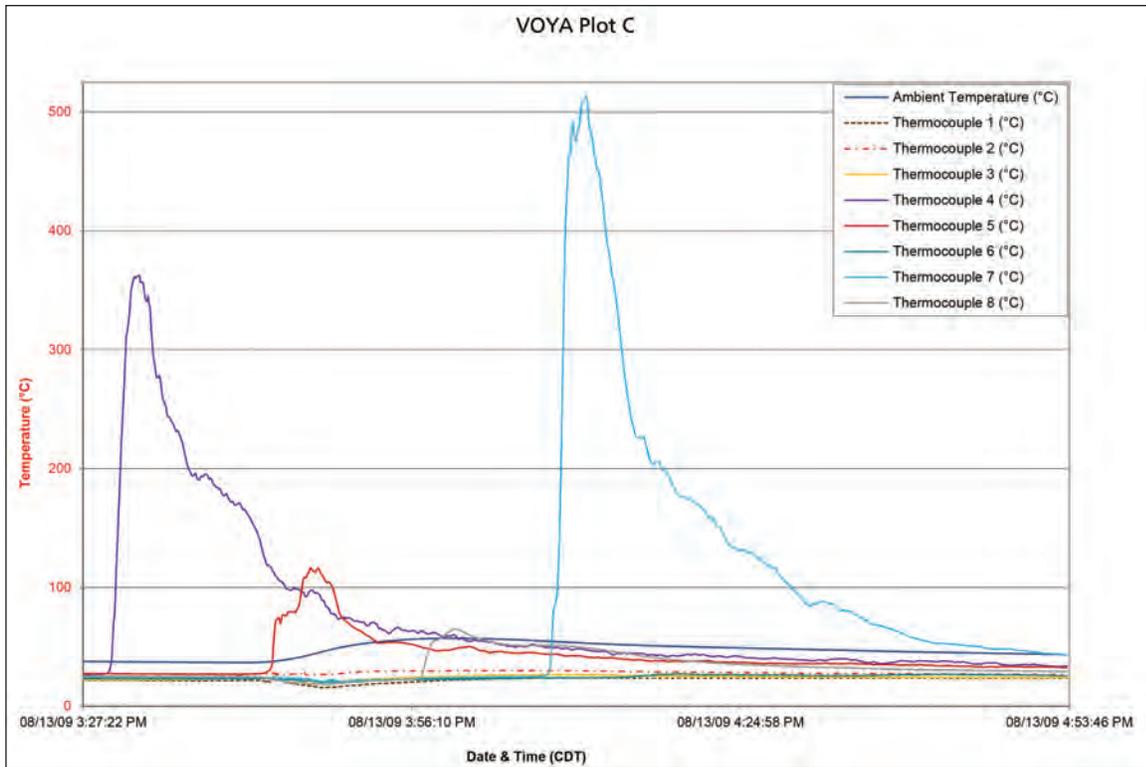


Figure 28c. VOYA Experimental Plot C, Woodland, backing fire.

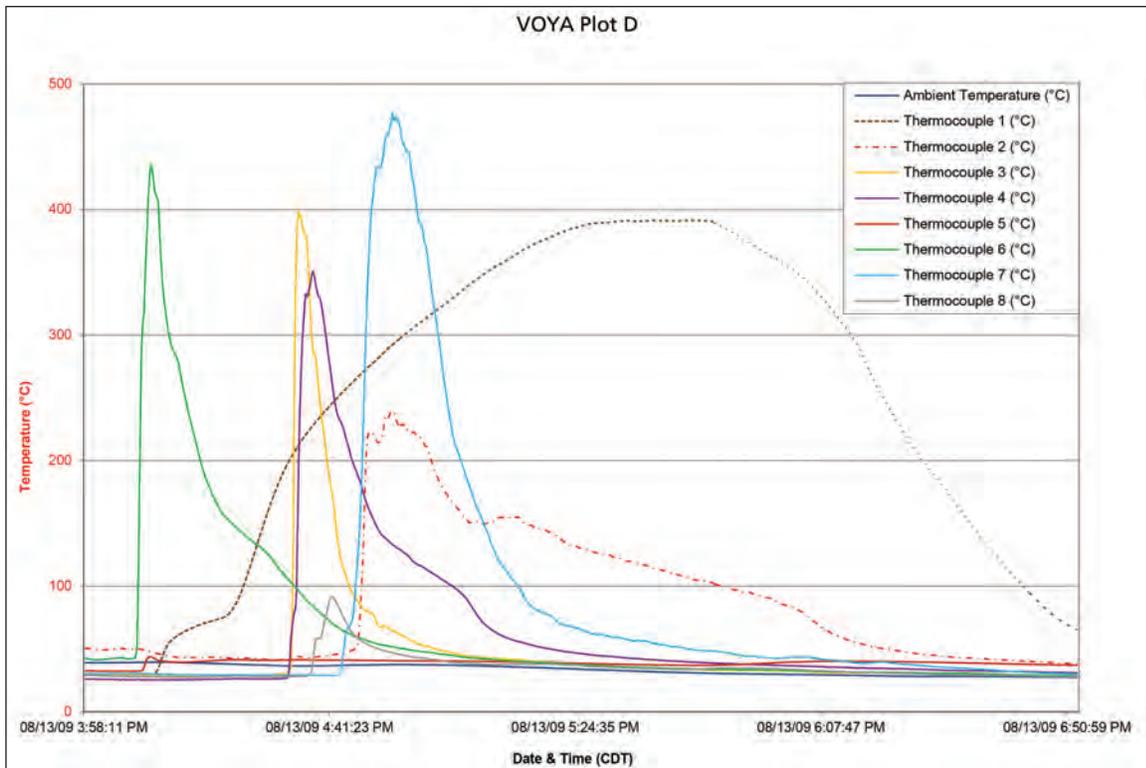


Figure 28d. VOYA Experimental Plot D, Woodland, backing fire.

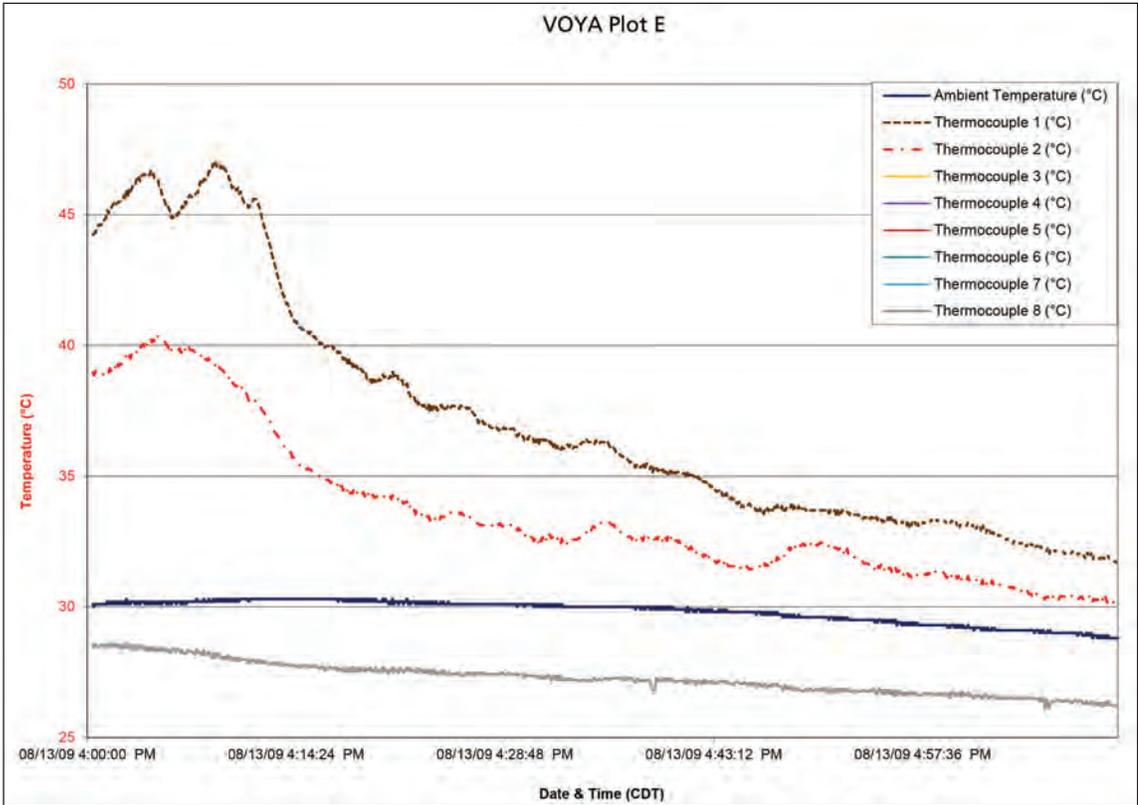


Figure 28e. VOYA Experimental Plot E, Woodland, flanking fire.

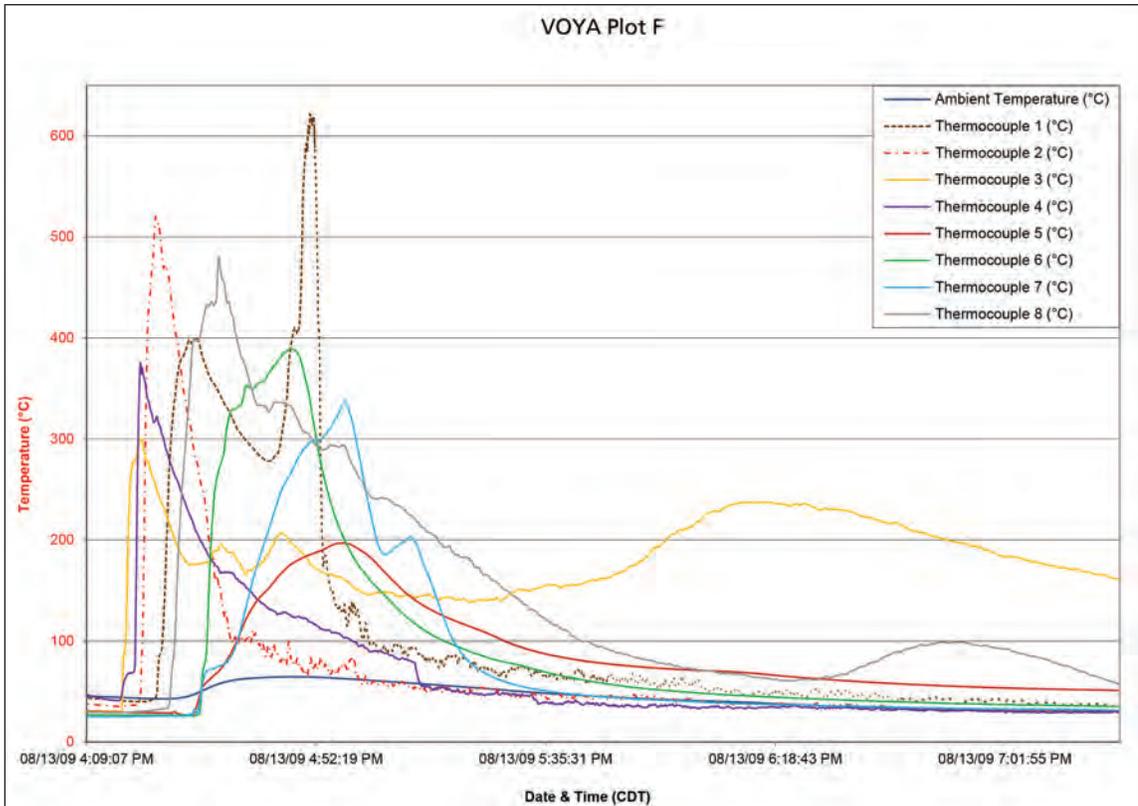


Figure 28f. VOYA Experimental Plot F, Woodland, head fire.

WIND CAVE NATIONAL PARK (WICA)

The mixed pine litter and grass fuels from experimental plots at WICA are unique to the JFSP research project. This was the only park in the study to have a primarily pine litter and grass fuel type. This fuel type tends to reflect ecosystems found in the western United States and stands in contrast to other areas in the Midwest. Nearly 90% of the park can be characterized as fuel model 1, 2, or 9. Mixed-grass prairie is generally described as fuel model 1 (59% of the park). Fuel loads tend to range from 1 to 4 tons per acre in this fuel type, depending on precipitation, time since last fire, and level of bison grazing. The ponderosa pine forests of Wind Cave are characterized as fuel model 2 (26% of the park) or model 9 (4% of the park); model 2 if the primary carrier of fire is grass fuel and model 9 if the primary carrier is pine needles and small-diameter woody fuels.

All six plots at WICA were successfully burned on October 29, 2008. Grassland plots recorded burn durations of 19 minutes 30 seconds to 35 minutes 35 seconds and maximum temperatures of between 439°C to 745°C (Figure 29 a-c, Table 2). Average burn temperatures for the grassland plots were between 55°C and 129°C (Table 2). The grassland/woodland fuels plots exhibited much longer burn duration times between 66 minutes 10 seconds and 161 minutes 5 seconds and higher maximum temperatures of 747°C and 768°C (Figure 29 d-f, Table 2).

Incidence of minor to heavy combustible residue account for 54% of all impacts observed on the WICA artifacts (Table 8). Charring and minor to medium scorching were observed on 15% of objects. No Change was recorded on 19% of the WICA collection on a broad range of material types. Significant impacts, such as fracturing and melting, were observed infrequently on bone, glass, and lead objects (Table 8).

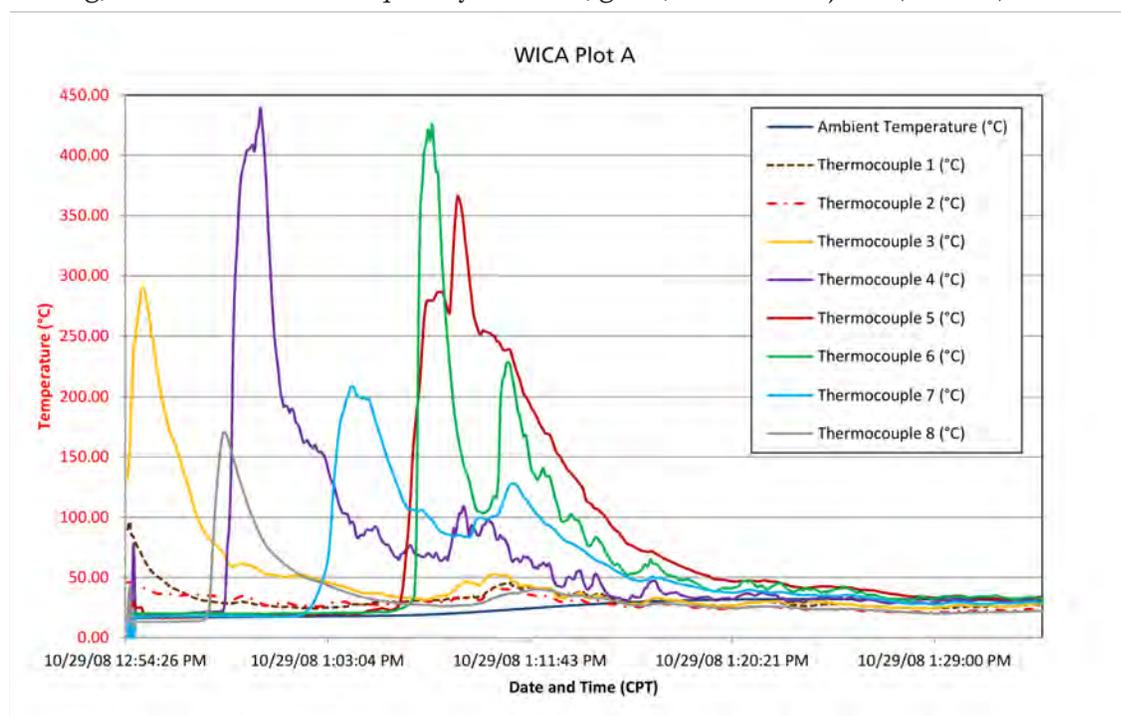


Figure 29a. WICA Experimental Plot A, Grassland, backing fire.

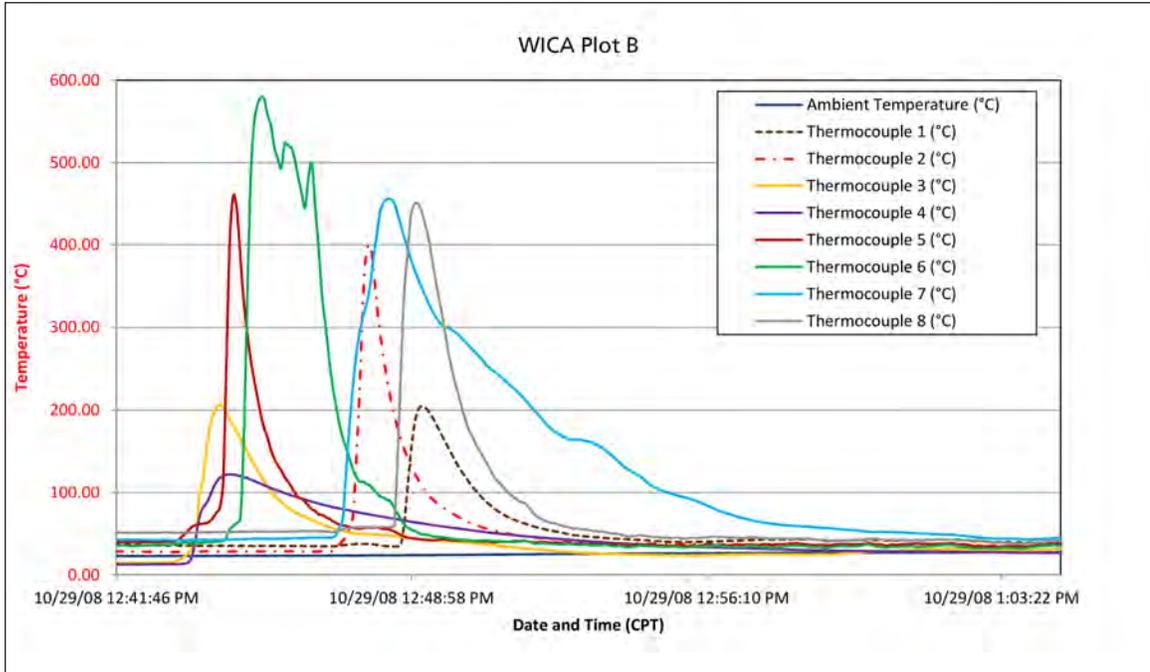


Figure 29b. WICA Experimental Plot B, Grassland, flanking fire.

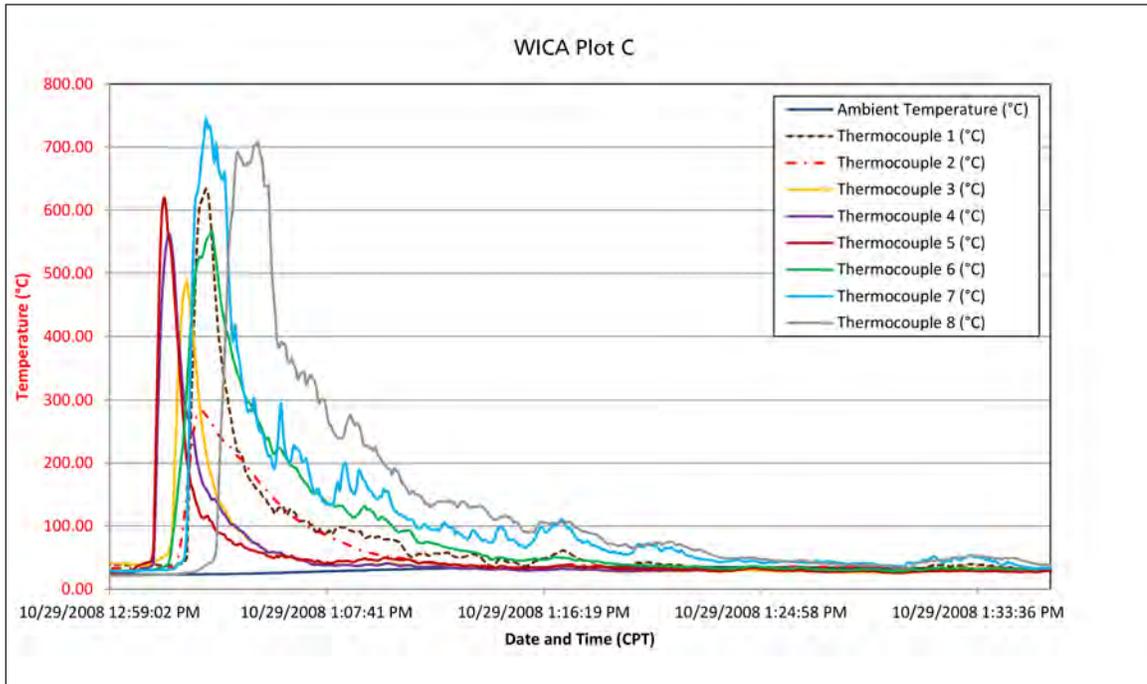


Figure 29c. WICA Experimental Plot C, Grassland, head fire.

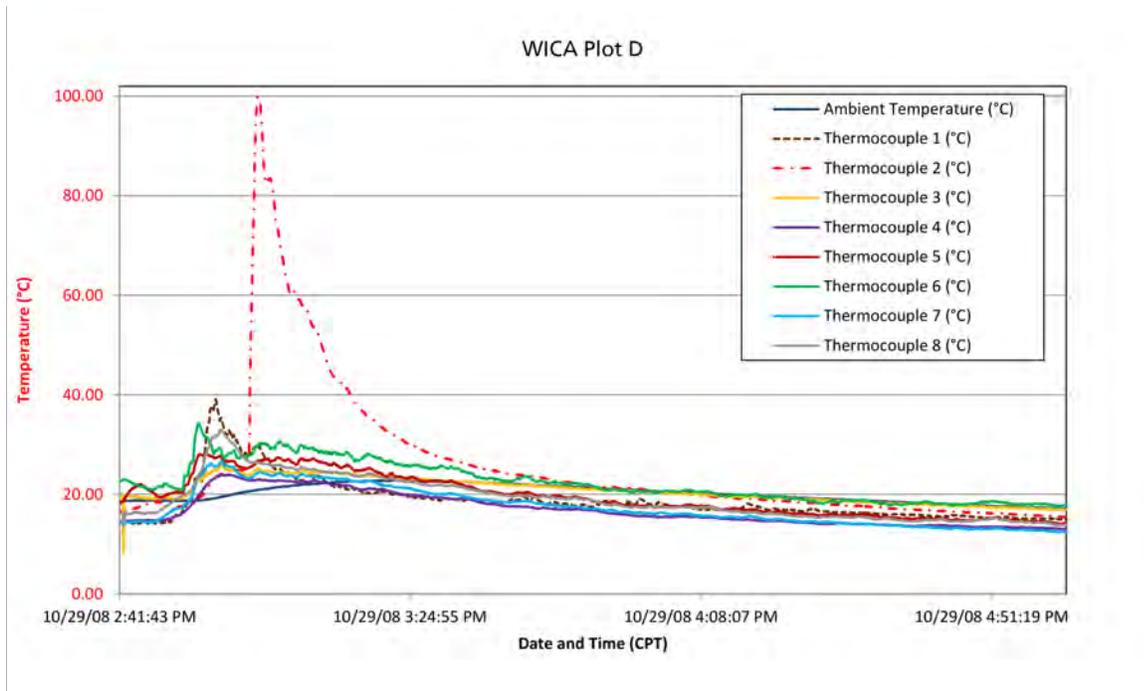


Figure 29d. WICA Experimental Plot D, Grassland/Pine Woodland, backing fire.

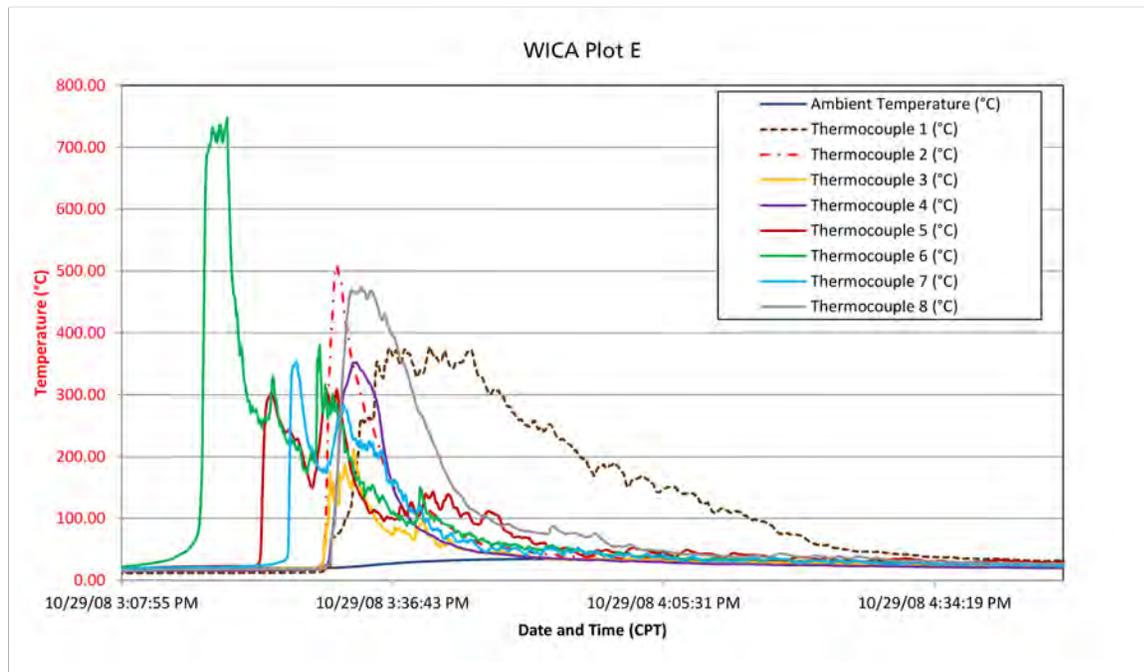


Figure 29e. WICA Experimental Plot E, Grassland/Pine Woodland, flanking fire.

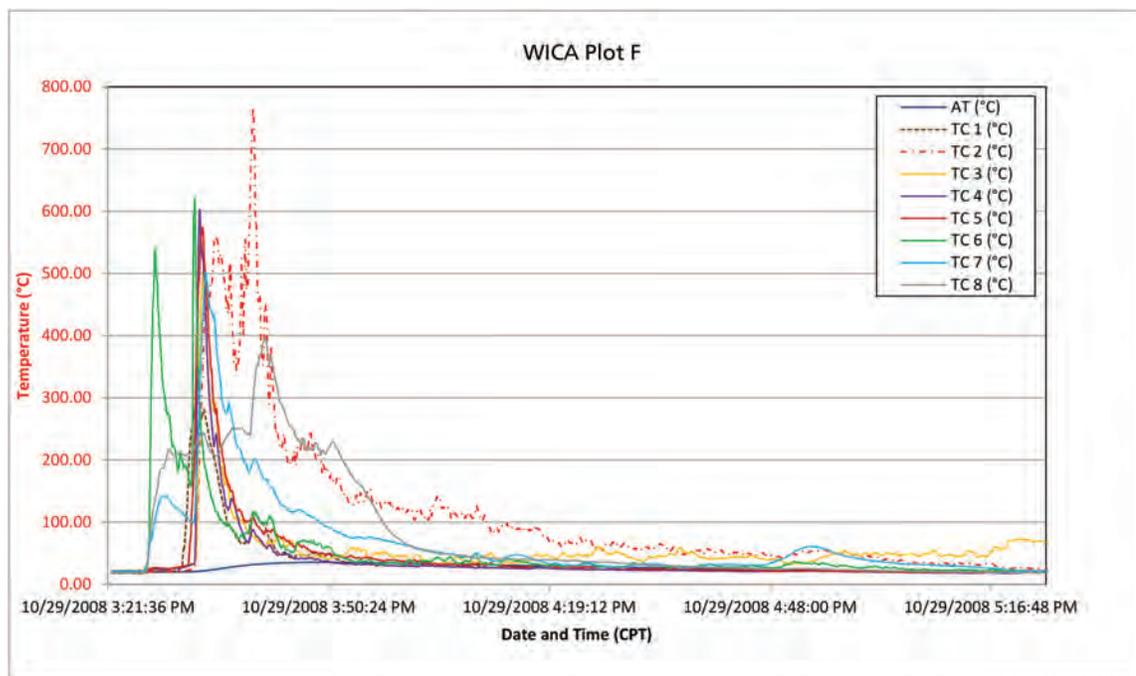


Figure 29f. WICA Experimental Plot F, Grassland/Pine Woodland, head fire.

SUMMARY OF IMPACTS

Analysis of data from the six parks has shown both expected and surprising results. The majority of artifacts subjected to fire during prescribed burns did not exhibit any significant impacts. A significant macro-scale impact to an artifact was defined as an irreversible change to an object and a loss of its inherent information potential, destabilization of an object that would lead to degradation and loss of information potential, or the complete destruction of an object. The adherence of combustive residue to artifacts was the most frequent impact observed. Between 48% and 75% of artifacts exhibited low to high amounts of combustive residue. Significant impacts to artifacts such as scorching, fracturing, cracking, spalling, or melting were typically observed in only 5% to 10% of assemblages. However, experimental plots with higher fuel loads or longer burn residence times did increase the occurrence of these impacts into the 20 – 25 % range. Parks with experimental plots that yielded more significant impacts include BUFF, VOYA, and WICA. The incidence of major or significant impacts to the artifact assemblages was likely a combination of fuel type/fuel load and artifact material. Artifacts such as bone, shell, leather, wood, and lead exhibited more frequent significant impacts when compared to materials such as ceramic, stone, metal, and glass. The majority of impacts observed are reversible, did not destabilize an object, did not lead to a loss of information potential, and did not completely consume the object.

When available fuels have the potential to increase burn duration and intensity, increased incidence of significant impacts to archeological resources may result. For example, grass fuels typically are of short burn duration and lower temperature (Table 2), resulting in minor impacts such as the adherence of combustive residue. In plots where fuels increased burn duration and intensity, the potential for impacts increases,

especially on artifact materials that are susceptible to modification at lower temperatures and shorter burn duration such as lead, leather, wood, and shell.

Historic archeological assemblages may be particularly susceptible to impacts from wildland fire. In the Midwest, historic sites frequently include surface scatters or shallow deposits with perishable materials that are vulnerable to significant impacts from wildland fire. As the current study demonstrates, surface expressed historic archeological resources need to be considered along with prehistoric sites when evaluating wildland fire programs. In fact, these may be of primary concern with evaluating burn programs and alternatives for mitigating impacts from fire.

FUELS VARIABILITY

This study demonstrated that there is significant inter- and intra-park variability in fuels and corresponding burn durations and temperatures (Figure 30). Our study has produced a measure of burn conditions at each park, but the variability in fuels at several of the parks could produce varying impacts to archeological resources. Because the type and amount of fuels are two of the primary components related to fire impacts on archeological resources, understanding the fuel conditions at each park is key to predicting potential impacts to archeological resources. Using burn temperature and duration as a relative measure of burn conditions clearly indicates that parks with higher loads of woody fuels have increased potential to impact archeological resources. The parks with the highest combined temperatures and durations also included plots with lower temperatures and durations. The parks that showed higher burn temperatures and longer durations also correlate with increased incidence of significant impact to archeological resources. Grassland plots consistently recorded lower temperatures and shorter durations than woodland plots. This directly correlated with minor or minimal impacts in grassland plots.

The amount, moisture content, and consumption of fuels on the ground surface (e.g., duff and leaf litter) also influence the impacts observed on artifacts. In some cases, leaf litter and duff served to insulate the artifacts lying underneath because the fuels were not entirely consumed by fire. In other cases the leaf litter/duff layer did not contain the density of fuels necessary to sustain fire through an experimental plot. Hence, the amount of ground surface fuel buildup has direct consequences for archeological sites with surface components. Cyclical burn programs in many instances are intended to reduce the amount of litter and surface fuel buildup which may begin to increase the number and severity of impacts to archeological resources by reducing the amount of litter materials that serve to insulate archeological materials lying on the ground surface. Additional data collection is needed in order to account for some of the fuels variability observed in parks with mixed fuels environments.

FIRING TECHNIQUE

The results of using three separate firing techniques to manipulate burn conditions varied between parks and fuel types. In areas with a uniform fuel type (e.g., grass fuels), firing technique can be used to alter burn duration and intensity. In areas with more variable fuels the use of a different firing technique was either masked by fuels that burn for an extended period once the flame front had passed or did not result in any significant difference in fire conditions. Separate firing techniques could not be used on several plots during the study because of logistical reasons during some of the prescribed burns. Additional research is needed to better understand the relationship between firing technique and fire conditions in a variable fuel environment.

EXPERIMENTING WITH ARTIFACT CLEANING

A sample of eighteen artifacts was selected for an experimental study of artifact cleaning techniques to measure the permanence of fire-related impacts. The artifacts are a representative collection of different materials that are typical of the parks in the JFSP study. Artifacts were stored in plastic storage bags contained in plastic storage boxes for four to twenty-eight months after burning and *before* their removal for this study. Artifact materials include bone, brass, ceramic (stoneware and whiteware), kaolin pipe clay, ferrous metal, glass, lead, flaked stone, pewter, aboriginal pottery (unglazed), shell, and tin (enamel-ware). Artifacts were selected that had medium to heavy combustive residues on their surface in order to allow cleaning effectiveness to be determined on those artifacts that were most heavily affected by fire. Each burn location contained a particular fuel type (grassland, grassland/woodland, and woodland) in order to determine what effects different fuels might have on the post-burn condition of the artifact. Three bone artifacts and three flaked stone artifacts were selected from each fuel-type in order to determine if fuel-type would influence the effectiveness of different cleaning methods.

Cleaning methods were determined using the experimental cleaning steps outlined in Roberts (1988) and Spafford-Ricci and Graham (2000). Both of these articles recorded, in careful detail, the methods and procedures used to restore items burned or otherwise affected by structural fires in the Huntington Library and Art Gallery in Pasadena, CA and the Royal Saskatchewan Museum, respectively. Although it is understood that structural fire fuel types in a museum would be quite different from wildland fire in the Midwest National Parks, the clear steps and guidelines used in these articles provided a basis on which to clean a sample of artifacts from the Joint Fire Science Project.

ARTIFACT CLEANING LABORATORY METHODS

The methods chosen were separated into two categories: dry cleaning and wet cleaning. Dry cleaning methods involved the use of a soft, dry brush, groom/stick (a gummy material that adheres to soot, dirt, or other loose materials), and soot sponges (latex sponges that are meant to be used dry). Wet cleaning methods included a mixture of warm tap water and Ivory™ soap, a 50:1 solution of distilled water and Orvus™ Paste, a 50:1 (2%) solution of ammonium hydroxide mixed with Ivory™ soap, mineral spirits, 50:50 solutions of alcohol and ethanol, and a 3:1 solution of warm tap water and Gojo™. Dry methods were attempted on every artifact. Wet methods were attempted following the suggestions of Roberts (1988) and Spafford-Ricci and Graham (2000) about which solutions to use on which artifact material. In addition, some wet methods were attempted that were not suggested in the articles above, especially with artifacts that were particularly difficult to clean.

Cleaning methods were tested one at a time with dry methods being followed by wet methods. Cleaning ceased when one or more effective methods were found. All methods were applied to a small area of the artifact in order to allow further cleaning

attempts and to retain a fire-damaged surface for future comparative and research purposes. The dry methods were applied to artifacts as follows:

- Dry, soft-bristle jeweler's brushes were used to remove loose particles from the artifact. Artifacts were gently brushed in a parallel or circular motion.
- Groom/Stick was applied to the surface of the artifact for 1-2 minutes in the desired area then peeled off. It was then dabbed or rolled along the surface of the artifact.
- Soot sponges were used with a gentle to vigorous (depending on the artifact) circular motion on the area to be cleaned.

Wet methods for the artifacts varied according to material type and to cleaning suggestions found in the Roberts (1988) and Spafford-Ricci and Graham (2000) articles. Wet methods were applied as follows:

- A mixture of Ivory™ soap and warm tap water was applied using cotton swabs. Generally, a saturated cotton swab was gently rubbed onto the surface of the artifact. Following this, a dry swab was used in the same manner. This was repeated a number of times, depending on effectiveness of the solution (until the swabs were coming off clean or the solution showed no effect). The area cleansed was then rinsed using swabs soaked in water. Final drying was also done with a cotton swab. This technique was used on a number of material types, including ceramics, kaolin pipe clay, glass, lead, flaked stone, pewter, aboriginal pottery, shell, and tin enamel-ware.
- A 50:1 solution of distilled water and Orvus™ Paste was applied using the same swabbing procedure for the Ivory™ soap/warm tap water solution. This solution was used on brass, ceramics, kaolin pipe clay, ferrous metal, glass, lead, flaked stone, pewter, and shell.
- A 50:1 (2%) solution of distilled water and ammonium hydroxide, mixed with Ivory™ soap, was used on glass, stoneware, whiteware, and kaolin pipe clay. This technique required the use of a vapor hood. Objects were rubbed and dried with cotton swabs, as in the Ivory™ soap/tap water method (usually repeated 2-3 times), with intervening periods in which they were allowed to soak in solution for 1-2 minutes. The ammonium hydroxide showed a strong tendency to destroy cotton swabs quickly, especially where rubbed surfaces were irregular.
- Mineral spirits were applied to artifacts in undiluted concentrations using a similar wet swab/dry swab method. This technique also required the use of a vapor hood. Rinsing was done with distilled water, followed by drying with tissue paper. Only lead, brass, and ferrous metal were cleaned using this method.

- A 50:50 solution of alcohol and distilled water was used on all three bone artifacts. The solution was applied using the wet swab/dry swab method. The cleansed area was dabbed with a swab using warm tap water followed by drying with another cotton swab.
- A 50:50 solution of ethanol and distilled water was used on one of the bone artifacts in the study. It was applied in the same manner as the 50:50 alcohol/distilled water solution, but was rinsed with distilled water instead of tap water.
- A 3:1 solution of warm tap water and Gojo™ was used on a single lithic artifact (chert) in the study. It was applied with the swab method detailed above and rinsed with tap water.

After cleaning, artifacts were allowed to air dry and were re-packed in plastic zip-lock bags with an MWAC artifact card. The steps and effects of cleaning were recorded on MWAC Artifact Cleaning Worksheets. These worksheets were filed and placed with before and after photographs of the artifacts which show the cleansed area on each artifact. The effectiveness of each cleaning method used on each artifact was described using five categories: *not attempted*, *ineffective*, *somewhat effective*, *effective*, and *very effective*. Artifacts on which a cleaning method was not used received a designation of *not attempted*. *Ineffective* was used when there was no visible effect on the combustive residue found on the artifact. *Somewhat effective* was used when some visible effect occurred, but the results were heavily limited (for instance, some material might come off on a cotton swab, but continued cleaning removed only minor to negligible amounts of residue). *Effective* was used when cleaning of the artifact surface occurred with effort (multiple episodes of cleaning might be used, resulting in eventual removal of residues on the surface). Finally, *very effective* was assigned to cleaning methods that showed removal of residues with a minimum amount of work (for example, the alcohol and ethanol used on bone removed residue with the first or second round of cleaning with a cotton swab).

ARTIFACT CLEANING RESULTS

Table 9 shows the results of the cleaning experiment by method. As can be seen, the dry methods (dry brushing, groom/stick, and soot sponges) were, for the most part, ineffective. They removed some loose residue, but typically had little to no effect on the heavier combustive residues found on the test artifacts. A summary of the effectiveness of specific methods follows:

- Dry brushing seemed to be most effective on pieces of bone or pottery with a significant amount of loose, dry residue. However, its effectiveness seemed less dependent upon material type and more on the presence or absence of loose residue (combustive residue, large pieces of plant material, etc.).
- Groom/stick seemed to have the most effect on burned bone artifacts with large amounts of loose residue and charred/scorched areas (it is possible that it was actually removing some of the charred/scorched bone in addition to the loose residue). The designation of somewhat effective was given when the

groom/stick removed some loose material, but had very little visible effect on the artifact itself.

- Soot sponges were the least effective dry method, only having a mild effect on loose residue found on bone artifacts and possibly removing charred/scorched bits of bone when used. It seemed to have little effect on other materials.

Wet methods were much more effective than dry methods, except in cases where the artifact surface was quite rough or porous (unglazed ceramic surfaces, corroded ferrous metal) and combustive residues had penetrated into the body of the material. A summary of the effectiveness of different methods follows:

- The Ivory™ soap/warm tap water solution was effective to very effective on flaked stone surfaces and pewter, removing heavy combustive residues very quickly and clearly (Figure 31a-b). It was somewhat effective on the rest of the artifacts on which it was attempted on, removing a portion of heavy residues but not the more stubborn, thickly covered areas. There were no cases in which this solution was completely ineffective.
- The Orvus™ paste/distilled water solution was most effective on smooth surfaces such as brass, pewter, flaked stone, lead, and glazed whiteware, removing most if not all of the combustive residue on the artifact. It was only somewhat effective on rougher surfaces like unglazed stoneware and shell, removing a small portion of residue from the surface of the artifact. The swabs used on rough materials were discolored in many cases, but seemed to have minimal effectiveness. This solution was ineffective on corroded ferrous metal, kaolin pipe clay, and glass. The results for kaolin clay and ferrous metal were anticipated because of extremely rough surface texture (in the case of the corroded metal) and absorption of the combustive residue (in the case of the kaolin clay). The glass seems an anomaly because of its smooth surface. However, the combustive residue on the glass was especially thick and difficult to remove.
- The 50:1 (2%) solution of ammonium hydroxide mixed with Ivory™ soap was very effective on smooth surfaces such as glazed ceramics and glass. It removed the residues that were difficult to remove with other methods, especially after artifact surfaces were soaked in the solution for 1-2 minutes. However, it had no effect on rough and porous surfaces like kaolin pipe clay and the unglazed surfaces of stoneware. Even at 2% concentration, this solution was particularly caustic, destroying the cotton swabs as they were used. Rough materials made this situation worse, requiring the use of more cotton swabs. Because of this, rinsing and drying on all artifacts was done quickly to prevent damage.
- Mineral spirits, used exclusively on metals (brass, lead, and ferrous metal), were very effective for lead and brass, removing any combustive residues in a short period of time. The corroded ferrous metal, however, proved resistant to cleaning and this method had no effect. This is likely due to the roughness of the material surface, which literally tore cotton swabs apart as they were used.



Figure 31a. Pre-cleaning photograph of a novaculite flake.

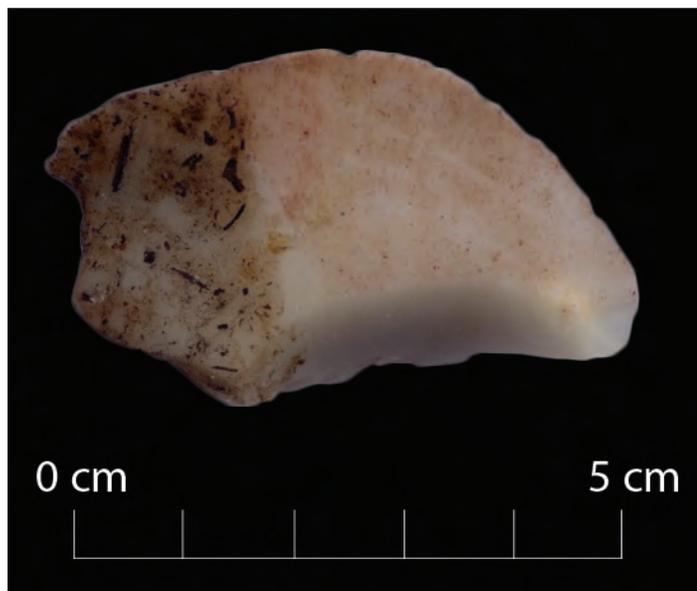


Figure 31b. Post-cleaning photograph of the same flake with a portion cleansed with the solution of Ivory™ soap and warm tap water.

- The solution of alcohol and distilled water was used exclusively on bone and was very effective in all cases. It removed any residues present (although it could not clean the scorched or charred portions of the bone) and left the bone's surface in a clean state with a smooth surface texture (Figure 32 a-b).
- The solution of ethanol and distilled water was tried on a single bone artifact in order to see if it was better or worse than alcohol (which had already been

shown to be effective). It performed just as well, removing combustive residues completely and leaving the bone surface in a clean state with a smooth surface texture (Figure 33 a-b).

- The solution of Gojo™ and warm tap water was tried on a single flaked stone artifact in order to aid in its cleaning, which was proving difficult (although effective, the ivory and tap water solution was requiring a substantial amount of scrubbing with swabs). After five repetitions, it proved effective at removing combustive residues. It should be noted that Gojo is abrasive and care should be taken in its use.



Figure 32a. Pre-cleaning photograph of a bone ischium.



Figure 32b. Post-cleaning photograph of the bone ischium after a portion was cleansed with a solution of alcohol and distilled water.



Figure 33a. Pre-cleaning photograph of a bone rib fragment.



Figure 33b. Post-cleaning photograph of the bone rib fragment after small area was cleaned with a solution of ethanol and distilled water.

The amount of time involved in cleaning portions of these artifacts ranged from about 30 minutes to 2 hours, depending on how many methods were tested until an effective one was found. The need to use the vapor-hood and other safety precautions for potentially harmful chemicals (namely, ammonium hydroxide), the destructiveness of certain wet methods on the cotton swabs being used for cleaning, and repetition of certain processes could extend the time significantly. However, one or two of these methods applied to material on which they are effective would take less time than what is listed above, further indicating that cleaning fire-damaged artifacts is not beyond the means of National Parks or other agencies that deal with potential fire damage to cultural resources. All of the materials used in this study suggested by Spafford-Ricchi and Graham (2000) and Roberts (1988) are relatively safe to handle and are fairly easily and cheaply acquired. With this, and the short amount of time that it takes to clean artifacts using the effective methods, most fire-damaged artifacts can be cleaned with a minimum of money, time, and effort. Another important item that may affect the cleansing of objects is the amount of time that passes between the moment of fire damage and the time when the artifacts are cleaned. Many of the artifacts in this study had been stored for from a couple of months to over two years. This seemed to have little effect on the cleaning of combustive residues on the surface of the artifacts. However, it is possible that this lengthy storage period allowed artifacts with porous properties (unglazed ceramic, clay, bone) to absorb greasy combustive residues, staining them permanently. Although further study is needed in this regard to confirm this supposition, it is recommended that artifacts be cleaned as soon as possible after recovery from a burned area.

Overall, the results of this study show that cleaning of fire-damaged artifacts can be accomplished, especially since the impacts on some material types appear to be

non-permanent (e.g. combustive residues). Porous materials such as unglazed ceramics and kaolin pipe clay, very rough materials such as corroded iron or unglazed stoneware, and highly combustive materials such as bone are exceptions to this statement. Porous materials tend to absorb the combustive residue from a fire and become stained. Rough materials provide a surface that is full of small ruts, pits, and other features that are destructive to tools and prohibitive to cleaning the entire surface (residue gets trapped in areas that cannot be easily reached by tools). Finally, organic materials such as bone can be scorched or charred, resulting in fire damage to the structure of the bone itself. This cannot be cleaned without removing the burned portions of the artifact altogether. Aside from these exceptions, however, many historic and prehistoric materials can be cleansed with minimally invasive techniques.

OUTDOOR ARTIFACT WEATHERING EXPERIMENTS

A select group of twenty-seven artifacts from the PERI experimental burn were chosen to gather baseline information on post-burn artifact weathering. A sample plot was established in Lincoln, Nebraska, to expose the burned artifacts to seasonal weathering and monitor the changes on a longer-term scale to assess the permanence of impacts resulting from fire. The weathering plot was designed to contain a representative sample of material types and post-burn conditions that would demonstrate the effects of natural weathering on burned artifacts. The plots were allowed to weather for seventeen months (2007-2009) and then re-analyzed and photographed using post-burn methods. Seasonal weathering processes proved effective at removing most non-permanent impacts such as combustive residues (Figure 34a-c). The majority of objects placed in the weathering plot did not exhibit evidence of burn impacts after seventeen months of seasonal weathering. This initial study seems to indicate that natural weathering will eliminate many impacts over a relative short period of time.



Figure 34a. Pre-burn photograph of a large bone fragment.



Figure 34b. Post-burn photograph of the same bone fragment.



Figure 34c. Photograph of the same bone fragment after seventeen months of natural weathering.

ARTIFACT CLEANING SUMMARY

Artifact weathering and conservation experiments have demonstrated that a majority of the macro-scale impacts observed during the post-burn analysis are non-permanent and removable. For example, both weathering and cleaning of artifacts were able to remove combustive residue from the surface of an artifact. Impacts of a more permanent nature such as cracking, fracturing, melting, or spalling could not be reversed but were observed infrequently on burned artifacts. This indicates that many of the impacts observed during this study are of a non-permanent nature and can be removed via natural weathering or cleaning in a laboratory.

EXPERIMENTAL PROGRAM RECOMMENDATIONS

Following the completion of this project, a host of questions remain and will need to be addressed through future research endeavors. This project did not address impacts to microscopic, chemical, or geophysical properties of archeological objects, features, or sites. Nor did it attempt to account for the entire range of impacts that may occur as a result of wildland fire. Additional research efforts are encouraged to address other aspects of the interface between wildland fire and archeology. It is recommended that each park's fire program work with their archeological advisor(s) to carefully consider the impacts and long-term effects of wildland fire on archeological resources and tailor their programs accordingly to ensure that the condition of all resources are maintained or enhanced by a park's actions. The Midwest Region fire effects research is only the first step to establish baseline data for the region. Future studies will be able to use this baseline to explore numerous other questions regarding the fire/archeology interface in the Midwest.

A practical outcome of this research project will be the application of the results to assessments of fire program undertakings under Section 106 of the National Historic Preservation Act by providing a better understanding of the potential to adversely impact archeological resources. Data from this research project indicate that there are fire conditions within the Midwest Region that will not adversely impact archeological resources while other conditions may cause serious damage to the archeological record. The information generated from the experimental burns will provide managers with the flexibility to concentrate efforts on fire conditions that have the potential to adversely impact archeological resources and develop solutions to mitigate or reduce those negative impacts.

The experimental research program has resulted in a better understanding of the relationship between wildland fire and impacts to archeological resources in the Midwest Region. In many cases, fire conditions within the region do not pose a significant threat. Conversely, we have identified a combination of wildland fire conditions and archeological resource types that could lead to the loss or degradation of archeological information during both single and possibly multiple burn events. Archeological sites that include surface components with perishable objects and soft metals, including bone, shell, wood, leather, cloth fabric, lead, and copper were found to be most susceptible to damage from wildland fire in the Midwest Region. These resources were found to be particularly vulnerable to damage when wildland fuels included heavier 100 and 1000 hour woody fuels at such parks as Buffalo National River (BUFF), Pea Ridge National Military Park (PERI), Voyageurs National Park (VOYA), and Wind Cave National Park (WICA).

The buildup of wildland fuels above historic levels is viewed as the most significant threat to the preservation of archeological resources relating to wildland fire. However, not all applications of wildland fire should be considered a threat to the preservation of archeological resources. Maintaining reduced fuel loads and healthy forests are considered the best methods to reduce impacts to archeological resources. Based upon the results of the experimental burn program, a combination of recording

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archeological resources, wildland fuels reduction, and additional research is viewed as the preferred strategy for preserving surface and near-surface archeological resources in the Midwest Region. In order to reduce the incidence of damage to archeological resources, general recommendations are provided to guide applications of fire within the Midwest Region and are followed by specific recommendations for parks that participated in this study.

- It is recommended that land managers, with the advice and assistance of their archeological advisor(s), conduct pre-burn archeological inventories of the prescribed burn units to identify surface archeological resources with particular attention paid to the most vulnerable materials listed above.
- Exclusion of archeological sites should be avoided whenever possible as this may lead to future undesirable conditions that may cause catastrophic damage to many types of archeological materials. If temporary exclusion of an area is the preferred alternative, the park should employ a strategy of mechanical and hand fuel reduction and removal in order to reduce the possibility of adverse wildland fuel accumulations in the future.
- Ultimately, land managers may wish to employ a strategy of fuel reductions combined with recording and/or collecting of the most vulnerable archeological materials in order to reduce significant impacts from wildland fire to archeological resources.
- Until research is conducted that will lead to a better understanding of impacts from repeat burns, land managers should minimize the exposure of archeological resources to wildland fire to the greatest extent possible by reducing the number of cyclical burns to the minimum required to achieve the needs of the natural resources program and do not pose a serious threat to archeological resources.
- Land managers should conduct post-burn assessments of selected archeological resources in order to confirm or revise findings of the experimental research study discussed in Sturdevant et al. (2009).

Because of the mix of heavy fuels and the prevalence of sites that include the most threatened types of archeological materials located on the ground surface, it is recommended that BUFF, VOYA, and WICA employ the following steps to reduce impacts to archeological resources.

- Conduct pre-burn surface archeological inventories of prescribed fire units and areas with the potential for future uncontrolled wildland fire.

EXPERIMENTAL PROGRAM RECOMMENDATIONS

- Identify, record, and collect (when necessary) the archeological materials most threatened by wildland fire including wood, bone, shell, leather, and soft metal objects.
- At archeological sites threatened by uncontrolled wildland fire, it is recommended that parks develop a plan to identify and protect sensitive resources. In addition, employing a strategy of fuels reduction utilizing a combination of prescribed fire, mechanical, and hand removal of fuels will reduce the long-term threats to archeological resources.
- Although the potential for permanent damage from wildland fire to historic cemeteries is thought to be low, the chance of damage increases as the fuel loads increase. It is recommended that the culturally sensitive nature of cemeteries be considered and that exclusion from wildland fire be employed with a strategy of manual fuel reduction at all historic cemeteries.
- Exclude archeological sites that are threatened with loss from wildland fire and employ a follow-up strategy of fuels reduction. A park's archeological advisor will be able to assist with the identification of threatened archeological resources.
- It is recommended that fire programs control burn conditions to the extent possible by reducing burn temperatures and durations during prescribed burning of archeological sites. Reductions in burn temperatures and durations can be achieved by burning during cool seasons, reducing the 10, 100, and 1000 hour fuels within archeological sites, and minimizing "explosive" or extreme fire behavior resulting from wind-driven head and flanking fires.

Wildland fuel accumulation that may lead to high-intensity fire conditions is considered a threat to archeological resources at EFMO, PERI, and TAPR. The following recommendations will contribute to enhanced preservation of archeological resources in these parks.

- Conduct pre-burn inventories of prescribed fire units with the potential to contain surface archeological resources most susceptible to damage by prescribed fire.
- Identify, record, and collect (when necessary) the archeological materials most threatened by wildland fire including wood, bone, shell, leather, and soft metal objects.
- EFMO should conduct a research study of the effect of wildland fire on geophysical signatures of buried archeological features. EFMO is particularly suited for a research study of this kind, because the geophysical properties of

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mounds and other archeological features have been examined in the past and are better understood than archeological resources at other parks.

- It is recommended that fire programs control burn conditions, to the extent possible, by reducing burn temperatures and durations during prescribed burning of archeological sites. Reductions in burn temperatures and durations can be achieved by burning during cool seasons, reducing the 10, 100, and 1000 hour fuels within archeological sites, and minimizing “explosive” or extreme fire behavior resulting from wind-driven head and flanking fires.
- Exclude archeological sites that are threatened with loss from wildland fire and employ a follow-up strategy of fuels reduction. A park’s archeological advisor will be able to assist with the identification of threatened archeological resources.

CONCLUSIONS

This multi-park research program has provided data for assessing the impacts and potential for damage to the archeological record from applications of prescribed fire throughout the Midwest Region. The intent of the experimental research program was to build on previous studies (Buenger 2003; Sayler et al. 1989) and provide land managers with specific information to identify archeological resources that are susceptible to significant impacts from wildland fire. Identifying and protecting cultural resources is defined as one of the primary goals of the National Wildland Fire Management Policy (USDA and USDOJ 2009:6). This will allow managers to focus efforts on resources threatened by fire and devise treatments to reduce or mitigate anticipated negative impacts. There may also be cases where the preservation of archeological resources could be enhanced by the use of wildland fire including fuel reduction, ground clearing, and reducing vegetation for archeological investigations.

Without the effective collaboration between the NPS Fire and Archeology programs this project would have not been possible (Figure 35). The JFSP research project facilitated the first integrated research effort between the Fire and Archeology programs in the Midwest Region. The collaborative effort that was necessary for the successful completion of our research also led to a better understanding of broader program goals and how fire and archeology staff can work together to achieve effective fire-use and preservation of archeological resources. Continued dialogue and collaboration will strengthen both the Archeology and Fire programs and will help meet the needs of NPS units throughout the Midwest Region.

Experimental studies have the potential to provide valuable data for assessing the impacts and potential for damage to the archeological record from applications of prescribed fire throughout the Midwest Region (Figure 36). By producing data specific to the many environmental zones in the Midwest, park managers will be better equipped to evaluate the fire/archeology interface than if they relied solely on data generated from other parts of the country. However, following the completion of this project, a host of questions will remain and can be addressed through future research endeavors, including impacts to geophysical investigations and the long-term cumulative effects from prescribed burning. The Midwest Region fire effects research is only the first step to establish baseline data for the region. Future studies will be able to use this baseline to explore numerous other questions regarding the fire/archeology interface in the Midwest.

The current study represents a starting point for inquiries into the wildland fire and archeology interface in the Midwest Region. Many questions remain unresolved and require additional research to understand and clarify the processes and modifications to the archeological record. For instance, what are the impacts for cyclical burn episodes when fuel loads and insulating factors are reduced over time? What effect does wildland fire have on geophysical and micro-scale archeological data sets? Under what circumstances are buried archeological resources threatened by wildland fire? Does wildland fire enhance the preservation of certain types of archeological resources when fuel loads become heavy and have the potential to cause catastrophic impacts from fire?



Figure 35. Research team members recording burn conditions at Wind Cave National Park.



Figure 36. Research team member observing the burn at Pea Ridge National Military Park.

When comparing types of archeological resources (e.g., prehistoric vs. historic) are different impacts reflected and what are the management implications for each type of resource? These are only some of the questions that could be addressed by future studies. One area of particular importance is providing more data on regions of the country where the wildland fire/archeology interface is poorly understood (Sturdevant et al. 2009:20). Studies in other regions should be designed to account for both fuel conditions and archeological resources typical of an area. Additional research efforts are crucial to archeological site preservation and management if archeological resources are to coexist unimpaired with increasingly frequent wildland fire use.

REFERENCES CITED

- Ahlgren, C. E.
1960 Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. *Ecology* 41:431-445.
- Anderson, Hal E.
1982 *Aids to determining fuel models for estimating fire behavior*. USDA Forest Service General Technical Report INT-122. Intermountain Forest and Range Experiment Station, Ogden, Utah.
- Anderson, R.C.
1982 An evolutionary model summarizing the roles of fire, climate, and grazing animals in the origin and maintenance of grasslands: an end paper. In *Grasses and Grasslands: Systematics and Ecology*. J.R. Estes, R. Tryl and J.N. Brunken (eds.) pp. 297-308. University of Oklahoma Press, Norman, Oklahoma.
- Benn, David W.
2004 Effigy Mounds National Monument Archeological Overview and Assessment. Report on file, National Park Service, Midwest Archeological Center, Lincoln, Nebraska.
- Bennett, Joanne L.
1999 Thermal Alteration of Buried Bone. *Journal of Archaeological Science* 26:1-8.
- Buenger, Brent A.
2003 *The Impact of Wildland and Prescribed Fire on Archeological Resources*. Unpublished Ph.D. dissertation, Department of Anthropology, University of Kansas, Lawrence.
- Cannon, Kenneth P., and Patrick Phillips
1993 *Post-Fire Inventory and Evaluation In Yellowstone National Park, Wyoming: The 1989 Field Season*. Midwest Archeological Center Technical Report No. 24. National Park Service, Midwest Archeological Center, Lincoln, Nebraska.
- Carey, J. H.
2007 *Pinus banksiana*. (<http://www.fs.fed.us/database/feis/>). USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana.
- Carlson-Drexler, Carl G., Douglas D. Scott, and Harold Roeker
2008 "The Battle Raged... With Terrible Fury": Battlefield Archeology of Pea Ridge National Military Park. Midwest Archeological Center Technical Report No. 112. National Park Service, Midwest Archeological Center, Lincoln, Nebraska.
- Carroll, S. B., and L. C. Bliss
1982 Jack pine - lichen woodland on sandy soils on northern Saskatchewan and northeastern Alberta. *Canadian Journal of Botany* 60:2270-2282.

WILDLAND FIRE AND ARCHEOLOGY INTERFACE IN THE MIDWEST

Catton, Theodore

2008 Life Leisure, and Hardship Along the Buffalo: Historic Resources Study, Buffalo National River. National Park Service, Midwest Regional Office, Omaha, Nebraska.

Cavaioli, Maryjane

2002 Fire Reveals New Pictographs at the Kuehl Site: The Effects of Wildfire on Pictograph Sites. In *Cultural Resources and Fire Management Planning Instructor Manual*. National Park Service, Stephen T. Mather Training Center, Harpers Ferry, West Virginia.

Chrosiewicz, Z.

1974 Evaluation of fire - produced seedbeds for jack pine regeneration. *Canadian Journal of Forest Research* 4:455-457.

Cogan, Dan, Hollis Marriott, Jim Von Loh, and Michael J. Pucherelli

1999 *Wind Cave National Park, USGS-NPS Vegetation Mapping Program Products* (<http://biology.usgs.gov/npsveg/wica/index.html>). USGS-NPS Vegetation Mapping Program, USGS Center for Biological Informatics, Denver, Colorado.

Connor, Melissa, Kenneth P. Cannon, and Denise C. Carlevato

1989 The Mountains Burnt: Forest Fires and Site Formation Processes. *North American Archaeologist* 10:293-310.

Deal, Krista

2002 Fire Effects to Lithic Artifacts. In *Cultural Resources and Fire Management Planning Instructor Manual*. National Park Service, Stephen T. Mather Training Center, Harpers Ferry, West Virginia.

Eddy, Thomas A.

1999 *Riparian Communities Comparison of 1997 and 1998 Vegetation Sampling on the Tallgrass Prairie National Preserve*. Division of Biological Sciences Emporia State University, Emporia, Kansas. Report on file, National Park Service, Tallgrass Prairie National Preserve, Kansas.

Galindo, Jennifer

2004 Wind Cave Archeological Inventory Project: Final Report. Report on file, National Park Service, Midwest Archeological Center, Lincoln, Nebraska.

Haecker, Charles M.

2002 Effects of Fire on Historic Structures and Historic Artifacts. In *Cultural Resources and Fire Management Planning Instructor Manual*. National Park Service, Stephen T. Mather Training Center, Harpers Ferry, West Virginia.

Haines, Jeremy D., and Jeanne Stevens Schofer

2008 Wildland Fire and Cultural Resource Management: A View from the American Southwest. *Heritage Management* 1:269-292.

- Heinselman, M. L.
1973 Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. *Quaternary Research* 3:383-396.
- Hinterthuer, Burnetta
1977 *A Survey of the Flora of Selected Glades in Northwest Arkansas*, MA Thesis, University of Arkansas, Fayetteville, Arkansas.
- Hester, James J.
1989 Effects of Forest Fires and Burn Programs on Archeological Resources. *Archeological Sites Protection and Preservation Notebook Technical Notes I-8*. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.
- Hop, Kevin, Don Faber-Langendoen, Michael Lew-Smith, Norman Aaseng, and Sara Lubinski
2001 *Voyageurs National Park, USGS-NPS Vegetation Mapping Program Products* (<http://biology.usgs.gov/npsveg/voya/index.html>). USGS-NPS Vegetation Mapping Program, USGS Center for Biological Informatics, Denver, Colorado.
- Hop, Kevin, Sara Lubinski, and Shannon Menard
2005 *Final Report: Effigy Mounds National Monument, Iowa*. USGS-NPS Vegetation Mapping Program, USGS Center for Biological Informatics, Denver, Colorado. (<http://biology.usgs.gov/npsveg/efmo/index.html>).
- Hough, Ian, Jeri DeYoung, David Barr
2005 Fire Effects Research and Preservation Planning at Wupatki and Walnut Canyon National Monuments, Northeast Arizona. In *The Colorado Plateau II: Biophysical, Socioeconomic, and Cultural Research*, pp. 333-348, Charles van Riper III and David J. Mattson editors. The University of Arizona Press, Tucson, Arizona.
- Jones, Bruce A.
1999 Archeological Overview and Assessment for Tallgrass Prairie National Preserve, Chase County, Kansas. Midwest Archeological Center Technical Report No. 61. National Park Service, Midwest Archeological Center, Lincoln, Nebraska.
- James, K., and DeBacker, M.
2007 *Plant Community Monitoring Trend Report, Tallgrass Prairie National Preserve*. Natural Resource Technical Report NPS/HTLN/NRTR—2007/030. National Park Service, Fort Collins, Colorado. Report on file, National Park Service, Tallgrass Prairie National Preserve, Kansas.
- Johnson, F.L., and G.D. Schnell.
1988 *Effects of Prescribed Burning on Plant Communities at Buffalo National River, Arkansas*. National Park Service Report #CX 7029-3-0033, Santa Fe, New Mexico. Report on file, National Park Service, Buffalo National River, Arkansas.

WILDLAND FIRE AND ARCHEOLOGY INTERFACE IN THE MIDWEST

Ladd, D.

1991 Reexamination of the role of fire in Missouri oak woodlands. In *Proceedings of the Oak Woods Management Workshop*. Peoria, Illinois, 21–22 October, 1988, pp. 67-80. Eastern Illinois University.

Lauver, Chris L., and Clayton F. Blodgett

1998 *Assessing the Accuracy of Digital Kansas GAP Vegetation Map Products and Describing the Plant Communities on the Tallgrass Prairie National Preserve*. Kansas Biological Survey and Kansas Applied Remote Sensing Program. Report on file, National Park Service, Tallgrass Prairie National Preserve, Kansas.

Lentz, Stephen C., Joan K. Gaunt, and Adisa J. Willmer

1996 *Fire Effects on Archeological Resources, Phase I: The Henry Fire, Holiday Mesa, Jemez Mountains, New Mexico*. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Logan, John M.

1992 *The Glades of Buffalo National River, Arkansas*. MS Thesis. Iowa State University, Ames Iowa.

1999 *A Qualitative Vegetational Assessment of Selected Open Fields of the Buffalo National River, Arkansas*. Report #1443PX715099021. Report on file, National Park Service, Buffalo National River.

Loyd, Janine M., Thomas M. Origer, and David A. Fredrickson (editors)

2002 *The Effects of Fire and Heat on Obsidian*. Department of Interior, Bureau of Land Management, Washington, D.C.

National Map LANDFIRE

2007 National Map LANDFIRE: LANDFIRE National Fire Behavior, 13 Anderson Fire Behavior Fuel Models. (2007, February - last update). U.S. Department of Interior, Geological Survey. [Online]. Available: <http://landfire.cr.usgs.gov/viewer/viewer.htm> [2009, August 24].

National Park Service

1998 *Opportunities to Enhance and Maintain the Tallgrass Prairie Ecosystem within the Boundaries of Tallgrass Prairie National Preserve*. National Park Service, Midwest Regional Office, Omaha, Nebraska.

Nelson, P. W.

2005 *The terrestrial natural communities of Missouri*. Missouri Department of Conservation, Jefferson City, Missouri.

O'Brien, M.J., and R. W. Wood.

1998 *The Prehistory of Missouri*. University of Missouri Press, Columbia Missouri.

- Picha, Paul R., Stanley A. Ahler, Rodney D. Sayler, Robert W. Seabloom
 1991 Effects of Prairie Fire on Selected Artifact Classes. *Archaeology in Montana* 32:15-28
- Pyne, Stephen J.
 1997 *Fire in America*. Reprinted. University of Washington Press, Seattle, Washington. Originally published 1982, Princeton University Press, Princeton, New Jersey.
- Richner, Jeffrey J.
 2008 Expressions of the Past: Archeological Research at Voyageurs National Park. Midwest Archeological Center Technical Report No. 104. National Park Service, Midwest Archeological Center, Lincoln, Nebraska.
- Roberts, Barbara
 1988. An Account of the Conservation and Preservation Procedures Following a Fire at the Huntington Library and Art Gallery. *Journal of the American Institute for Conservation* 27(1):1-31.
- Sabo, George, III, Ann M. Early, Jerome C. Rose, Barbara A. Burnett, Louis Vogele, Jr., and James P. Harcourt
 1990 Human Adaptation in the Ozark and Ouachita Mountains. Arkansas Archeological Survey Research Series No. 31. Arkansas Archeological Survey, Fayetteville, Arkansas.
- Sayler, Rodney D., Robert W. Seabloom, and Stanley A. Ahler
 1989 *Impacts of Prescribed Burning on Archeological and Biological Resources of the Knife River Indian Villages NHS*. Report on file, National Park Service, Midwest Archeological Center, Lincoln, Nebraska.
- Scott, Douglas D.
 1979 *Don't Burn that Wickiup! A Value at Risk Some Considerations of Cultural Resources in Fire Management*. Bureau of Land Management. Report on file, National Park Service, Midwest Archeological Center, Lincoln, Nebraska.
- Spafford-Ricci, Sarah, and Fiona Graham
 2000. The Fire at the Royal Saskatchewan Museum, Part 2: Removal of Soot from Artifacts and Recovery of the Building. *Journal of the American Institute for Conservation* 39(1).
- Spencer, Mark D.
 2010 Passages through Many Worlds: An Historic Resource Study of Wind Cave National Park. National Park Service, Midwest Regional Office, Omaha, Nebraska.

WILDLAND FIRE AND ARCHEOLOGY INTERFACE IN THE MIDWEST

Sturdevant, Jay T.

2006 *Initial Recommendations for Treatment of Medium Density Archeological Sites During Prescribed Burns Based on Data from the 2005 Experimental Prescribed Burn Program, Knife River Indian Villages National Historic Site, North Dakota*. Memorandum from Archeologist, Midwest Archeological Center to Superintendent, Knife River Indian Villages National Historic Site, dated May 9, 2006. Memorandum on file, National Park Service, Midwest Archeological Center, Lincoln, Nebraska.

Sturdevant, Jay T., Rod Skalsky, Cody L. Wienk, Brennan Dolan, Dustin Gonzales, and David Amrine

2009 *Experimental Study of Local Fire Conditions and Effects on Surface or Near-Surface Archeological Resources at National Park Service Units – Midwest Region*. JFSP Final Report for JFSP Project No. 06-2-1-05. Report on file, National Park Service, Midwest Archeological Center, Lincoln, Nebraska.

Swain, A. M.

1973 A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. *Quaternary Research* 3:383-396.

Switzer, Ron R.

1974 The Effects of Forest Fire on Archeological Sites in Mesa Verde National Park, Colorado. *The Artifact* 12(3):1-7.

Tratebas, Alice M., Niccole Villa Cerveney, and Ronald I. Dorn

2004 The Effects of Fire on Rock Art: Microscopic Evidence Reveals the Importance of Weathering Rinds. *Physical Geography* 25:313-333.

Traylor, Diane, Lyndi Hubbell, Nancy Wood, and Barbara Fiedler

1990 *The 1977 La Mesa Fire Study: An Investigation of Fire and Fire Suppression Impact on Cultural Resources in Bandelier National Monument*. Southwest Cultural Resources Center Professional Papers Number 28. National Park Service, Branch of Cultural Resources Management, Division of Anthropology, Santa Fe, New Mexico.

U.S. Department of Agriculture

2009 *The PLANTS Database* (<http://plants.usda.gov>, 24 August 2009). National Plant Data Center, Baton Rouge, Louisiana.

U.S. Department of Agriculture and U.S. Department of Interior

2009 *Guidance for Implementation of Federal Wildland Fire Management Policy*. National Interagency Fire Center, Boise, Idaho.

Vale, Thomas R. (editor)

2002 *Fire, Native Peoples, and the Natural Landscape*. Island Press, Washington, D.C.

Winthrop, Kate

2004 *Bare Bones Guide to Fire Effects on Cultural Resources for Cultural Resource Specialists*. Bureau of Land Management.

TABLES

Table 1. Definition of Analytical Categories.

<p>This list provides the impact categories used to conduct the artifact analysis during the post-burn phase of the experimental project. The following terms have been adapted for this study from Sayler et al. (1989) and Buenger (2003:105-106). The definitions provide a clear statement that was used by laboratory personnel to identify and qualify impacts that were observed on individual artifacts. In many cases, individual artifacts demonstrated the presence of multiple impact categories.</p>
<p>Charring – Defined as heat oxidation of the object with consumption of the material or artifact by fire as observed through weight change, as well as color change that penetrated the body of the object. Charring was often displayed on bone and other consumable materials.</p>
<p>Color Change – A marked change in the majority of surface color when compared to the pre-burn analysis of an object. Color changes were observed on the entire range of artifacts from shell to metals and ceramics.</p>
<p>Combustive Residue – This is observed as adhesive or tacky build up on the surface of an artifact (Buenger 2003:105, Sayler et a. 1989:44). The residue appears to change the texture of the surface, however, it may be removed from some artifacts without significantly altering the material. Combustive residue was displayed on most artifacts.</p>
<p>Cracking – A change introduced into the body of the material where intrusive fissures are observed, without complete separation (in that case, the term would be fracture). Cracking may have been present in the pre-field assessment but is more numerous or larger in the post field assessment, resulting in observable change. Cracking was frequently observed on bone but can also be seen on materials such as shell or ceramics.</p>
<p>Crazing – This was observed on historic ceramics during the pre-field analysis and is defined as the observable cracks or lines in/on the glaze, where the glaze does not expand or stretch at the same rate as the body of the vessel. Crazing can be exaggerated by the sustained application of fire. Generally only recorded on glazed artifacts such as historic ceramics.</p>
<p>Fracture – A complete separation of one portion of the artifact from another, completely altering the shape of the artifact, for example a single lithic flake becoming two or more pieces of lithic material as a result of being exposed to sustained heat from fire. Fracturing significantly affects the shape of the object and was observed as seen on prehistoric pottery, as well as lithics, historic ceramics, historic glass, and bone.</p>
<p>Melting – This occurs when the artifact is reformed or broken-down, or a portion (at least 50%) of the shape has been altered. This is separate from charring in that, not only has the material been consumed, but a percentage of the shape has been changed. Melting is typically observed on soft metal or glass artifacts.</p>
<p>Scorching – Defined as heat oxidation of the object with no consumption of the material, this is observable through weight change and also through color change (this definition is much different than Sayler et al. 1989:44) that penetrates the body of the object. Scorching was observed on several types of materials including on historic ceramics, metals, and bone.</p>
<p>Spalling – Also a complete separation of a portion of the artifact from the rest of the object, however, this typically occurs with a small portion of the surface material, for example glaze on historic ceramics or surface “potlid” spalling on lithics where the removed material does not significantly affect the shape of the object. Spalling typically does not penetrate the entire object and is generally a cone or teardrop shape. Spalling can be observed on lithic tools and both historic and prehistoric pottery.</p>

Table 2. JFSP Park Fuel Summary.

Park	Fuel Type	Avg. Fuel Load (tons/acre)	Burn Duration	Max. Temp (°C)	Avg. Temp (°C)	
			B F H	B F H	F H	
VOYA						
	Woodland	6.7	1:10:15(A) 1:24:35 (C)	513 (C) 449 (A)	47 (C) 57 (B)	41 (A) 29 (B)
	Woodland	3.5	1:10:55 (E) 2:46:05 (D)	477 (D) 47 (E)	622 (F) 62 (E)	26 (E) 109 (F)
BUFF						
	Woodland	10.0	0:33:20 (B) 0:43:40(A)	545 (A) 577 (B)	671 (C) 67 (B)	106 (B) 102 (C)
	Woodland	25.4	1:14:35 (E) 1:23:45 (D)	833 (D) 694 (E)	679 (F) 67 (F)	109 (E) 116 (F)
WICA						
	Grassland	9.8	19:30 (B) 33:55 (A)	439 (A) 439 (A)	745 (C) 74 (B)	108 (B) 129 (C)
	Grass/ Wood	19.5	2:41:05 (F) 1:23:05 (E)	747 (E) 747 (E)	100 (D) 100 (D)	97 (F) 25 (D)
TAPR						
	Grassland	2.4	7:15 (B) 9:25 (C)	492 (C) 208 (B)	403 (A) 47 (B)	83 (A) 47 (B)
	Grassland	1.7	n/a (F) 4:20 (E)	n/a (F) 451 (E)	375 (D) n/a (F)	106 (E) 66 (D)
PERI						
	Grassland	4.4	31:45 (A) 28:35 (B)	462 (B) 459 (A)	630 (C) 377 (F)	91 (A) 95 (C)
	Woodland	16.2	8:55 (E) 15:55 (D)	254 (D) 383 (E)	57 (B) 56 (D)	94 (E) 77 (F)
EFMO						
	Grassland	8.4	31:25 (A) 22:30 (B)	649 (A) 649 (B)	536 (C) 368 (D)	81 (C) 81 (C)
	Woodland	11.0	n/a (F) 14:50 (D)	n/a (F) n/a (E)	368 (D) n/a (E)	53 (D) n/a (E)

n/a = plots did not burn

Burn method = B backing fire, F flanking fire, H head fire

Plots shown in parentheses.

* -no data provided

Table 3. BUFF Post-burn Incident Summary.

Incident	Material Class													Incident Total	Incident %
	Bone	Ceramic	Glass	Brass			Nonferrous			Pottery	Shell	Stone Flaked			
				Copper	Lead	Tin	Pewter								
No Change	-	-	-	-	-	-	-	-	-	1	-	1	2	1	
Charring															
Minor	4	-	-	-	-	-	-	-	-	-	-	-	4	1	
Medium	1	-	-	-	-	-	-	-	-	-	-	-	1	0	
Heavy	1	-	-	-	-	-	-	-	-	-	-	-	1	0	
Color Change	5	-	-	2	-	-	1	1	1	1	-	3	13	5	
Combustive Residue															
Minor	2	3	1	-	-	-	1	-	-	15	8	4	34	12	
Medium	10	10	7	-	1	4	-	-	1	7	2	4	46	17	
Heavy	17	25	12	9	-	-	-	4	2	4	8	29	110	39	
Crazing															
Minor	-	1	-	-	-	-	-	-	-	-	-	-	1	0	
Medium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Heavy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Fracturing	10	-	3	-	-	-	-	-	1	-	7	1	22	8	
Cracking	4	-	-	-	-	-	-	-	-	-	-	-	4	1	
Melting	-	-	-	-	-	-	1	-	-	-	-	-	1	0	
Scorching															
Minor	15	-	-	-	-	-	-	-	1	-	-	-	16	6	
Medium	6	-	-	-	-	-	-	1	-	-	-	-	7	3	
Heavy	3	1	-	-	-	-	-	-	-	-	-	-	4	1	
Spalling	1	-	-	-	-	-	-	-	-	-	16	-	17	6	
Incident Total / Material Class	79	40	23	11	1	6	6	6	6	28	41	42	283	100	

Table 4. EFMO Post-burn Incident Summary.

Incident	Material Class													Incident Total	Incident %
	Bone	Ceramic	Glass	Ferrous	Nonferrous		Pottery	Shell	Stone Flaked	Ground	Incident				
					Brass	Lead					Pewter	Total	%		
No Change	1	1	2	1	1	-	4	1	4	-	15	6			
Charring															
Minor	7	-	-	-	-	-	-	-	-	-	7	3			
Medium	1	-	-	-	-	-	-	-	-	-	1	0			
Heavy	1	-	-	-	-	-	-	-	-	-	1	0			
Color Change	19	13	3	2	4	3	4	4	26	-	79	33			
Combustive Residue															
Minor	5	6	1	-	1	1	8	1	3	-	27	12			
Medium	11	5	3	1	3	-	8	-	3	-	35	15			
Heavy	7	7	4	1	1	2	1	4	23	1	51	21			
Crazing															
Minor	1	-	-	-	-	-	-	-	-	-	1	0			
Medium	-	-	-	-	-	-	-	-	-	-	-	-			
Heavy	-	-	-	-	-	-	-	-	-	-	-	-			
Fracturing	1	-	-	-	-	-	-	-	-	-	1	0			
Cracking	4	-	-	-	-	-	-	-	-	-	4	1			
Melting															
Scorching															
Minor	7	3	-	-	-	-	1	1	-	-	12	5			
Medium	10	-	-	-	-	-	-	-	-	-	10	4			
Heavy	3	-	-	-	-	-	-	-	-	-	3	1			
Spalling	-	-	-	-	-	-	-	-	-	-	-	-			
Incident Total /Material Class	78	35	13	5	10	6	26	11	59	1	247	100			

Table 5. PERI Post-burn Incident Summary.

	Material Class													Incident Total	Incident %
	Antler	Bone	Ceramic	Glass	Leather	Ferrous	Brass	Compound	Lead	Tin	Pottery	Shell	Stone Flaked		
Incident	-	-	1	-	-	1	-	-	-	-	2	-	1	5	2
No Change	-	-	1	-	-	1	-	-	-	-	2	-	1	5	2
Charring															
Minor	-	1	-	-	1	-	-	-	-	-	-	-	-	2	1
Medium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heavy	-	-	-	-	3	-	-	-	-	-	-	-	-	3	2
Color Change	-	1	-	-	3	-	1	-	3	-	-	-	-	8	4
Combustive Residue															
Minor	-	3	6	5	-	5	7	-	2	-	7	1	5	41	21
Medium	1	4	11	5	-	4	8	-	7	1	3	4	6	54	27
Heavy	-	7	7	4	4	4	9	1	6	2	2	4	4	54	27
Crazing															
Minor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Medium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Heavy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Fracturing	-	-	-	-	3	-	-	-	-	1	-	2	-	6	3
Cracking	1	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Melting	-	-	-	-	4	-	-	-	-	-	-	-	-	4	2
Scorching															
Minor	-	8	-	-	-	-	-	-	-	1	-	2	-	11	5
Medium	-	1	-	-	-	-	-	-	-	1	-	-	-	2	1
Heavy	-	-	-	-	4	-	-	-	-	-	-	-	-	4	2
Spalling	-	-	-	-	-	-	-	-	-	-	-	6	-	6	3
Incident Total / Material Class	1	26	25	14	22	14	25	1	15	9	14	19	16	201	100

Table 6. TAPR Post-burn Incident Summary.

	Material Class													Incident %
	Antler	Bone	Ceramic	Glass	Ferrous	Nonferrous		Pottery	Shell	Stone Flaked	Incident			
						Brass	Pewter				Tin	Total	%	
Incident														
No Change	1	10	5	2	8	2	4	-	4	2	15	53	22	
Charring														
Minor	-	5	-	-	-	-	-	-	-	-	-	5	2	
Medium	-	-	-	-	-	-	-	-	-	-	-	-	-	
Heavy	-	-	-	-	-	-	-	-	-	-	-	-	-	
Color Change	-	7	7	1	-	1	2	1	-	2	4	25	11	
Combustive Residue														
Minor	-	18	23	11	3	2	-	-	9	3	22	91	38	
Medium	-	9	6	4	-	-	2	1	2	-	3	27	11	
Heavy	-	3	5	1	-	1	4	-	-	2	4	20	9	
Crazing														
Minor	-	-	-	-	-	-	-	-	-	-	-	-	-	
Medium	-	-	-	-	-	-	-	-	-	-	-	-	-	
Heavy	-	-	-	-	-	-	-	-	-	-	-	-	-	
Fracturing	-	-	-	-	-	-	-	-	-	1	-	1	0	
Cracking	-	-	-	-	-	-	-	-	-	-	-	-	-	
Melting	-	-	-	-	-	-	-	-	-	-	-	-	-	
Scorching														
Minor	-	11	4	-	-	-	-	-	-	-	-	15	7	
Medium	-	1	-	-	-	-	-	-	-	-	-	1	0	
Heavy	-	-	-	-	-	-	-	-	-	-	-	-	-	
Spalling	-	-	-	-	-	-	-	-	-	-	-	-	-	
Incident Total / Material Class	1	64	50	19	11	6	12	2	15	10	48	238	100	

Table 7. VOYA Post-burn Incident Summary.

Incident	Material Class														Incident Total	Incident %
	Bone	Ceramic	Glass	Leather	Ferrous	Nonferrous			Pottery	Shell	Stone		Total			
						Brass	Pewter	Lead			Tin	Copper		Flaked		
No Change	1	-	-	-	4	3	-	2	-	-	1	1	4	-	17	6
Charring																
Minor	4	-	-	-	1w	-	-	-	-	-	-	-	-	-	5	2
Medium	3	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1
Heavy	2	-	-	-	-	-	-	1T	-	-	-	-	-	-	3	1
Color Change	6	7	-	-	-	4	1	1	3	-	6	4	10	1	43	14
Combustive Residue																
Minor	12	25	8	2	2	7	1	1	1	1	14	3	24	-	101	33
Medium	2	7	5	-	-	3	1	1	2	-	5	2	7	-	35	11
Heavy	5	3	2	-	3	3	1	3	2	-	1	1	9	2	35	11
Crazing																
Minor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Medium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Heavy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Fracturing	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1
Cracking	4	-	-	-	-	-	-	-	-	-	-	-	-	-	4	1
Melting	-	-	-	-	-	-	-	1	1	-	-	-	-	-	2	1
Scorching																
Minor	7	6	-	-	1	-	-	-	1	1	1	-	2	-	19	6
Medium	-	5	-	-	-	-	-	-	-	-	5	1	1	-	12	4
Heavy	5	1	-	-	1w	2	-	1	4	-	-	1	-	1	16	5
Spalling	2	-	-	-	-	-	-	-	-	-	-	2	4	-	8	3
Incident Total / Material Class	55	55	15	2	12	22	4	10	15	2	33	15	61	4	305	100

w=wooden handle on ferrous object
T=tobacco in tin can

Table 9. Cleaning Methods.

Artifact	Location	Fuel	DB	G/S	SS	I/TW	OP/DW	AH/I	MS	A/DW	E/DW	Go/TW
Bone Ischium	BUFF-PBC7	W	NE	SE	NE	NA	NA	NA	NA	VE	NA	NA
Bone Rib	TAPR-PAC5	G	E	E	E	NA	NA	NA	NA	VE	NA	NA
Bone Rib	WICA-PEC4	G/W	E	E	SE	NA	NA	NA	NA	VE	VE	NA
Brass Bullet Casing	EFMO-PBC7	G	NE	NE	NE	NA	E	NA	VE	NA	NA	NA
Brass Compound Button	EFMO-PAC8	G	NE	NE	NE	NA	VE	NA	NA	NA	NA	NA
Ceramic Stoneware Sherd	BUFF-PEC3	W	NE	SE	NE	SE	SE	NE	NA	NA	NA	NA
Ceramic Whiteware Sherd	BUFF-PEC3	W	NE	NE	NE	SE	E	VE	NA	NA	NA	NA
Clay Pipe Stem Fragment	BUFF-PEC3	W	NE	NE	NE	SE	NE	NE	NA	NA	NA	NA
Ferrous Metal Fragment	EFMO-PBC7	G	SE	NE	NE	NA	NE	NA	NE	NA	NA	NA
Glass	BUFF-PEC3	W	NE	SE	NE	SE	NE	VE	NA	NA	NA	NA
Lead Bullet	EFMO-PEC2	G	NE	SE	NE	SE	E	NA	VE	NA	NA	NA
Lithic (Chert)	EFMO-PAC1	G	NE	NE	NE	VE	NA	NA	NA	NA	NA	NA
Lithic (Chert)	BUFF-PBC3	W	NE	SE	SE	E	E	NA	NA	NA	NA	E
Lithic (Novaculite)	WICA-PFC3	G/W	SE	SE	SE	VE	NA	NA	NA	NA	NA	NA
Pewter Button	TAPR-PEC2	G	SE	NE	NE	VE	VE	NA	NA	NA	NA	NA
Pottery Sherd	BUFF-PDC6	W	E	SE	NE	SE	NA	NA	NA	NA	NA	NA
Shell Button	WICA-PCC4	G	NE	NE	NE	SE	SE	NA	NA	NA	NA	NA
Tin Enamel Ware Bowl	BUFF-PFC4	W	SE	NE	NE	SE	NA	NA	NA	NA	NA	NA

Key:

NA-not attempted
 NE-not effective
 SE-somewhat effective
 E-effective
 VE-very effectiv

Fuel Type:

G-Grassland
 W-Woodland
 G/W-Grass/Wood

Cleaning Method:

DB-Dry Brush
 G/S- Groom/Stick
 SS-Soot Sponge
 I/TW-ivory/Tap Water
 OP/DW-Orvus Paste/Distilled Water
 AH/I-Ammonium Hydroxide/Ivory
 MS-Mineral Spirits
 A/DW-Alcohol/Distilled Water
 E/DW-Ethanol/Distilled Water
 Go/TW-Gojo/Tap Water

