

Impacts of Prescribed Burning on Archeological and Biological Resources of the Knife River Indian Villages NHS

Final Report

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July, 1989

Time Period Covered: 23 May 1988 to 1 July 1989

A report submitted in partial fulfillment of requirements of Contract No. PX 1200-8-0833,
a cooperative agreement between the U.S. National Park Service and
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EXECUTIVE SUMMARY

We conducted literature reviews, field studies, and burning experiments during 1988-89 in North Dakota to: (1) determine potential impact on archeological resources of the Knife River Indian Villages NHS (KNRI) from prescribed burning programs, and (2) develop a recommended burning program for vegetation management. The park is charged with recreating the historic scene during the early 1800's, yet must also protect valuable archeological resources from harmful impacts. The park contains evidence of several centuries of human activity and harbors a wealth of archeological artifacts and historical sites. It is especially noted for its earthlodge village sites and historical associations with Lewis and Clark and other early explorers. At the present time, due to a lack of technical information and management guidelines, all fires are suppressed in the park, although fires are important to managing prairie ecosystems.

The impacts of prairie fires on 10 representative archeological materials were evaluated in four experimental plots established in mixed grass prairie on the Oakville Prairie Natural History Area of the University of North Dakota. Two separate burns were accomplished in October and November, 1988, and the test artifact materials collected and analyzed for a variety of changes in color, weight, structure, and morphology. Our experiments indicate that fire-related impacts to buried artifacts are negligible, but effects on surface-exposed artifacts will be significant, depending on fire conditions and artifact type and size. Virtually all artifacts will be scorched and smoke blackened and the duration of this effect is unknown. Organic items, such as bone and antler remains will be substantially altered by blackening and charring. Wood materials will be charred or consumed. Shell will be fractured or disintegrated. Many chipped stone items (flaking debris and tools) will be spalled and potlid fractured. Pottery will not be damaged structurally, but surface color may be altered. Small lead and glass items will be partially or fully fused or melted. The structure of larger stone items such as natural rock, fire-cracked rock, flint cobbles, and larger ground stone artifacts is generally not affected, although localized spalling may rarely occur.

Based on our studies, we recommend a phased burning program that recognizes several categories of artifact densities and relative importance or sensitivity to burning. Specifically, we recommend that: (1) the village sites not be burned until a thorough and professional collection of surface-visible artifacts is completed that will preserve this valuable information for future analysis, (2) archeological sites on KNRI with moderate artifact densities be surveyed to determine whether surface collection is warranted to mitigate fire damage, and (3) burning and other vegetation management programs may begin as soon as feasible on other areas and portions of the park which have low artifact densities, archeological sites deemed not significant or incompatible with the park's theme, or sites not susceptible to fire damage. Gradual logging, mowing, site-specific chemical treatment, and even grazing may be used to manipulate vegetation in several problems areas at KNRI.

ACKNOWLEDGMENTS

We appreciate the help of many people who worked on this project. Paul Picha prepared artifact and material samples used in the field burn, conducted all data recording for such materials, and performed literature reviews on fire effects on artifacts. Tom Goldenstein assisted in artifact sample preparation and field layout of artifacts. We are grateful for the help of Scott Ahler, Ron Fox, Bill Jensen, Collin Sayler, Greg Seabloom, Jeff Seabloom, and John Trevor in conducting the experimental burns. We especially appreciate the assistance of Tim Thiel and staff of the Turtle River State Park in assuring fire control during the field burn. Nikki Seabloom and John Trevor conducted the review of fire effects on plant species. We thank Bill Haviland of the Knife River Indian Villages NHS and other personnel of the U.S. Park Service for providing us with technical information and assistance during this study.

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IMPACTS OF PRESCRIBED BURNING ON ARCHEOLOGICAL AND BIOLOGICAL RESOURCES OF THE KNIFE RIVER INDIAN VILLAGES NHS

INTRODUCTION

The Knife River Indian Villages National Historic Site (KNRI) was established in 1974 for the purpose of insuring the preservation, interpretation, and research of unique historical and archeological resources associated with the Plains Indian and various cultural-historic periods (Hellickson-Key 1984). The park harbors evidence of several centuries of human activity, especially post ca. 1750, and is noted for its earthlodge village sites, historical associations with Lewis and Clark and other Euro-American explorers, as well as being a site of the agricultural phase of Plains Indian development. Cultural resource studies have revealed a wealth of archeological artifacts and historical sites within the 520 ha of KNRI (Lovick and Ahler 1982).

The park is charged with three major, but somewhat conflicting objectives: 1) recreate the 1804 historic scene, 2) protect park resources from human and natural impacts, and 3) maintain or improve natural habitat for the maximum positive effect on wildlife, where compatible (Hellickson-Key 1984). The KNRI is a linear tract on both sides of the Knife River located near its confluence with the Missouri River. As such, the park is comprised of floodplain with a forest type known as "Missouri River bottomlands" and higher elevation terrace zones, "Missouri River breaks", dominated by prairie grasses. At the present time, all fires are suppressed, although it is known that both fire and flooding played major historic roles in maintenance of the park's ecosystem. As a result of factors such as fire suppression, colonization of disturbed soils by invading plant species, and natural vegetative growth, there has been a steady buildup of grassland and riparian fuel loads (Clambey 1985). This situation increases the chances of an uncontrolled wildfire with potentially disastrous consequences for the park's cultural resources and surrounding private property.

Historical evidence demonstrates that fires, both natural and artificial, were regular occurrences in prairie grasslands (Wright and Bailey 1980, Higgins 1986a). Fire frequency in mixed grasslands often varied from 5-10 years or more, depending upon topography. Re-creation and maintenance of native grassland communities can usually be best accomplished through prescribed burning programs. Over 20 years of intensive fire ecology research (see Chapter VI) have produced a body of scientific knowledge that allows ecologists to predict the probable impact of fire on many of the key plant species and communities occurring at KNRI. However, the potential impacts of prescribed burning programs on archeological resources are not well known.

This report describes results of a research program designed to experimentally test major impacts of prairie fires on archeological materials common to KNRI. We also review known impacts of burning programs on both artifacts and selected plant species common to KNRI. Based on these results, we present a series of technical management recommendations to: (1) preserve the valuable archeological resources of KNRI, (2) mitigate potentially negative impacts of prescribed burning programs, and (3) utilize safe fire management procedures to enhance the plant and animal communities of KNRI. This work was completed in partial fulfillment of requirements of contract no. PX 1200-8-0833, a cooperative agreement between the U.S. National Park Service and the Institute for Ecological Studies at the University of North Dakota.

STUDY OBJECTIVES

- 1) Determine the effects of variable-temperature prairie fires on surface and sub-surface archeological materials through a series of small-scale fires on experimental plots in mixed grass prairie.
- 2) Describe the impacts of various prescribed burning programs on plant communities and maintenance of the park ecosystem.
- 3) Based on the preceding results, develop a technically sound and feasible fire management plan for future implementation at the Knife River Indian Villages NHS.

Archeological Issues

Two general issues related to the burning of artifact materials were of concern in this study. First, our experimental study was designed to simulate burning of an archeological site. Since the investigation was specifically geared to the urgent needs of the KNRI, we selected test items which have direct analogs in the archeological record at the KNRI. We wished to experimentally replicate a burning episode and determine and quantify the negative effects on items closely resembling actual artifacts found in the villages. We were interested in any major burning effects which might transform an artifact from one analytical category into another (including its disappearance from the record), and not just those effects which might transform "diagnostic" artifacts such as pottery rim sherds and projectile points into less diagnostic forms.

Second, we wished to explore the effects of burning on natural materials such as those which might occur either in archeological sites or in natural settings. We have sought to determine whether these items could be transformed into "artifacts" as the result of the burning process. An example of this transformation would be the modification of natural, unaltered rocks and cobbles into something an archeologist would classify as fire-cracked rock (cf. House and Smith 1975; Lovick 1983). The main issues/questions we attempted to evaluate are summarized as follows:

- 1) Would stone materials fracture, change color, or become smoke blackened?
- 2) Would prairie fires result in color and structural changes in stone equivalent to those observed for stones intentionally subjected to heat treatment that we commonly recognize in the archeological record?
- 3) Would pottery sherds fracture or change color as a result of refiring?
- 4) Is it possible for late, dark-colored Knife River ware sherds to be oxidized sufficiently through surface fires to resemble light-colored, "early" sherds? In other words, is it possible that early sherds exhibit a light color due to repeated exposures to surface fires rather than fundamental differences in ceramic technology?

This is an important issue because sherd color is one criterion used to assess the approximate age of ceramic remains in some collections from the KNRI. Specifically, Knife River ware and related pottery dating after about A.D. 1600 in the KNRI is decidedly darker in color than most of the sherds found in contexts dating in the period A.D. 1300-1600. The Knife River ware sherds are typically dark brown to black in color, while many of the earlier sherds are buff to medium brown in color. In contexts where diagnostic rim sherds and chronological controls are lacking, these sherd color distinctions have been used to isolate respective post-contact age and precontact age components at various sites in the park (cf. Ahler et al. 1983:56; Ahler 1988:81).

- 5) Would prescribed burning partially or completely consume organic materials, such as bone, wood, or charcoal, potentially resulting in their underrepresentation in the archeological record? Would color changes occur through burning resulting in "unburned bone" being transformed into the archeological category "burned bone"? Would episodes of burning reduce various wood remains to ash? Can natural cycles of burning result in the introduction of quantities of charcoal to archeological contexts?

- 6) Could exposure of glass items to prairie fires result in melting, crazing, check fracturing, or discoloration? Would lead objects be discolored or deformed? (Note: We focused on lead as a test metal because of its low melting point (327.5 C), falling within the temperature range we expected to see in the burning experiment. Although copper and iron artifacts are more common in KNRI sites, we felt that smoke glazing and other potential changes could be monitored equally well on lead. Changes in other physical properties such as ductility, malleability, and tensile strength might occur in any of these metals, but detection of such changes required instrumentation and analysis beyond the scope of the present study.)

STUDY AREAS

Knife River Indian Villages NHS

Knife River Indian Villages National Historic Site (KNRI) is located about 1.6 km north of Stanton, Mercer County, North Dakota. KNRI is an elongated tract containing 468.2 hectares in fee and 55.2 hectares in scenic easement along both sides of the Knife River at its confluence with the Missouri River (Hellickson-Key, 1984). The topography is gently rolling, with elevations varying from 518.2 to 529.1 meters MSL. Geology and soils of the area have been described by Reiten (1983), Groenwald et al. (1979), and Wilhelm (1978), and summarized by Clambey (1985). Briefly, the site comprises a number of terraces, with soils consisting of loams, fine sandy loams, fine sands, and gravels on the upper levels. Lower terraces include loams, silty clay loams, and silty clays.

The vegetation of KNRI was described by Clambey (1985). There are 257 plant taxa on the site, none of which are regarded as threatened or endangered. Riparian forests (132.3 ha) are dominated by green ash, boxelder, American elm, or cottonwood types. Former croplands (135.2 ha) have been reseeded to a variety of perennial grasses, including crested wheatgrass, western wheatgrass, sideoats grama, and smooth brome grass. Native prairie tracts (95.1 ha) are of the mixed grass type, and include needle-and-thread, blue grama, western wheatgrass, junegrass, and threadleaved sedge as dominant species. Mixed grasses and shrubs cover 87.0 ha of the tract.

The vegetation of the major village sites (Big Hidatsa, Lower Hidatsa, Sakakawea) is of special concern in this study. Repeated mowing of portions of Big Hidatsa and Sakakawea Village sites, and earlier excavation of Lower Hidatsa, has resulted in a disturbed flora consisting of weedy annuals (Clambey 1985). The Big Hidatsa and Sakakawea sites had been revegetated with native grasses, but are now dominated by kochia. The Lower Hidatsa site has extensive kochia, Russian thistle, lamb's quarters, sweet clover, wild mustard, and tumbling mustard. This site is also being invaded by buckbrush.

The climate of KNRI was described by Clambey (1985), summarizing prior work by Jensen (1974), Mack (1981), and Wilhelm (1978). Briefly, the area receives an average of 41.1 cm precipitation annually, 75% of which falls during April to September. Mean precipitation during April, May, and June, the most likely months for prescribed burning is 3.0, 5.1, and 8.6 cm respectively. Prevailing winds are from the west-northwest in April, and shift to east-southeast in May. Mean monthly temperatures during April and May are 5.6 C and 12.2 C respectively.

While there have been no detailed faunal studies specific to KNRI, several recent projects have been conducted in the vicinity. Casey et al. (1976) compiled a list of 2 amphibians, 7 reptiles, 116 birds, and 31 mammals observed in the vicinity of Stanton. Seabloom et al. (1978) conducted surveys of terrestrial vertebrates throughout southwestern North Dakota, including 3 sites along the Knife River in Mercer County. Additional surveys of vertebrate resources of the site were reported by Moore et al. (1989). Surveys of insects and soil invertebrates of the area

were conducted by Kannowski (1981) and Kannowski and Benner (1978).

The archeological resources of KNRI have been reported by Lovick and Ahler (1982), along with other site-specific reports by Ahler (1984) and Ahler and Weston (1981). Lessening predicted impacts of prescribed burns on these resources is one of the major objectives of this management plan.

Oakville Prairie Natural History Area

The experimental burn was conducted at the University of North Dakota's Oakville Prairie Natural History Area (Section 16, T151N, R52W, Grand Forks County). This tract is one of the few remaining examples of native tall grass prairie in the Northern Great Plains, and is the only one in the northern plains to be recognized for its research potential by the Council on Environmental Quality.

The plant communities and soils of the Oakville Prairie were studied by Redmann (1972). Soils consist of shallow lacustrine sediments which form a mantle over firm calcareous glacial till. A site in the southeast corner of the section was chosen for the experimental burn. The site consists of low prairie, dominated by big bluestem (*Andropogon scoparius*) and porcupine grass (*Stipa spartea*). Bluegrass (*Poa* spp.) and buckbrush (*Symphoricarpos occidentalis*) are abundant as invaders. Common forbs include stiff goldenrod (*Solidago rigida*), white prairieclover (*Petalostemum candidum*), purple prairieclover (*P. purpureum*), northern bedstraw (*Galium boreale*), stiff sunflower (*Helianthus rigidus*), silver leaf (*Psoralea argophylla*), purple milk vetch (*Astragalus goniatius*), white prairie aster (*Aster ericoides*), and yarrow (*Achillea lanulosa*).

METHODS AND MATERIALS

Selection of Experimental Artifact Materials

Ten representative artifact materials were included in the prescribed burning experimental program because similar or identical items commonly occur on archeological sites in the KNRI (Table 1). Controlled surface collection data from sites such as Sakakawea Village (32ME11) and Lower Hidatsa Village (32ME10) indicate that tens of thousands of artifacts are visible at the surfaces of the major villages in the KNRI. In approximate descending order of relative frequency, the following material classes have been observed and collected: animal bone, pottery sherds, fire-cracked rock, chipped stone flaking debris and tools, fired clay or burned earth, shell, ash, clinker, iron artifacts, glass beads, other glass items, bone/antler tools, copper/lead/brass artifacts, and other miscellaneous materials (cf. Ahler and Benz 1980:Tables 4, 7). Surface artifact collection data from other less prominent sites in the KNRI identify most of these same material classes, as well (cf. Lovick and Ahler 1982:Table 9).

Table 1. Summary information for sample materials included in the KNRI prescribed burning experiment.

Material Class	Size Grade	Source	Description
Natural Rock	1	Modern gravel pit near Hensler, Mercer County, ND	Granitic, basaltic and limestone cobbles collected from Pleistocene gravel beds
KRF Cobble	1	Modern gravel pits in Dunn County, ND	Natural cobbles and tabular pieces, some fractured and tested for quality
KRF Flakes	2	Dunn County, ND	Recent percussion flakes struck from natural cobbles
Pottery	2	Sakakawea Village,	Knife River ware body sherds KNRI, ND (Cat.No. 224/32ME11) from unprovenienced beach collections along Knife River
Bone	2	Domestic Cow Skeleton (<i>Bos</i> sp.)	Unweathered, recently broken rib element fragments
Shell	2	Freshwater mussels Red Lake River, Polk County, MN	Freshly collected and broken mussel valve fragments
Lead	3	Sporting Goods Store	Conical lead fishing sinkers "1/4 sz."
	3		Winged lead fishing sinkers "1/8 sz."

Table 1. Continued.

Material Class	Size Grade	Source	Description
Glass	3	Craft Supply Store	No. 10 "Crow" glass beads (white, blue, and red)
Wood	2	Hobby Supply Store	Balsa Wood (<i>Ochroma</i> sp.) Rectangular wood segment
	2		Birch Wood (<i>Betula</i> sp.) Rectangular wood segment
Wood Charcoal	3	Art Supplies Dept. UND Bookstore	Cylindrical wood charcoal segment

Size Standardization

Items for each material class were standardized for size before exposure to fire. Size standardization helped ensure that the various sample materials had a relatively constant surface-to-volume relationship within each class (cf. Bennett and Kunzmann 1987:6). The procedure employed to standardize size variability is referred to as size-grading; it has been used to structure the analysis of archeological collections from the KNRI (e.g., Ahler and Weston 1981:54-55). Size-grading involves passing the materials through U. S. Standard Sieve Cloth screens with the following designations and opening sizes:

- G1. Grade 1 = 25.4mm (1.00 inch)
- G2. Grade 2 = 12.7mm (0.50 inch)
- G3. Grade 3 = 5.60mm (0.223 inch)

A commercial mechanical shaker with nested screens is used for size-grading. The lead, glass, wood, and charcoal items used in the experiment were manufactured or cut to specific sizes and did not require further treatment to control size variation.

Natural Rock

We selected natural rock consisting of G1 (25 mm or larger sized) rounded cobbles of fine-grained, medium-grained, and coarse-grained rocks of various lithologies. Maximum size ranged up to 8 to 10 cm in diameter. These include unmodified stones which exhibited qualities characteristic of granitic, basaltic, and limestone materials. The cobbles were collected from a modern gravel pit dug into a high terrace along the Missouri River near Hensler, Mercer County, North Dakota. Naturally occurring cobbles, deriving from geologically similar sources and of similar dimensions, can occur in site deposits. Similar items were common cultural introductions at these sites when inhabitants transported stone for use as tools, such as stone hammers, or for use in stone heating operations.

Knife River Flint Cobble

A second class of stone included in the experiments was the Knife River flint (KRF) cobble (cf. Ahler 1986; Clayton et al. 1970). These include G1 (usually ranging up to 7 to 10 cm in size) unmodified cobbles or tabular pieces of KRF collected from several modern gravel pit locations in Dunn County, North Dakota (source locations are designated as sites 32DU534, 32DU328, and 32DU792). A number of the specimens had been tested after collection for flaking quality by removal of one or two percussion flakes, and some of the specimens were tabular pieces split off of larger tabular chunks. The surfaces of the items consisted primarily of cortex but in part of freshly flaked stone. We focused attention on the cortical characteristics of the cobbles, rather than on the interior of the piece. Cortical surfaces can be characterized as one of two general types: (1) either unpatinated, colors often a yellowish brown or brownish yellow (e.g., 10YR 5/4, 6/6, 7/8), or (2) patinated, colors often a light gray or white (e.g., 10YR 7/2, 8/1). The KRF cobbles resemble rocks which might occur naturally in regional archeological sites or which might have been culturally transported into the sites

for purposes of lithic reduction (sometimes in conjunction with intentional heat treatment).

Knife River Flint Flake

KRF flake specimens of a uniform dimension (G2 in size) were picked from samples of experimentally generated flaking debris struck from cobbles collected in the KRF primary source area in Dunn County, North Dakota. The aggregate was produced by various percussion strategies with the individual flakes being relatively thin in cross section and generally exhibiting feathered terminations (cf. Cotterell and Kamminga 1987:Figure 4). Similar materials are abundant in KNRI artifact collections.

Previous experimental studies involving KRF heat treatment (cf. Ahler 1983) suggested that observable changes in color and translucency might occur upon burning. Structural failures related to thermal shock might also occur. We included both the KRF flakes and the previous KRF cobble class to investigate differential effects of controlled burning on artifacts of similar material but of different size. Also, we intended to focus on the changes in cortical attributes in the KRF cobbles and changes in interior, non-cortical matrix in the KRF flakes.

Pottery

Pottery specimens were obtained from undecorated G2 body sherds from unprovenienced beach collections from Sakakawea Village (catalog number 224/32ME11) within KNRI (cf. Ahler et al. 1980). Based on color, thickness, paste and surface treatment, most of the body sherds would be classed as fragments from Knife River ware vessels or closely related Deapolis ware vessels (Lehmer et al. 1978). At Sakakawea Village, these sherds would date to about A.D. 1795-1834. These samples were selected in lieu of appropriate replicated test materials. They adequately reflect the most common type of pottery found in each of the major village sites within the KNRI.

Bone

Bone samples were collected from rib elements from remains of a domestic cow (Bos sp.). The condition of the bone was classified as relatively "fresh" (estimated time of death prior to collection was less than six months) and only lightly bleached from weathering. No evidence of surface cracking or other breakdown was observed. Rib splinter fragments (G2) used in the study were generated by percussion fracturing using a hammerstone against a stone anvil. Utilized specimens include portions of the head, neck, tubercle, shaft segments, and the sternal extremity (cf. Bass 1987:Figure 6). Morphologically, the specimens approximate both ethnographically produced remains generated by living hunter-gatherers during marrow extraction or bone grease preparation activities (cf. Binford 1978:151-152; 1984:119-122) and bone remains which are abundant in archeological assemblages from the KNRI (cf. Snyder 1988).

Shell

Freshwater mussel shell was included in the inventory because of its abundance in the KNRI archeological sites. The shells were collected along the Red Lake River near Fisher, Polk County, Minnesota. The hard outer shells from common pelecypod species were broken up in the same manner as described above for bone remains. All portions of the shell were included (e.g., umbo or beak region, body, and anterior/posterior valve margins) (cf. Cvancara 1983:Figure 1; Waselkov 1987:Figure 3.3). Similar to the bone remains, G2 fragments of fresh, uneroded shell were used. These test materials have direct counterparts in the KNRI archeological record (cf. Picha 1988), since mussel shell served a variety of functions in native technologies.

Metal

Two forms of lead objects (winged and conical fishing sinkers) were also included in the experiments. No significance is attributed to the two shape variants; either form could be assumed to simulate shaped metal artifacts potentially occurring within the KNRI village sites. All of the lead items were classed as size grade G3; the winged sinkers were about 18 mm long (about 3.5 g) while the conical sinkers were about 26 mm long (about 5.25 or 7 g each).

Glass

Modern productions of relatively large G3 glass beads were used as facsimiles of their archeological counterparts. Similar items occur with some frequency in postcontact age assemblages from the KNRI (e.g., Ahler and Swenson 1985:213-216; Haury 1988). The samples were acquired from a reservation store specializing in Native American craft supplies. The specimens were No. 10 "Crow" beads measuring ca. 8.6 mm in diameter. Equal numbers of white (#26, Munsell color N9), blue (#242, Rock-Color ca. 5B 6/6), and red (#81, Rock-Color ca. 5R 4/6) beads were used.

Wood

Test items derived from two tree species were used in the experiments, including birch (Betula sp.) and balsa (Ochroma sp.) wood. Both wood types could be classified as slightly or nonresistant to decay (Schiffer 1987:Table 7.1). The soft balsa wood was chosen to simulate more porous, semi-decomposed wood remains which are more likely to occur in near-surface archeological deposits. Birch was selected to approximate less decomposed wood materials which might occasionally occur in recent archeological sites. These two wood types were used because they were readily available in pre-cut standardized form suitable for experimental replication. Standard-sized segments measuring 50 X 12.9 X 9.5 mm (birch) and 50 X 12.8 X 9.4 mm (balsa) were cut from longer pieces of standard, rectangular cross section stock. Color was uniform within each species, the balsa being Munsell 10YR 8/3 and the birch 10YR 7/4, both classified as a pale brown.

Charcoal

Standard-sized, cylindrical wood charcoal segments measuring about 32.5 mm long X 11.5 mm in diameter were selected to mirror wood charcoal remains which occur in abundance in archeological sites. The charcoal items were cut from sticks of medium soft drawing charcoal. Similar to the wood samples, the pre-cut commercial charcoal was chosen because of the desirability of using standard-sized segments in the experiments.

Field Burn Experimental Layout

This section describes the physical layout of the field burn experiment. Four topics are addressed: (1) plot arrangement, (2) intraplot artifact arrangement, (3) interplot fuel load variation, and (4) temperature measurement.

Burning Plot and Artifact Arrangement

Within the Oakville Prairie tract, a much smaller site about 400 m² at the extreme southwest corner of the section was selected to contain the experimental burn (Figure 1). The site was further subdivided into four quadrants, each housing a single smaller burn plot positioned in the approximate center of each quadrant. Plots 1 (SE quadrant), 2 (NE quadrant), and 4 (SW quadrant) served to experiment with varying fuel loads for settings containing surface artifacts. Plot 3 (NW quadrant) was intended to simulate conditions for shallowly buried artifacts (see below).

A standardized layout for artifacts was used within each plot. Thirty spatially discrete artifact groups were placed at individual "sample" locations within each of the four plots, yielding a total of 120 sample locations. Each plot was therefore comprised of the 30 sample locations positioned in a grid arrangement with one meter spacing in an area measuring 6 X 5 meters. The plots were separated from each other by a 4 - 5 m strip which contained no artifacts. Each sample location was numbered sequentially from lower left to upper right in each plot, beginning with sample No. 001 in the southeast corner of Plot 1 and concluding with sample No. 120 in the northwest corner of Plot 4 (Fig. 1). The corners of each plot were marked with pin flags.

Up to ten material items were placed on or just below the ground surface at each of the 120 sample locations. Each sample consisted of a tightly grouped cluster about 20 cm in diameter. The largest items, the natural rock and KRF cobble, were placed at opposing east and west margins of the cluster, and the remaining smaller items were placed somewhat randomly within the space between the two large rocks. This systematic arrangement was followed to aid postburn recovery of the items; the larger cobbles would be readily visible after the burn, but many of the smaller items would not.

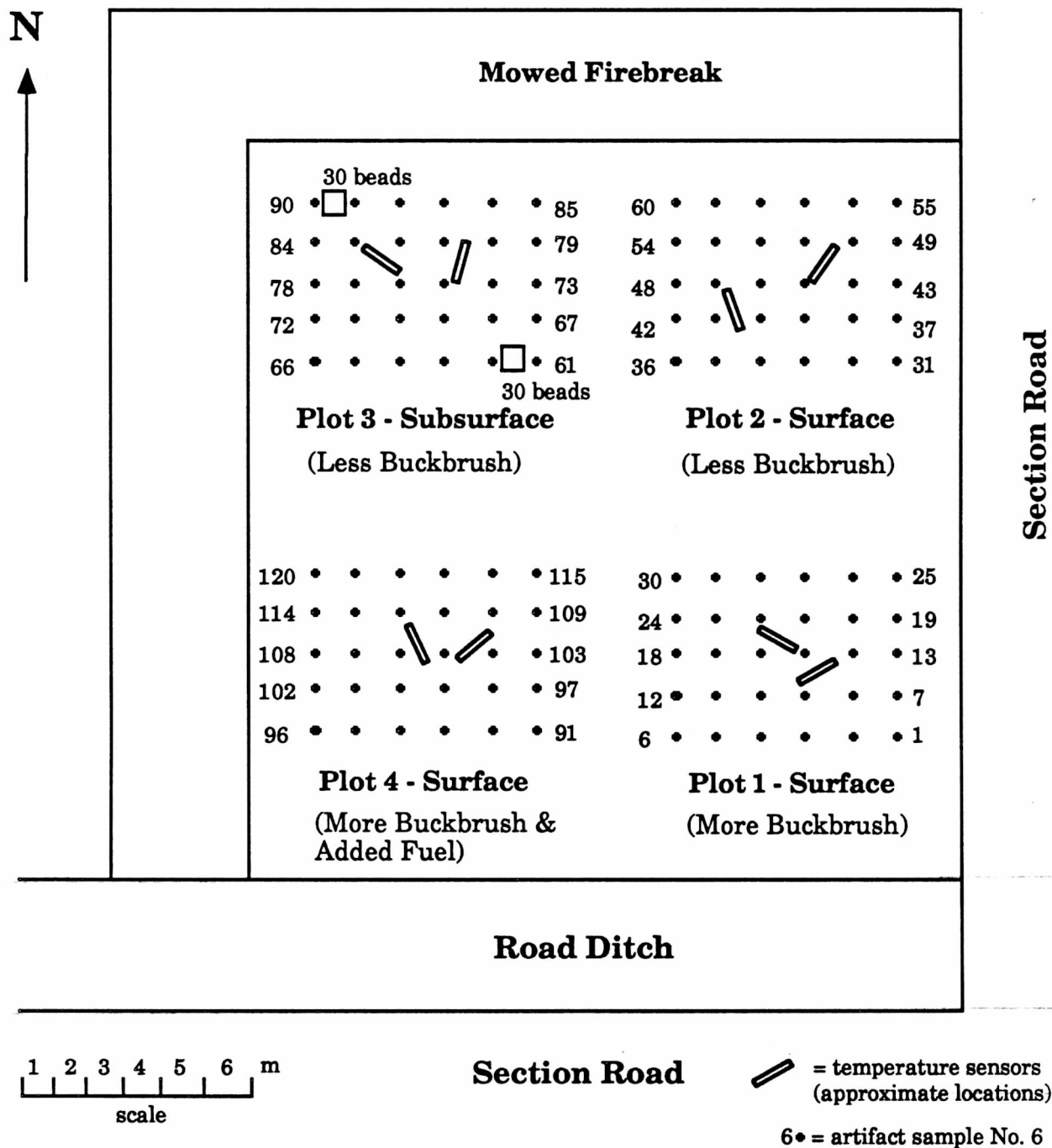


Fig. 1. Layout of experimental burning plots at Oakville Prairie Natural History Area, North Dakota.

Some variations on the basic pattern of artifact placement can be mentioned. Conical lead sinkers were placed at sample locations in Plots 1 and 2, while winged lead sinkers were used in Plots 3 and 4. Birch wood was placed in odd numbered sample locations (e.g., at samples 001, 003, 005, etc.) while balsa wood was placed in even numbered sample locations. Charcoal segments were placed in every third sample location (e.g., at 003, 006, 009, etc.). Finally, glass beads were placed at individual sample locations only in above-ground Plots 1, 2, and 4, in a sequence of red, white, blue, red, white, blue, etc., corresponding to sample numbers 001, 002, 003, 004, 005, 006, etc., respectively. In Plot 3, two special subsurface bead samples were substituted in place of individual beads at each sample location (see Fig. 1). (This was done because the beads were not available when the other artifacts were placed below ground in Plot 3). Thirty beads (10 red, 10 white, 10 blue) were placed below ground in each of two locations, one between samples 61 and 62, and another between samples 89 and 90.

Within Plots 1, 2, and 4, the items were individually placed by hand as close as possible to the ground surface in order to simulate a surface artifact scatter. For items which had been physically labeled with a sample number (natural rock, KRF cobble, KRF flake, bone, pottery, shell), the labeled face of the item was always placed downward to facilitate identification after the fire. Unlabeled items (lead, glass bead, wood segment, charcoal segment) were placed as nearly horizontal as possible. In the surface artifact plots (1, 2, and 4), each item was nestled by hand as far downward as possible into the existing vegetation cover, but in only a few instances were the artifacts directly touching the ground surface. In most cases, a layer of humus and organic material perhaps 0.5 cm thick separated the artifact from the underlying soil.

In Plot 3 an identical spatial arrangement was used to simulate a shallow subsurface artifact deposit. This was achieved by using a skimming shovel to carefully cut and peel back a patch of the vegetation mat at the root level, about 2 cm below surface, prior to depositing the sample items. After artifact placement in the shovel cut area, the vegetation mat was returned to its original position, covering the artifacts. Some of the larger artifacts occasionally protruded slightly through the vegetation mat.

Interplot Fuel Load Variation

Vegetation clipping samples to estimate preburn fuel loads were taken from 10 randomized 0.5 m² quadrats on the burn area. We used natural variation in fuel load among the four burn plots to examine effects of fire intensity and burn duration. Plots 1 and 4, on the south side of the burn area, contained considerable buckbrush, and consequently, had the highest fuel loads. Plot 2 (NE corner) contained a sparse distribution of buckbrush, and Plot 3 (NW corner) contained virtually no buckbrush. We estimated that Plot 2, with some buckbrush, had an average natural fuel load approximately equal to the mean as measured for nearby clippings (about 5000 kg/ha), while Plots 1 and 4 had an average natural fuel load somewhat above the mean for clippings (about 6000 kg/ha) and Plot 3 had an average natural fuel load somewhat below the mean for clippings (about 4000 kg/ha).

Immediately prior to burning, the fuel load in Plot 4 was artificially elevated to a level higher than any natural fuel load in the area. This was accomplished by placing clippings collected from the fire line around the area directly on the 5 x 6 m artifact plot, along with some additional buckbrush clippings taken from nearby areas outside the burn location. We estimate that the actual fuel load in Plot 4 at burn time was about twice the average for the area as measured by clipping samples (see Results), or about 10,000 kg/ha. Therefore, at burn time, the four plots could be ranked from high to low based on fuel load variation: Plot 4 (extremely high fuel load); Plot 1 (higher than area mean); Plot 2 (equivalent to area mean); Plot 3 (below the area mean).

Temperature Measurement

Maximum fire temperatures were measured with shavings of "Tempilstick" temperature sensitive crayons (Tempil Division, Big Three Industries, South Plainfield, NJ) enclosed in aluminum foil packets. A series of twenty packets, each measuring temperatures from 52°C (125°F) to 649°C (1200°F), were suspended at heights of both 2 cm and 10 cm above ground surface near the center of each of the four plots. This method allowed recording of one maximum temperature at 2 cm height and one maximum temperature at 10 cm height, accurate to about $\pm 27^{\circ}\text{C}$ (50°F), at a single location within each burn plot. Soil temperatures were measured at 2 cm depth with a YSI Model 42SC tele-thermometer immediately before and following the fire.

Variables Measuring Fire Impacts on Test Materials

Twelve dependent variables were recorded to measure the degree and type of alterations resulting from the controlled burn episode. Based upon our literature review of fire impacts on artifacts, we placed emphasis on recording easily detected changes in material appearance and shape. Due to the limited scope of the project, detailed assessments of chemical, physical, and structural changes requiring sophisticated instrumentation were not attempted.

For analytical convenience, the materials used in the experiment were assigned into two general groups. The first group comprises either natural or "non-manufactured" items which exhibit considerable variation in preburn condition in terms of size, shape, and color. For these items, we had to devise ways to determine, conclusively, the presence or absence of fire-related change. Included here are: (1) natural rock, (2) KRF cobble, (3) KRF flake, (4) pottery, (5) bone, and (6) shell. For each of these materials, we used xerographic, weight, and detailed color data to assess and evaluate the preburn and postburn conditions of each artifact. At the beginning of preburn data recording, each item in these six classes was labeled on one face with a number designating the intended sample location (001-120). The preburn shape of each item was then photographically documented by producing a full-size image of the labeled face on a photocopy machine. The postburn artifacts were matched with the preburn images to confirm if minor or major attrition, fracture, or shape change had occurred. Preburn and postburn weight data were also recorded to 0.1 gm on an

Ohaus Dial-O-Gram balance for each of these items, primarily as another means for documenting fracture, consumption, or loss of any part of an item. We did not attempt to determine small weight changes from water loss, due to the difficulty of attempting such measurements under field conditions. Finally, detailed preburn and postburn color information was recorded for each item in these six material classes. These data were recorded with the aid of Munsell Soil Color Charts (Munsell 1975) and a Rock-Color Chart (Geological Society of America 1980).

The remaining four material classes (lead, glass bead, wood, and charcoal) consist of "manufactured" items exhibiting very consistent and standardized preburn size, shape, and color characteristics. Postburn alterations in color, size and shape were readily determined for these materials by simple inspection and comparison to additional unburned samples of the items. Because of the simplicity and effectiveness of this comparative approach, detailed weight data, color data, and preburn shape data were not recorded for the individual specimens in these four material classes.

Color Change

Three variables were used to document color of test materials. These include preburn color (COLBEFORE), postburn color (COLAFTER), and an assessment of color change due to the burning process (COLCHA). As previously noted, standardized soil and rock color charts were used to document preburn and postburn hue, chroma, and value designations for the six "non-manufactured" material classes (natural rock, KRF cobble, KRF flake, pottery, bone, and shell). Artifact surfaces were compared with the color charts and a "best fit" selection was determined by passing the given item beneath a series of colors chips and matching it to the closest designation. Because lighting conditions could influence color, these readings were taken in a well-lit laboratory setting near a window where both natural sunlight and rays of artificial light from an electric desk lamp were permitted to fall on the artifact. One individual (PRP) collected all of the data during the preburn and postburn phases in an attempt to minimize interpersonal differences in color recognition and other perceptual differences which might occur. Every attempt was made to keep laboratory conditions such as lighting as constant as possible during the data collection process.

Stone and ceramic materials often exhibited a range of colors. In these instances, the predominant colors were recorded as a color string (see Appendix 2). The rock charts proved useful for determining cortical surface colors for stones as well as for bone surfaces. For natural rock and KRF cobbles, color was recorded for the cortical surface of the item, on the face away from the label (i.e., on the upward face of the artifact in the burn position). For pottery, color was recorded on the exterior vessel face (the face opposite the item label); this face was also placed upward during the burn process. Preburn and postburn color was also recorded for the interior surface of the vessel for each pottery sherd. This was the labeled face of the sherd, placed downward in the field burn situation. These data on interior sherd surface color, thought to be of secondary importance to color changes on the surface of the sherd facing the fire, were not analyzed

here. For bone, color was recorded for the largest contiguous exterior surface present on the bone fragment. In the field, the labeled face of the bone was placed downward, and the color-recorded face of the item may or may not have been placed upwards. For KRF flakes, color was recorded for the non-cortical, ventral face of the flake which represented the interior of the flint core. This was the face of the flake placed downward in the field setting, away from the fire, so it may not have experienced the same thermal exposure as the dorsal face of some flakes. Color of shells was similarly documented on the interior nacre surface of the shell. As with the flakes, this surface was placed downward during the field burn, away from the fire, and it may not have experienced the same thermal exposure as the opposing side of the shell item.

In all instances, postburn color incorporated the color of the smoke glaze or additive residue which sometimes accumulated on the surface of the item during the burning process. Thus, the postburn color value does not provide a good measure of color change within the matrix of the item itself (for example, a change color from yellow to red for the cortex on a KRF cobble, or a darkening of the stone matrix in the KRF flake). Such a measure could only be obtained by removing the smoke glaze and other residues adhering to the surfaces of the artifacts. A simple test showed this residue not to be readily water soluble, so we decided not to attempt to remove it. However, we noted where color change seemed to occur in the matrix of the item, independent of any accumulated residues.

For the six non-manufactured material classes, the assessment of color change (COLCHA) was handled in the following manner. Because both preburn and postburn Munsell color data were available, it was possible to quantify color change. This process involved calculating the maximum difference in Munsell color value for each item. The resulting figure indicates the degree of shift in color toward lighter [a positive (+) change] or darker [a negative (-) values (cf. Shepard 1956:107-112)]. Because the available charts depicted color values only between 9 and 2, the maximum possible change would be a (+/- 7). When multiple colors were recorded on a given specimen, preburn and postburn color were recorded at the same locations on the piece. For example, on the KRF cobbles, three dominant colors were sometimes recognized on the cortex of the stone. When computing a color change value the individual preburn and postburn locations were compared and the figure exhibiting the maximum change was selected.

As previously noted, no detailed preburn and postburn color data were recorded for the "manufactured" lead, glass, wood, and charcoal items. Color change was determined by comparing the experimental item with a representative sample of unaltered items not included in the field experiment. For these materials, color change was simply recorded as absent (0) or present (1).

Weight Change

Preburn weight (WTBEF) and postburn weight (WTAFT) were recorded to 0.1 gm for the six "non-manufactured" classes (pottery, bone, shell, and various stone classes). Items exhibiting weight change < 0.2 g were coded as weight

change absent (0); weight changes equal or greater than 0.2 g were coded 1. No weights or weight change data were recorded for the "manufactured" items (lead, glass, wood, charcoal).

Fracture/Cracking

Two variables describing changes in shape or morphology were used. One is the absence (0) or presence (1) of fracture (FRACT). The presence of a fracture in non-manufactured items was determined by detailed comparison of preburn and postburn weight data, matching of the artifact to its photocopied preburn image, and careful inspection of each item. For manufactured items, detailed comparisons between experimental specimens and unused standards were made. A second variable describes the particular type of fracture (FRTYP) (see Chapter III).

Observed fracture types include "crazing/shrinkage cracks" and "potlidding/spalling". For more severe thermal damage, where structural breakdown was evident, a "disintegration" fracture type was defined. A "miscellaneous" fracture type (generally, a transverse break) was used to describe situations where changes in artifact shape or weight were recorded, but where the mechanism responsible for the observed change may not be fire-related. An example of this would be breakage of a specimen, possibly resulting from handling or accidental trampling during the experiment, which otherwise exhibited no indications of thermal stress. Presence of fracture and fracture type were not recorded for wood and charcoal samples.

Melting

For lead and glass categories the occurrence and degree of melting (i.e., slight or full deformation) were recorded as a type of fracture. This categorization was accomplished by visually examining the recovered items for detectable changes in shape, outline, and color. If only a minimal amount of heat deformation or a surface fusion was indicated, the specimen was recorded as slightly deformed. Major change in the shape of the object resulting from melting was recorded as fully deformed. The unaltered lead sinkers and glass beads served as control samples for comparative purposes.

Scorching

The variables scorching (SCORCH) and charring (CHARR) were used as a relative measure of the degree and intensity of color change and structural change exhibited by the various sample materials exposed to heat, flame, and smoke during the field burn.

Scorching refers to various changes in surface color and/or texture resulting from burning. For organic materials such as bone, wood, charcoal, and shell, scorching was indicated by a browning of tissues or surfaces, suggesting either the presence of an additive residue or smoke glaze, or possibly, an incipient combustion process acting upon organic matter in the object. For these organic items, scorching is potentially a subtractive process acting upon the artifact. In

the case of noncombustible, inorganic materials such as stone, pottery, lead, and glass, scorching simply refers to a darkened color change, presumed to represent the accumulation of carbon or residues on the item surface associated with smoke impregnation.

The scorching variable was recorded to provide a quantitative estimate of the surface area of the item visibly altered by exposure to fire. The percentage of the total upward-facing surface area of the artifact observed to be scorched was recorded, with values ranging from 0 to a potential maximum of 100%.

Charring

The charring variable was recorded only for organic materials including bone, wood, and wood charcoal to document both color and formal structural changes induced by fire. Charring denotes the more intensive combustion of organic materials within the item, reflected as a blackened, carbonized appearance, and possibly, some degree of shrinkage or other shape change. Charring in bone is quantified in a manner similar to that for scorching, with the recorded value indicating an estimated percentage of the upward-facing surface (ranging from 0 to 100%) exhibiting a blackened appearance. For wood and charcoal items, a value for charring was recorded which reflected the estimated percentage of volume loss (0-100%) due to consumption by the fire. This estimate was based on comparing unburned control samples with the experimental specimens.

Consumption

The variable (LOSS) documented the recovery rate and circumstances of specimen loss during the experimental process. Due to a variety of factors, not all the sample specimens initially placed in the burn experiment were recovered. All recovered items were recorded as found (code 0). Based on circumstances and the material in question, missing items were recorded as either absent and presumed lost (code 1), or absent and presumed to have been consumed by fire (code 2). For missing items, the particular code was determined while considering both the material type (stone, metal and ceramic items were assumed not to be consumed) as well as the condition of the other artifacts placed near the specimen in question. For example, loss by consumption was assumed more likely for wood specimens missing from sample batches in which all the recovered non-wood artifacts showed relatively severe effects from the burn.

The final variable (COMMENT) contains notes on salient preburn and/or postburn observations of particular items. Examples include statements concerning location of altered surfaces on the artifact.

EFFECTS OF FIRE ON CULTURAL MATERIALS: A SELECTED REVIEW

by

Paul R. Picha and Stanley A. Ahler

Introduction

One of the goals of this project was to ascertain the potential impacts of controlled fire on cultural resources within the KNRI. Most existing information concerning the effects of fire on surface and subsurface archeological remains is descriptive and seldom quantitative. In the following sections, we review relevant published and unpublished information on the reported effects of: (1) uncontrolled burning or wild fires, (2) controlled burning or prescribed fires, and (3) results of controlled experimentation. Our purpose is to briefly summarize salient information on this topic, rather than to present an exhaustive review.

Uncontrolled Burning

Uncontrolled burning, as the term implies, relates to episodes of "wild burning" commonly referred to as either "forest fires" or "prairie fires" depending upon existing vegetation and physiography at the burn site. The rash of recent (1988) well-publicized fires such as those in Yellowstone National Park, Wyoming, and the Black Hills of South Dakota are vivid examples of this type of burning on a large scale. It is important to distinguish between the various fire settings and assess each separately because the potential impacts to cultural resources vary greatly with the type of fire.

The intensity of burning in a wildfire is determined by a number of factors. These include wind, humidity, topography, vegetation type, and the amount of combustible material available at the site (cf. Pilles 1984:7). It is this latter variable which greatly determines fire intensity. Forest fires, for example, produce higher temperatures and burn for longer duration than do prairie/grass fires. Wright and Bailey (1982) propose that temperature ranges approach 1400°C for fires in forested settings, with sustained temperatures in excess of 800°C for periods of 40 minutes or longer. Pitchy roots of some tree species contribute to these higher temperatures and lengthy burn times (cf. Pilles 1984:7; Wendorf 1982:175). In contrast, Stinson and Wright (1969) report that prairie fires reach a maximum temperature of about 700°C, with temperatures in excess of 65°C lasting for only 1 to 10 minutes. These differences in fire temperature and duration can result in variable impacts to cultural remains.

Impacts of fire on cultural resources situated in forested settings have apparently received more attention than their grassland counterparts. One of the earliest reports concerns the effects of a 1972 forest fire on archeological sites in Mesa Verde National Park, Colorado (Switzer 1974). Among his conclusions concerning this fire, Switzer noted that pottery sherds of all types exhibited

spalling and separation, particularly along coil lines within the sherds. Heat was so intense that sherds on the ground surface were apparently refired to a white or very light gray color, and carbon paint designs were burned out. A significant degree of oxidation and prolonged temperatures above 700°C were inferred to have existed (Switzer 1974:3).

Masonry pueblo structures constructed of dressed sandstone blocks were also damaged by the fire. Switzer (1974:3) noted color changes, severe cracking, spalling and disintegration of the bond between the grains of quartz which comprise the stone. Unfortunately, Switzer did not describe the effects on other possible artifact classes such as stone, bone, and shell.

Pilles (1984) summarized information on forest fire-related impacts to archeological sites gathered from four additional Southwestern wild fires occurring between 1977 and 1979. Pilles (1984:7) stated that damage to archeological materials begins at temperatures of about 300°C and provided additional information concerning possible damage to ceramic and stone artifacts. Ceramic sherds were thought to show effects of oxidation or carbonization at about 500°C. Pilles (1984) noted a glaze-like coating, inferred to be from pine pitch, on the exposed surfaces of sherds. This coating is partially water soluble, permitting pottery type identifications in most cases.

Chipped stone and ground stone artifacts were also susceptible to varying degrees of fire-related change at temperatures exceeding 300°C. Many of these alterations appear dependent on the particular characteristics of stone material involved. Pilles (1984:7) noted that sandstone manos were severely fire-cracked whereas basalt manos were only fire-blackened. Fine-grained stones were judged to be more resilient to thermal stress. Chert artifacts were burned grey to black in color, but only occasionally exhibited cracking or spalling (Pilles 1984:8).

Pilles (1984) briefly addressed the question of effects of uncontrolled wildfires on buried artifacts and subsurface cultural deposits. Based on results of limited subsurface excavations undertaken at seven archeological sites within two of these fire zones, there appeared to be negligible, if any damage, to buried remains. Pilles (1984:8) noted that fire damage to artifacts and related materials was "limited to the surface and the first few centimeters below the ground. Below 5 cm., there was no apparent change to soil or cultural materials." The exception was in locations where subsurface burning of stumps or tree roots took place.

Noxon and Marcus (1983, cited in Hester 1989) reported on the effects of a 1981 forest fire on a sandstone cliff at a location called Four Faces in the Needles District of Canyonlands National Park in southeastern Utah. Two major effects were noted: (1) extensive smoke or carbon blackening of the cliff face, and (2) extensive exfoliation of the heated cliff face in which pieces ranging in size from small flakes to large chunks were dislodged. Negative effects from the fire would have been severe had aboriginal rock art in the form of pictographs or petroglyphs been present at this location. The propensity for pinyon pine and juniper to grow against some cliff faces, due to localized moisture concentrations, would tend to exacerbate the negative effects of wild fires on cliff-face resources.

As summarized in Hester (1989:4), some additional negative effects of wild fires on open archeological sites can be noted. Many of these are indirect effects, site-wide in scope, in contrast to the impacts observed for individual kinds of artifacts. Included here are increased erosion due to loss of vegetation cover, increased vandalism due to increased surface visibility, contamination from fire retardants, and introduction of modern charcoal and carbon into the archeological site (cf. Kelly and Mayberry 1980). Most serious perhaps are mechanical impacts from fire suppression equipment such as bulldozers used to construct fire lines and staging areas for fire-fighting operations.

Only limited information is available concerning effects of uncontrolled burning on archeological sites in other physiographic settings. Racine and Racine (1979) briefly discuss the potential importance of burning as an aid in identifying archeological sites in Arctic tundra settings.

Dry climatic conditions and lack of precipitation in prairie and mixed grassland settings can contribute to the incidence of uncontrolled fires. The drought of the summer of 1988 on the Northern Plains provided ideal conditions for wild fires. Consequently, several observations on the effects of these recent fires to cultural remains in North Dakota were obtained.

A large wildfire occurred in the Little Missouri Badlands in early August 1988. This fire burned approximately 200 acres of mixed grassland and juniper-covered terrain within the confines of Theodore Roosevelt National Park. Archeologists from the University of North Dakota (UND) were called in to monitor and assess damages to cultural resources in this smaller tract. David Kuehn (personal communication to P. Picha, 3 January 1989) reported surface collecting a KRF flake exhibiting a dark coating from one recorded site in the area he surveyed. He suggested the coating to be tree resin, probably from Creeping Juniper (*Juniperus* sp.), which inhabit the area (cf. Pilles 1984:7). Kuehn further reported that scrubbing with water did not remove this coating from the surface of the stone.

In mid-August 1988, one of us (PRP) had the opportunity to observe the effects of a wildfire burn firsthand. The Fantail Creek Fire consumed several thousand acres of Little Missouri Badlands terrain in Billings County, North Dakota. After the fire was suppressed, archeologists affiliated with the U. S. Forest Service and UND assessed impacts to cultural resources and assisted with monitoring activities (cf. Anderson 1985). The fire burned over fairly rugged terrain primarily consisting of upland grasslands and juniper-forested side slopes. Potential damage to surface artifacts and features was thought to be far greater than to buried remains. Among the noted effects to surface materials (i.e., natural rocks) was the presence of a "brownish glaze" on exposed faces similar to that reported by Pilles (1984:7). In one instance the sandstone rocks comprising a cairn were discolored (toward red) and smoke blackened, although no fracturing was observed. The cairn was situated in a prominent grassed setting along the upland rim. More specific details concerning impacts of this fire are due to be reported by the U. S. Forest Service.

Effects of Prescribed Burning

Use of prescribed burning or controlled fire as an ecosystem management tool is well-known to ecologists. However, the effects of such procedures on cultural resources are not well documented, hence the need for additional investigation. Some preliminary prescribed burning studies carried out by fire ecologists and archeologists working cooperatively have been undertaken in recent years. Much of the impetus of this work stems from the necessity to obtain data for comparison with those gathered from uncontrolled wild fires. It is not surprising then that the American Southwest and California have been the focus of the majority of this research (cf. Kelly and Mayberry 1980; Pilles 1982).

A study by Kelly and Mayberry (1980) involved test plots (5 X 5 meters in size) containing groups of artifact clusters (ceramic, metal, glass, bone, shellfish, and stone) placed on the ground surface to create "artificial archeological sites". Six test plots were utilized in a variety of ecological settings containing various fuel loads and vegetation types in Yosemite National Park, California, and Sequoia-Kings Canyon National Park, California. Fuel types varied from mixed conifer forests with sparse understory and thick duff to sequoia white-fir forests with sparse hardwood understory. Specific attention was given to the "diagnostic features" of artifact specimens after burning (1980:604). A series of variables was identified which was thought to measure these effects: specimen friability, weight, visible characteristics such as color, trademarks, patterns, or form and composition (1980:605). The test plots were set afire, and later, introduced specimens were collected and re-examined to determine the effects of different temperatures and duration of heating on test materials.

The Kelly and Mayberry (1980) burning program has been reported only in a sketchy fashion. The report suggests the researchers experienced considerable difficulty in accurately recording burn temperatures. Near-surface temperatures in the range of 93 to 260°C are suggested, but these appear exceptionally low when compared to temperatures recorded in other forest burn situations (e.g., Wright and Bailey 1982). The preliminary results of this study suggested that thermal alteration to artifact materials in these tests was rather minimal. Kelly and Mayberry (1980:606) state that "effects of burning duff layers and sparse small-size fuels in association with placed artifacts produced carbon smudging but did not alter the diagnostic values of the artifacts - namely, surface color, design, integrity, or form." Unfortunately, more detailed information concerning temperature, burn duration, and specific alterations to artifacts has not been reported.

Based upon that study and later experimentation, Kelly (1981, cited in Hester 1989:5) suggested that, at temperatures below about 500 to 600°C, effects on artifacts are not sufficiently great to alter their scientific research value. Hester (1989:6) has used this suggestion and the general results of the Kelly and Mayberry (1980) study to conclude that controlled burns with "cool" combustion temperatures can avoid significant impacts to archeological sites and artifacts, and that controlled burns can be effectively used to control vegetation on archeological sites without damage to archeological resources. A key element in Hester's conclusions, however, is Kelly's emphasis on the "diagnostic features" of

the artifacts. If one is only interested in classifying an artifact according to proper culture-historic type, then perhaps Hester's conclusions are warranted. If one is concerned about the broader behavioral implications of the physical state of the artifacts (presence or absence of charring, calcination, spalling, fractures, etc., even among "undiagnostic" artifacts), then perhaps conclusions such as those reached by Hester are not warranted.

Data from Materials Science and Experimental Archeology

Considering the limited data on fire-related effects on material classes such as stone, ceramics, bone, shell, and metal, a number of other fields of study were consulted for information on effects of thermal exposure. These include materials science and experimental archeology (cf. Bronitsky 1986; Skibo et al. 1989).

Stone

Studies by scientists working in the fields of archeology, geology, and materials science, among others, have addressed various effects of heating on stone. Much of the archeological work has focused on various fine-grained siliceous rocks used by prehistoric peoples to fashion stone tools. Experimentation has been used to: (1) verify the intentional use of thermal alteration by native stone workers to enhance flaking quality of materials, and (2) provide methods to identify its occurrence in the archeological record (cf. Crabtree and Butler 1964; Nelson 1968; Mandeville 1973; Purdy 1974; Rick 1978; Ahler 1983, Griffiths et al. 1987). More limited experimentation has addressed the origin and characteristics of heat-altered, non-siliceous stone (fire-cracked rock), which is nearly ubiquitous in archeological sites (cf. House and Smith 1975; McParland 1977; Witkind 1977; Pierce 1989).

This body of research has identified three general types of heat-related change for stone materials: (1) fracture, (2) structural change, and (3) color change. Regardless of lithology, observed heat-related change may be subsumed under one of these general headings. For additional convenience, the lithic class may be further divided into fine-grained siliceous rocks (e.g., flint, chert, obsidian, etc.) verses coarser crystalline stones (e.g., granitic materials).

Replication experiments have been used to identify various types of heat-related fracture of stone. Purdy (1975) used archeological and experimental chert samples from Florida to identify temperature effects on fine-grained siliceous materials. Two of the more common heat-related fractures at temperatures between 350-400°C are: (1) shrinkage cracks or crazing (see Purdy 1975:Plate 6a,b, Plate 7a), and (2) potlid fractures or spalling (see Purdy 1985:Plate 3a,b). Shrinkage cracks or crazing occur as a very small-scale comminution of the artifact surface, often requiring magnification for identification. Intersecting crack lines form perpendicular to the artifact surface. In severe cases, the artifact may break along these lines into blocky, angular fragments. Potlids or spall fractures, in contrast, consist of thin pieces of the stone which separate from

the main body of the piece in a plane roughly parallel to the outer surface. In flatter-shaped, fine-grained specimens, the spalls may occur as nearly circular lenses of various sizes; in coarser-grained more spherical objects, the spalls may resemble curved "peels" which conform to the outer shape of the parent specimen.

Shrinkage cracks and crazing are generally associated with heating stone materials to very high temperatures. In contrast, potliding and spalling fractures result from rapid rises and drops in temperature which create localized thermal expansion or tension stresses within the stone. Potliding, therefore, occurs as a product of what might be called "thermal shock", a feature not necessarily associated with notably high temperature.

A second detectable trait set associated with heating (or burning) is a series of structural changes. Included here are differences in luster and translucency between heated and unheated samples of the same stone material. This feature is most readily recognizable on freshly flaked surfaces of fine-grained siliceous materials, and the presence of high luster is one of the key traits for detecting the occurrence of intentional heat-treatment in the archeological record (cf. Crabtree and Butler 1964). Detailed studies of weight loss and microtopography of fresh fracture surfaces within flints and cherts (Mandeville 1973; Griffiths et al. 1987) indicate that structural changes in flake properties are due to loss of interstitial water and recrystallization of the microchalcedonic matrix.

Color change is a third trait associated with heating in stone materials. Specific color changes vary by stone type, depending on composition. The presence of ferric impurities in many stones accounts for color changes upon heating. When ferric materials are involved, brownish or yellowish colors frequently change to a reddish hue (cf. Collins and Fenwick 1974:135). Some dark stones may become lighter in color at very high temperatures when the highly dispersed, microscopic organic matter that contributes to their color is oxidized.

Many of the diagnostic fractures, structural, and color changes in heat-treated rock have been experimentally demonstrated on flakable stones. For example, Rick (1978) studied temperature effects on two kinds of cherts (Burlington and Chouteau) occurring in the Lower Illinois River valley in central Illinois. A second experimental study applied to Knife River flint (KRF) (Ahler 1983) is especially pertinent because this material is the most common flaked lithic type found on archeological sites within the KNRI.

Rick (1978:20-21) noted that both crazing and spalling fractures occur when chert nodules from the southern Illinois sources were experimentally heated. He reported a fracture rate of 35.4% for cherts heated to temperatures above 370°C. The frequency of thermal destruction increased markedly with increased rate of heat application. Approximately two-thirds of specimens suffered potliding with heat rates of 250°C per hour or greater; potliding frequency falls to 25% or less at heating rates lower than 100°C per hour.

Rick (1978:Figure 7) illustrates a vivid example of structural type of modification on a sample of Burlington chert. Both peak heating temperature

and heating duration played a role in structural change on this material. The critical temperature for change in the luster of Burlington chert apparently occurs between 290 and 430°C. This change in luster has also been observed in various other cherts in both archeological and experimental samples (cf. Collins and Fenwick 1974; Mandeville and Flenniken 1974). Rick (1978:18-19) also documents the process of color change for Burlington chert samples; detectable changes were most apparent for specimens heated between 230-290°C.

Ahler (1983:3- 5, Table 1) suggests that temperatures below 325°C are unlikely to induce thermal flaws such as shrinkage cracks or crazing in Knife River flint (KNF). However, thermal stress resulting in fracture of KRF materials was reported at higher temperatures between 425-525°C.

KRF has been found to be extremely sensitive to spall fracture under rapid temperature changes (Ahler 1983:5). This type of fracture can occur at a wide range of temperatures. Sensitivity to thermal shock is a characteristic KRF shares with many other fine-grained stones usually classified as flints or chalcedonies (cf. Ahler 1983:2,5). Based on Ahler's experimental work, we might expect a high rate of spall fracture to occur in KRF artifacts exposed to wild fires or controlled burns.

Ahler (1983:6) reported observable differences in luster between heated and unheated specimens of KRF. Unheated KRF exhibits a dull luster with infrequent ripple marks; while fresh flake scars on a heated piece are waxy or greasy in luster with increased ripple marks. Evidence suggests that temperatures as low as 150°C will result in detectable luster change in the material in some cases (ibid.). Decreased translucency in KRF can accompany heating; temperatures of 200°C are sufficient to result in such modification.

KRF also changes color when subjected to heat. Cortex color changes occur independent of and at lower temperatures than changes in the body or interior matrix of the stone (Ahler 1983:3-4). Yellow and brown cortex colors alter to red or reddish brown; this change is absent at 150°C and is complete at 200°C. White and gray cortex colors show little change upon heating. Ahler (1983:3) reports a change in the interior or matrix color in KRF from brown or reddish brown to a dark brown starting at about 250°C, continued darkening to a near-black at 425°C, then development of a gray or dark gray mottled rind on the stone at temperatures of 550°C and above.

Research examining the effects of firing on coarser grained rocks has been undertaken as well. Over 50 years ago, geologists conducted studies concerning thermal alteration of igneous rocks. Blackwelder (1927:107) reported that heating temperatures between 300-400°C will cause fracture in basaltic materials. Tarr (1915:357) implies that heating temperatures below 250°C will not lead to fracture of granitic materials, although higher temperatures will.

Archeologists have also been interested in effects of fire on course-grained materials. McParland (1977:32) and Witkind (1977:207) reported spalling fracture of dolomite, limestone, and quartz rocks heated in experimental campfires. Oak wood firing temperatures in Witkind's study reached 606°C. The factors

responsible for fracture (excessive temperature or rapid changes in heating temperature) appear to apply to coarse-grained as well to fine-grained rocks of various lithologies.

In coarser grained rocks like granite, exposure to heat results in structural changes to the specimen as well. Differential expansion of the various minerals in the stone during heating causes stress which may lead to structural breakdown (Blackwelder 1933:101-102; Tarr 1915:366). The friable condition of granitic cobbles recovered in fire-related archeological contexts would seem to support this assertion.

Color change also accompanies heat alteration for coarser-grained stones. Due to the iron content in rocks such as granite or limestone, burned specimens will often exhibit enhanced reddish color when fired in an oxidizing atmosphere (Witkind 1977:207). A blackening of stone surfaces can also occur as the result of carbon impregnation in a reducing firing atmosphere. Fire-cracked rock from archeological contexts often exhibits both of these attributes (cf. House and Smith 1975; Picha 1980).

Pottery

The firing stage during ceramic production insures the destruction of the clay-mineral crystals (Rye 1981:96). This process occurs between about 500-800°C for most clay materials. Initial firing temperatures exceeding this upper limit can cause damage to the pottery vessel. Following Rye (1981:114-118), examination of the cross section of "firing cores" provides some indication of both the firing atmosphere and the firing temperature. Refiring may have some effect on sherd core area (see below). A common characteristic of aboriginal pottery is its blackened exterior, and more infrequently, interior surfaces. Rye (1981) and Shepard (1956) point out that blackened pottery is produced by carbon deposition, although a number of processes taking place during the life history of the vessel can also affect its final color.

The identification of reburned or refired pottery, especially specimens exhibiting blackened surfaces, may be difficult to ascertain. Shepard (1956:223) notes that "gray or black ware pottery may be oxidized at or below its original firing temperature or a temperature higher than the original may be required. Consequently, all white, gray, or black pottery is unsuitable for judgment of firing temperature by color change on refiring."

Experimentation with native ceramics suggests that sherd color may be more greatly affected by refiring than its physical structure. Buff-colored sherds refired in an oxidizing atmosphere can be darkened from thermal exposure above 500°C (Bennett and Kunzmann 1987:11-12). Similarly, the blackened core area of a sherd originally fired in a reducing atmosphere may fade or lighten in color during refiring (ibid.; Rye 1981:116-119). The key variables involved are heating temperature, duration, and heating atmosphere. Bennett and Kunzmann (1987:12) suggest that refiring temperatures in excess of 600°C are necessary to initiate sherd color change. Differences in available fuel load play a role in firing

duration and atmosphere. During a burning episode, the soil surface is initially in a reducing atmosphere, but may convert however to an oxidizing one following combustion of the available fuel (ibid.). Core fading as a result of thermal exposure during prescribed burning was not perceived to be a serious problem by these researchers.

Bennett and Kunzmann (1987) conclude that native ceramics are structurally safe during episodes of refiring provided temperatures are below either 600°C or the original firing temperature. When the original firing plateau is exceeded, captured available moisture and water continues to be expelled, and structural changes in the sherd, such as fracture, might occur. At extremely high temperatures (+1000°C) the ceramic may actually begin to melt (Bennett and Kunzmann 1987:11; Rye 1981:108).

Bone

Mammalian bone remains consist of cancelous tissue and compact bone (Schiffer 1987:183). The specific effects of certain environmental agents (e.g., differential weathering profiles) acting upon bone survivorship have received far more attention in recent studies than have issues relating to burning (Hesse and Wapnish 1985:88). The available archeological literature concerning the potential effects of burning on vertebrate faunal remains is relatively meager.

One of the earliest studies was concerned with identification of cremated human remains. A three-fold classification for cremated human remains was proposed (Baby 1954, cited in Binford 1973:376):

1. Completely incinerated. Fragments range from light to blue-grey to buff and show deep "checking", diagonal transverse fracturing, and warping.
2. Incomplete incineration (smoked). Fragments are blackened through the incomplete combustion of organic material present in the bone. Frequently, bits of charred periosteum are found adhering to the outer surface.
3. Nonincinerated or "normal bone". These fragments were not affected by the heat, but show some smoking along the edges.

It should be pointed that this classification is derived from a study of 1500- 2000 year old human remains from Middle Woodland Hopewell burial contexts in Ohio.

Thurman and Willmore (1980-81) reported the results of a replicative cremation experiment using "green bone" undertaken in the spring of 1969. An oak fire was built with the human bone remains being placed in proximity to it. The air temperature was judged to be about 47°F. Unfortunately, no information was presented concerning the maximum temperature reached during the firing. Other cremation experiments involving oak fires suggest firing temperatures may reach ca. 900°C (Buikstra and Swegle n.d., cited in Shipman et al. 1984:322). Thurman and Willmore (1980-81:280) report severe effects to green bone within 12

to 15 minutes after placement in fire, including complete calcification, extensive check cracking, fragmentation, and partial consumption of the various specimens. A number of factors, including duration of burning, fuel type and load, air temperature, proximity to the center of the fire, and manner of cooling, may affect specific results.

Bennett and Kunzmann (1987) suggest that low temperature firing can produce both charring and other detectable changes in bone material. On fresh bone, weight loss has been reported on specimens heated to temperatures as low as 100°C (cf. Von Endt and Ortner 1984). This phenomenon may be linked to the loss of fatty materials in the bone. Burning at temperatures above 300°C results in charring to the bone (Bennett and Kunzmann 1987:13). When even higher firing temperatures are attained, the char is oxidized and bone structure is altered producing a chalky appearance (ibid.).

Shipman et al. (1984) report a laboratory burning experiment conducted with freshly cleaned goat and sheep bones and teeth from juvenile animals. The bones and teeth were placed in a small test kiln and heated for four hours until both the specimens and the furnace reached a specified given temperature. Shipman et al. (1984:312-313, Table 2) develop a pathway model of color changes occurring with increasing temperature during the heating process: "The color data from our samples fall into five distinct stages, with the verbal descriptions given here supplementing the numerical Munsell data given in Table 2. In Stage I (20- <285°C), specimens are commonly neutral white, pale yellow, and yellow; in Stage II (285- <525°C), common colors are reddish brown, very dark grey-brown, neutral dark grey, and reddish-yellow; in Stage III (525- <645°C), specimens are neutral black, with medium blue and some reddish-yellow appearing; in Stage IV (645- <940°C), neutral white predominates, with light blue-grey and light grey also present; in Stage V (940+°C), specimens are neutral white with some medium grey and reddish-yellow." The authors further suggest that this diversification of color begins at a critical temperature of about 400°C. A series of associated microscopic morphological changes in dentin and bone tissue also occur as a result of differential thermal exposure (Shipman et al. 1984:314-320).

Based on this information, some tentative conclusions can be drawn regarding cremated bone samples. Bone remains showing lightly smoked surfaces (i.e., nonincinerated or "normal bone") were likely exposed to low temperatures for brief periods of time. Charred and blackened specimens (i.e., incomplete incineration or "smoked") were probably heated above 300°C for some length of time. Finally, more heavily burned (i.e., completely incinerated) remains are thought to have been exposed to temperatures above 400°C for an extended duration.

Shell

Like bone remains, the general effects of burning or thermal alteration on shells have seldom been investigated directly in archeological pursuits. Few experimental data address the effects of fire on shell remains. Most information

results from pottery tempering studies (e.g., Million 1975:218-219; Rye 1981:33-34) and radiometric dating practices (Taylor 1987).

A main constituent of shell is calcium carbonate (CaCO_3). For ceramic artifacts with calcium carbonate inclusions in the paste, Rye (1981:32-33) notes that "all forms of calcium carbonate act as non-plastics when mixed with clay. Their behavior during and after firing varies with temperature. Up to 750°C , they remain relatively inert and pottery fired below this temperature is stable. When heated above 750°C , calcium carbonate begins to decompose into CO_2 and CaO ."

Million (1975:218, citing Porter 1964) indicates that mussel shell exhibits crystalline structural changes when heated above 100°C , permitting ease in crushing during pottery temper production. This occurs when mussel shell changes structurally from aragonite to calcite during the heating process (Avery 1987:24). Calcite exhibits a weaker crystalline structure than aragonite, hence the ease in crushing burned shell remains. Waselkov (1987:105) indicates the possibility of damage from fire during food preparation activities for mussels in archeological contexts, but offers no quantitative data for the effects of heat upon shell.

We can speculate that general thermal damage analogous to those reported for bone may occur for shell as well. Color changes resulting from contact with flame and smoke are possible; the thin outer shell layer (periostracum) may become discolored. More intense heat may actually incinerate this layer. The pearly shell layer (nacre) on the shell interior could also discolor. Structural changes from low temperature heating may occur. Longer or more intense exposure may result in stress fracture and incineration (cf. Ford 1989:169).

Metal

Several factors can promote deterioration of metals, including processes referred to as corrosion (cf. Schiffer 1987:189-198). Burning is a second process which can affect metal objects. Various metals can become deformed when their respective crystallization points are reached. Waite (1976:Table 1) gives the following melting points for various metals of interest in this study: iron (Fe) - 1535°C ; copper (Cu) - 1083°C ; and lead (Pb) - 327.5°C . The high melting point values for iron and copper are not likely to be reached in the burning contexts relevant to the KNRI. The value for lead is sufficiently low, however, for lead to be melted in burning sites.

Heating of metals, even to temperatures below the melting point, may yield changes in properties such as malleability, ductility, or tensile strength. Such changes are probably not readily detectable from the physical appearance or form of the artifact. Their detection would require instrumentation and analysis far more sophisticated than the present study allows. We expect that firing at relative low temperatures may yield smoke glazing and carbon impregnation, similar to stone and other non-organic materials in wildfire and field burn experimental situations.

Glass

Glass is a solid formed by fusion of a mixture consisting of silica and various metal oxides (Goffer 1980:137-139, cited in Schiffer 1987). This solid is comprised of three basic components: the former, usually silica (SiO_2), the modifier, often potash (K_2O), and the stabilizer, often lime (CaO) (ibid.). Among the properties of the various constituents, the modifier is of particular interest. One of its important characteristics is that it serves to lower the melting point of glass to around 700-900°C compared to temperatures in excess of 1500°C for other fused silica materials (Goffer 1980:Fig. 9.9).

As with certain stone materials containing silica, a rapid increase in temperature for glass can lead to structural damage. Craze cracks on the surface of glass can result from tensile stresses (Goffer 1980:163). It is conceivable that fracturing similar to pitting or spalling in siliceous stones could occur under certain circumstances.

Bennett and Kunzmann (1987:12) reported little change to the sample of historic glass remains which they fired experimentally. One piece of window glass was reported to exhibit surface fusing as the result of the suspected high lead content present in the glass (ibid.). This alteration took place at a firing temperature in excess of 500°C.

Finally, as with many of the other materials discussed above, exposed surfaces of glass items may become smoke glazed or impregnated with carbon during burning episodes.

Wood and Charcoal

Organic materials such as wood can be affected to varying degrees by differences in heating temperature and length of heating duration. Certain kinds of wood are more resistant to burning than others (cf. Rossen and Olson 1985:Table 2). Charcoal results from the incomplete oxidation of organic materials, while ash is derived from a complete oxidation process (Smart and Hoffman 1988:172-173). As Hillman (1981), Lopinot (1985) and Miksicek (1987:219) suggest, this carbonization process occurs when plant remains are subjected to heating temperatures between 250 and 500°C under low oxygen conditions. Episodes of burning at high temperatures with abundant oxygen reduces these organic remains to mineral ash.

Summary

Available information suggests that various archeological materials can be expected to exhibit a broad array of changes as a result of exposure to heating/burning, with the particular physical and chemical properties of each artifact class dictating the possible consequences. In general, the effects of wild

or controlled burning on artifacts can be predicted to be more severe in forested situations than in prairie situations, due to the greater fire duration and higher temperatures likely to be reached in forested settings.

A series of observable traits are postulated to be the direct result of burning and thermal exposure. These are listed below in parentheses following each material. The trait listed first is the one believed to occur most commonly in burn situations. The trait listed last is the one perhaps least likely to occur or likely to occur only in situations of extreme temperature and burn duration. The physical makeup and chemical composition of each of the materials plays a large role in determining what effects, if any, may result from exposure to fire.

1. Fine-Grained Siliceous Stone (smoke glaze, fracture, color change, structural change)
2. Coarse-Grained Crystalline Stone (smoke glaze, color change, fracture, structural change)
3. Pottery (smoke glaze, color change, fracture, structural change)
4. Bone (possible smoke glaze, charring, possible fracture, consumption)
5. Shell (possible smoke glaze, fracture, charring)
6. Metal (smoke glaze, melting)
7. Glass (smoke glaze, crazing, melting, fracture)
8. Wood/Charcoal (smoke glaze, charring, consumption)

EXECUTION OF THE EXPERIMENTAL BURNING PROGRAM

by

Paul R. Picha and Stanley A. Ahler

This section deals with two general topics pertaining to the conduct of the field burn experiment. These include: (1) scheduling and details of preburn, burn, and postburn activities, and (2) data concerning independent variables (e.g., atmospheric and temperature data).

The preburn fieldwork and burning experiments took place over a ten week period from late August to early November, 1988, at the Oakville Prairie research site. Vegetation clipping samples were taken on August 27, 1988, and represented the peak of growth for Oakville Prairie for the season. Mean vegetation biomass from Oakville Prairie was intermediate between the lowest and highest averages recorded on sample plots at KNRI (Fig. 2). Thus, the Oakville Prairie grassland adequately represented general grassland conditions found at KNRI.

On October 15, the firebreak area was mowed, and the first burn was attempted. A light breeze died and a light rain began to fall just as the head fires were set along the west margin of the burn area. The fire burned relatively slowly through Plot 4 (containing the added fuel load), entered the west edge of Plot 3, but then died and could not be restarted. The burn attempt was abandoned until a later date and all artifacts were left in place until the next attempt.

Weather conditions improved sufficiently to permit another burn on November 2, 1988. Aided by a moderate breeze from the south, the remaining three sample plots (1, 2, and 3) were burned completely in a head fire which moved relatively rapidly from south to north across the burn area. Artifact samples were again left in place immediately following the burn. Fuel consumption on burned areas was complete after both fires. Weather, fire behavior, and soil conditions for the two experimental burns are summarized in Table 2.

Before attempting to retrieve the artifact collection, a few episodes of light rain and snow were allowed to pass and wash down some of the charred residue on the ground surface, making the artifacts more visible for collection. The samples were subsequently picked up and returned to UND for postburn analysis. Artifacts in Plot 4, the site of the first test burn, were collected on November 6. The individual samples were relocated by finding the approximate margins of each artifact cluster marked by the opposing natural rock and KRF cobbles. The appropriate area was carefully searched by hand with artifacts being collected and placed in a paper bag. Every attempt was made to recover all remaining specimens in each sample. However, in certain instances, some materials could not be relocated. The remaining three plots (Plots 1, 2, and 3) were revisited and materials collected on November 9.

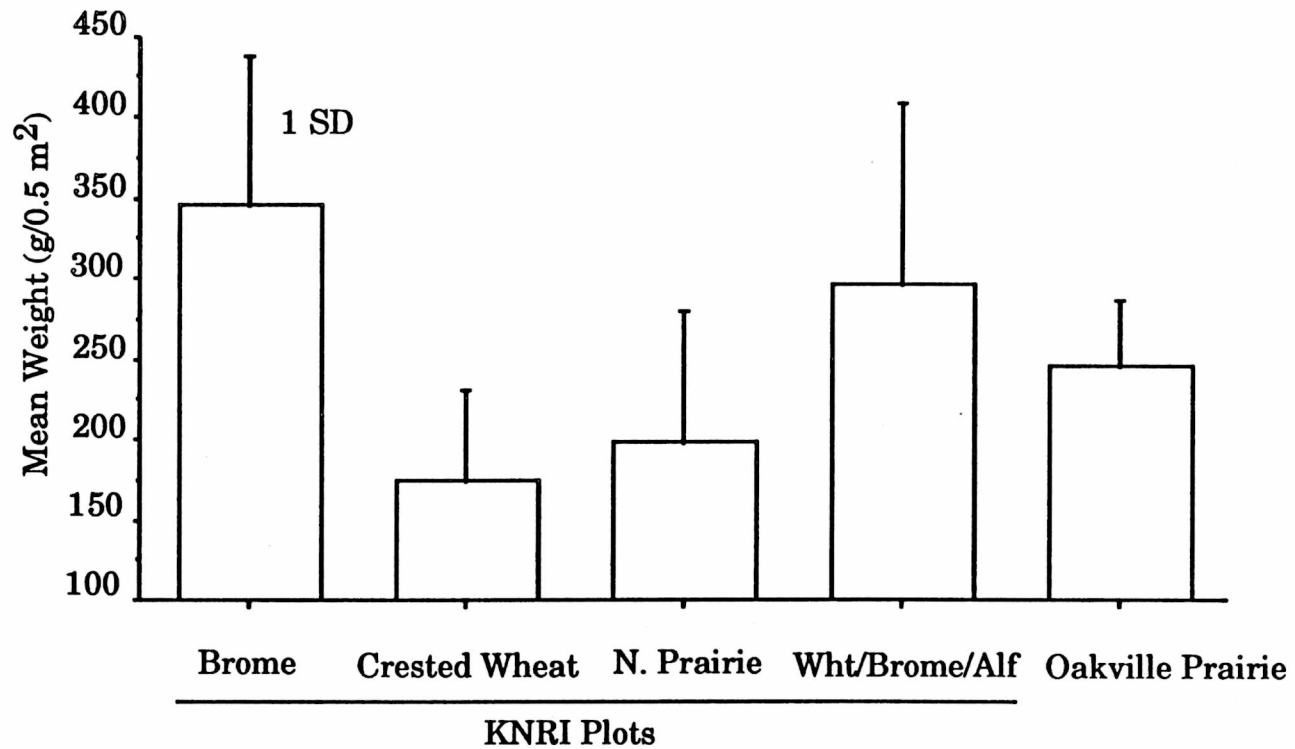


Fig. 2. Mean dry weights (g/0.5 m²) of vegetation clipping samples from Oakville Prairie and 4 plots on Knife River Indian Villages NHS.

Table 2. Summary of weather, temperature, and moisture measurements¹ during the experimental burns on Oakville Prairie Natural History Area, North Dakota, 1988.

	15 October	2 November		
Weather:				
Air Temperature (°C)	23	9		
Wind Speed (km/h)	0-8	32-53		
Relative Humidity (%)	78	54		
10 hr Fuel Moisture (%)	34	-		
Fire Behavior:				
Spread Rate (m/min)	2	3		
Flame Height (m)	0.61	2		
	<u>Height above soil:</u>			
Maximum Fire Temp. (°C)	2 cm	10 cm	2 cm	10 cm
Plot 1	-	-	177	343
Plot 2	-	-	399	399
Plot 3	-	-	316	288
Plot 4	121	399	-	-
Soil Temperature (°C - 95% CI):				
Preburn	14.1 (12.8-15.4)	6.1 (5.5-6.7)		
Postburn	18.0 (7.0-29.0)	8.8 (5.9-11.7)		

¹ See Methods for description of measurements.

The large rock and cobble items were easy to locate and retrieve during the postburn collection process because of their size. Bone, shell, wood, and glass beads were generally easy to locate and collect, because of their light or bright colors. Pottery, charcoal, and KRF flakes were more difficult to relocate, due primarily to their small size and predominantly dark colors. The dense lead objects were particularly difficult to find, frequently requiring a careful handsifting of the surface soil at the sample location. Several bone items were noted as being substantially displaced from their original sample locations. Rodent activity was the suspected cause for displacement of the bone. No vandalism or human disturbance of the burn site or the artifacts was noted.

Initial processing of the sample materials began shortly after return to the archeology laboratory. Artifact samples were transferred from temporary paper collection bags to ziplock style plastic bags for more permanent storage. Provenience and other pertinent information was marked on the new containers. The remainder of the postburn data collection process took place during mid-November and early December 1988. Data analysis, report writing, and preparation phases continued into 1989.

Effects of a Prairie Fire on Artifact Materials

This section describes the effects of the field burn experiment for the 10 material classes. In our analysis, we attempted to seek answers to a number of unsolved basic questions regarding fire impacts on archeological materials. Specifically, do wild fires and prescribed burning of prairie vegetation result in negative effects to individual artifacts or entire deposits? How do these effects vary by material type, fuel load, burn duration, temperature, and artifact position? Can the effects of natural wild fire burning be differentiated from effects of burning associated with cultural activity?

The following sections summarize the effects to the sample materials placed in the field burn. The discussion is organized by material class. A synopsis of results for all material classes is provided in Tables 3 and 4. Appendix 2 and 3 gives a complete listing of data collected from these samples.

Natural Rock

A color change was reported for the majority of natural rock specimens placed in surface Plots 1, 2, and 4. Rocks in Plot 1 had the highest overall frequency (80%) of color change, followed by Plot 4 (70%), and Plot 2 (50%) (Table 3). All altered specimens exhibited a lowering (darkening) of Munsell value. The greatest mean value change occurred in Plot 4 (-2.4), followed closely by Plot 1 (-2.2), and Plot 2 (-1.2). For these plots, the average change was -1.9, a drop of nearly two points in Munsell value.

Table 3. Summary of color change, scorching, and charring on experimental materials at the Oakville Prairie Natural History Area.¹

Material Type	Plot	N	Color Change:					Scorching:			Charring:		
			Lightened		Darkened		Mean Value Change ²	n	Mean (%)	Area ³	n	Mean (%)	Area ³
			n	%	n	%							
Surface Samples: Plots 1,2,4													
Natural Rock	1	30	0	0.0	24	80.0	-2.2	28	93.3	77.8	NA		
	2	30	0	0.0	15	50.0	-1.2	19	63.3	52.5	NA		
	4	30	0	0.0	21	70.0	-2.4	23	76.7	28.5	NA		
KRF Cobbles	1	30	1	3.3	27	90.0	-2.2	29	96.7	67.0	NA		
	2	30	2	6.7	16	53.3	-1.1	18	60.0	35.3	NA		
	4	30	1	3.3	21	70.0	-2.3	24	80.0	30.8	NA		
KRF Flakes	1	30	0	0.0	10	33.3	-0.3	20	66.7	41.0	NA		
	2	30	0	0.0	5	16.7	-0.2	15	50.0	13.3	NA		
	4	30	0	0.0	5	16.7	-0.2	27	90.0	38.3	NA		
Pottery	1	30	5	16.7	1	3.3	+0.2	5	16.7	7.0	NA		
	2	30	0	0.0	0	0.0	0.0	0	0.0	0.0	NA		
	4	30	4	13.3	5	16.7	+0.1	15	50.0	19.7	NA		
Bone	1	30	0	0.0	27	90.0	-3.0	30	100.0	80.3	6	20.0	1.2
	2	29	0	0.0	24	82.8	-2.3	26	89.7	53.6	3	10.3	1.2
	4	28	0	0.0	25	89.3	-3.8	25	89.3	46.1	13	46.4	7.7
Shell	1	30	0	0.0	20	66.7	-2.3	25	83.3	42.5	NA		
	2	30	0	0.0	13	43.3	-1.0	26	86.7	27.2	NA		
	4	28	0	0.0	21	75.0	-2.9	26	92.9	54.8	NA		
Wood	1	28			25	89.3	DNA	25	89.3	17.5	15	53.6	6.7
	2	30			29	96.7	DNA	29	96.7	21.2	14	46.7	1.8
	4	24			24	100.0	DNA	14	58.3	6.7	21	87.5	14.6

Table 3. Continued.

Material Type	Plot	N	Color Change:				Mean Value Change ²	Scorching:			Charring:		
			Lightened		Darkened			n	Mean (%)	Area ³	n	Mean (%)	Area ³
			n	%	n	%							
Surface Samples: Plots 1,2,4													
Charcoal	1	10	0	0.0	0	0.0	DNA	0	0.0	0.0	0	0.0	0.0
	2	10	0	0.0	0	0.0	DNA	0	0.0	0.0	0	0.0	0.0
	4	10	0	0.0	0	0.0	DNA	0	0.0	0.0	0	0.0	0.0
Lead	1	30			23	76.7	DNA	23	76.7	28.3	NA		
	2	30			29	96.7	DNA	29	96.7	24.5	NA		
	4	26			20	76.9	DNA	20	76.9	41.2	NA		
Glass Beads	1	30			18	60.0	DNA	18	60.0	13.8	NA		
	2	30			19	63.3	DNA	19	63.3	23.5	NA		
	4	30			22	73.3	DNA	22	73.3	33.7	NA		
Surface Samples: Plots 1,2,4													
Nat.Rock	1,2,4	90	0	0.0	60	66.7	-1.9	70	77.7	52.9	NA		
KRF Cobble	1,2,4	90	4	4.4	64	71.1	-1.9	70	77.7	44.4	NA		
KRF Flakes	1,2,4	90	0	0.0	20	22.2	-0.2	62	68.9	30.9	NA		
Pottery	1,2,4	90	9	10.0	6	6.7	+0.1	20	22.2	8.9	NA		
Bone	1,2,4	87	0	0.0	76	87.4	-3.0	81	93.1	60.4	22	25.3	3.3
Shell	1,2,4	88	0	0.0	54	61.4	-2.1	77	87.5	41.2	NA		
Wood	1,2,4	82	78	95.1	DNA	68.0	82.9	16.1	50.0	61.0	6.4		

Table 3. Continued.

Material Type	Plot	N	Color Change:				Mean Value Change ²	Scorching:			Charring:		
			Lightened		Darkened			n	Mean (%)	Area ³	n	Mean (%)	Area ³
			n	%	n	%							
Surface Samples: Plots 1,2,4 continued													
Charcoal	1,2,4	30	0	0.0	0	0.0	DNA	0	0.0	0.0	0	0.0	0.0
Lead	1,2,4	86	72	83.7	DNA	72	83.7	31.0	NA				
Gl.Beads	1,2,4	90	59	65.5	DNA	59	65.5	23.7	NA				
Subsurface Samples: Plot 3													
Nat.Rock	3	30	1	3.3	4	13.3	-0.2	3	10.0	5.8	NA		
KRF Cobble	3	30	0	0.0	1	3.3	-0.1	1	3.3	1.3	NA		
KRF Flakes	3	30	0	0.0	0	0.0	0.0	3	10.0	0.5	NA		
Pottery	3	30	3	10.0	0	0.0	+0.2	0	0.0	0.0	NA		
Bone	3	30	0	0.0	17	56.7	-0.8	3	10.0	1.8	0	0.0	0.0
Shell	3	30	0	0.0	4	13.3	-0.2	5	16.7	2.0	NA		
Wood	3	30	5	16.7	DNA	5	16.7	1.0	0	0.0	0.0		
Charcoal	3	9	0	0.0	0	0.0	DNA	0	0.0	0.0	0	0.0	0.0

Table 3. Continued.

Material Type	Plot	N	Color Change:				Mean Value Change ²	n	Scorching:		n	Charring:	
			Lightened n	%	Darkened n	%			Mean (%)	Area ³		Mean (%)	Area ³
Subsurface Samples: Plot 3													
Lead	3	30	22	73.3	0	0.0	DNA	0	0.0	0.0	NA		
Gl.Beads	3	60	0	0.0	DNA	0	0.0	0.0	NA				

¹ DNA = data not available, not recorded; NA = variable not applicable.

² mean change in color value as read from Munsell charts.

³ mean surface area (%) of each item exhibiting scorching or charring (see Methods for exceptions to charring).

Table 4. Summary of shape change, weight loss, and consumption for experimental materials at the Oakville Prairie Natural History Area, North Dakota, 1988.¹

Material Type	Plot	N	Shape Change			Weight Loss		Consumption		Mean % Volume
			n	%	Type	n	%	n	%	
Surface Samples: Plots 1,2,4										
Natural Rock	1	30	0	0.0		0	0.0	NA		
	2	30	0	0.0		0	0.0	NA		
	4	30	0	0.0		0	0.0	NA		
KRF Cobbles	1	30	0	0.0		0	0.0	NA		
	2	30	0	0.0		0	0.0	NA		
	4	30	1	3.3	1 spall	1	3.3	NA		
KRF Flakes	1	30	4	13.3	1 craze, 2 spall, 1 misc	0	0.0	NA		
	2	30	1	3.3	1 spall	0	0.0	NA		
	4	30	9	30.0	9 spall	5	20.0	NA		
Pottery	1	30	1	3.3	1 miscellaneous	1	3.3	NA		
	2	30	2	6.7	2 miscellaneous	1	3.3	NA		
	4	30	0	0.0		0	0.0	NA		
Bone	1	30	0	0.0		0	0.0	NA		
	2	29	2	6.9	2 miscellaneous	1	3.4	NA		
	4	28	1	3.3	1 spall	2	7.1	NA		
Shell	1	30	4	13.3	1 spall, 1 disintegration, 2 miscellaneous	1	3.3	NA		
	2	30	2	6.7	1 spall, 1 miscellaneous	0	0.0	NA		
	4	28	12	42.9	6 spall, 6 disintegration	7	25.0	NA		

Table 4. Continued.

Material Type	Plot	N	<u>Shape Change</u>			<u>Weight Loss</u>		<u>Consumption</u>		Mean % Volume
			n	%	Type	n	%	n	%	
Surface Samples: Plots 1,2,4										
Wood	1	28	NA			DNA		15	53.6	13.1
	2	30	NA			DNA		14	46.7	1.8
	4	24	NA			DNA		21	87.5	29.4
Charcoal	1	10	NA			DNA		0	0.0	0.0
	2	10	NA			DNA		0	0.0	0.0
	4	10	NA			DNA		0	0.0	0.0
Lead	1	30	2	6.7	2 full melt	DNA		NA		
	2	30	0	0.0		DNA		NA		
	4	26	5	19.2	3 partial, 2 full melt	DNA		NA		
Glass Beads	1	30	1	3.3	1 partial melt	DNA		NA		
	2	30	0	0.0		DNA		NA		
	4	30	1	3.3	1 partial melt	DNA		NA		
Nat. Rock	1,2,4	90	0	0.0		0	0.0	NA		
KRFCobbles	1,2,4	90	1	1.1	1 spall	1	1.1	NA		
KRF Flakes	1,2,4	90	14	15.5	1 craze, 12 spall, 1 misc	5	5.5	NA		
Pottery	1,2,4	90	3	3.3	3 miscellaneous	2	2.2	NA		
Bone	1,2,4	87	3	3.4	1 spall, 2 miscellaneous	3	3.4	NA		

Table 4. Continued.

Material Type	Plot	N	Shape Change			Weight Loss		Consumption		Mean % Volume
			n	%	Type	n	%	n	%	
Surface Samples: Plots 1,2,4										
Shell	1,2,4	88	18	20.5	8 spall, 7 disintegration, 3 miscellaneous	8	9.1	NA		
Wood	1,2,4	82	NA			DNA		50	61.0	13.7
Charcoal	1,2,4	10	NA			DNA		0	0.0	0.0
Lead	1,2,4	86	7	8.1	3 partial, 4 full melt	DNA		NA		
Gl.Beads	1,2,4	90	2	2.2	2 partial melt	DNA		NA		
Subsurface Samples: Plot 3										
Nat. Rock	3	30	0	0.0		0	0.0	NA		
KRFCobbles	3	30	1	3.3	1 miscellaneous	0	0.0	NA		
KRF Flakes	3	30	1	3.3	1 miscellaneous	0	0.0	NA		
Pottery	3	30	1	3.3	1 miscellaneous	0	0.0	NA		
Bone	3	30	0	0.0		0	0.0	NA		
Shell	3	30	2	6.7	2 miscellaneous	0	0.0	NA		
Wood	3	30	NA			DNA		0	0.0	0.0

Table 4. Continued.

Material Type	Plot	N	Shape Change			Weight Loss		Consumption		Mean % Volume
			n	%	Type	n	%	n	%	
Subsurface Samples: Plot 3										
Charcoal	3	9	NA			DNA		0	0.0	0.0
Lead	3	30	0	0.0		DNA		NA		
Gl.Beads	3	60	0	0.0		DNA		NA		

¹ DNA = data not available, not recorded; NA = variable not applicable.

Scorching, an impregnation of smoke additives and resins into rock surfaces, was observed for a large number of specimens in the three surface plots. Scorching was visible on 63.3% of the specimens in Plot 2, 76.7% of those in Plot 4, and 93.3% of those in Plot 1 (Table 3). Scorching was highly correlated with color change. The extent or degree of scorching was highest in Plot 1 where, on average, 75% of the exposed surface area of each cobble was scorched. This proportion was about 50% in Plot 2 and 25% in Plot 4.

No incidence of fracture was observed in the natural rock (Table 4). Consequently, no observed weight change was recorded for the natural rock cobbles.

The effects of the burn on natural cobbles in subsurface contexts in Plot 3 were far less pronounced (Table 3). Only a small fraction (10%) exhibited scorching. Color change was slightly more common, with an overall mean darkening in Munsell value of -0.2. Five specimens (16.6%) exhibited color change, however, we feel that one cobble which became lighter in color may have changed color due to subsurface burial in the soil rather than from thermal factors. Changes in the minerals adhering to the surface of some cobbles may possibly explain small changes in coloring.

Knife River Flint Cobble

The observed effects of fire on KRF cobbles mirror those for the natural rock class. The overall pattern of color change and scorching frequency and intensity is nearly identical to that for the natural rock cobbles. The relative intensity of effects according to plot is also the same. KRF cobbles in Plot 1 exhibited the most frequent detectable color change (93.3%), followed by Plot 4 (73.3%), and Plot 2 (60%) (Table 3). Frequencies of scorching for the KRF cobbles parallel these numbers also (Table 3). Similarly, the mean Munsell value change among the three plots is greatest in Plot 4 (-2.3), next greatest in Plot 1 (-2.2), and least in Plot 2 (-1.1), with an overall mean change in color value of -1.9 (Table 3). Not a single instance was noted in which the brown to yellowish-brown cortex on a KRF cobble was altered to a red or reddish brown color (typically a shift in Munsell hue from 10YR to 2.5YR) (Appendix 2).

One instance of weight change and fracture was observed (Table 4). One KRF cobble in Plot 4 exhibited a thermal spall fracture and associated weight loss. This type of fracture is associated with thermal shock rather than an extreme temperature (cf. Rick 1978:20-21). Ahler (1983:4-5) has reported that KRF is particularly sensitive to this type of fracture.

KRF cobbles in subsurface Plot 3 showed very little detectable change compared to their surface counterparts (Table 3). Only a single specimen exhibited slight evidence of scorching. No heat-related fractures or weight loss was observed (Table 4).

Knife River Flint Flake

Detectable color changes were recorded for a majority of flakes placed in the surface plots. However, the nature of this change is somewhat different from that reported for the other stone types. For natural rock and KRF cobbles, color change resulted from a decrease in mean color value and overall darkening in color. This pattern was generally not the case for the KRF flakes. The mean value change for flakes in the surface plots was much less (-0.2). Some darkening of the ventral surfaces was reported, the highest incidence occurred in Plot 1 (33.3%). Most often the noted change was associated with a decrease in color chroma (brightness or purity of the color; cf. Shepard 1956:Figures 7 and 8). This decrease was usually on the order of 1-2 points on the Munsell scale (see Appendix 2). The drop in color hue is thought to be related to a decrease in translucency.

A second feature observed on several of flakes was an opaque black (10YR2/1) glaze, associated with scorching and smoke blackening. Scorching occurred on 50 to 90% of the flakes placed in the surface plots (Table 3). This glaze or scorching has not been observed on either thermally altered KRF debris replicated experimentally or in flaking debris aggregates from archeological contexts. A brief washing with a brush and water did not remove the residue. It is presently unclear if the decrease in translucency posited for the specimens is directly attributable to the thermal alteration of the KRF, as reported by Ahler (1983:4) in heat treatment experiments, or is attributable to the light-masking effects of the carbonaceous residues on the scorched specimens. None of the yellow or brown cortical remnants on the KRF flakes changed to red during the burning process.

Fourteen KRF flake specimens exhibited evidence of fracture (Table 4). Of these, 13 (10.8%) were related to effects of thermal stress. The vast majority were potlid/spall fractures resulting from a rapid increase or decrease in temperature. One specimen in Plot 1 exhibited a transverse fracture which could possibly have resulted from exposure to extreme temperature. Fractures were most common in Plot 4 (30.0%) and were least common in Plot 2 (3.3%). A correlated weight loss (>0.1 g) was reported for five specimens (5.5%) from the surface plots. All weight loss occurrences were associated with Plot 4.

One characteristic of the potlid/spall fractures observed on the KRF flakes merits further discussion. Although this general fracture type has been reported to occur with some frequency in KRF materials, some differences may exist between spalled specimens in this study and burned KRF flakes from archeological contexts. The spalling observed on experimental specimens is often visible only as localized areas of shallow surface pitting, rather than pitting over the entire surface of the artifact. This trait may serve to differentiate the firing contexts.

KRF flakes in subsurface locations in Plot 3 had a minimal amount of change. A small number (10%) exhibited localized scorching, often along a single edge (Table 3). Mean color values did not change on any specimens in the plot. Similarly, no significant morphological or weight change was recorded (Table 4). One specimen exhibited a miscellaneous fracture, almost certainly not heat related, which may have been caused by accidental trampling.

Knife River Ware Pottery

As a whole, ceramic materials exhibited limited change directly attributable to the refiring process. Detectable color change occurred in a minority of cases from the surface plots (Table 3). The general trend was an overall lightening (+0.2) in mean Munsell value. A number of sherds in the brown range of the color spectrum darkened in value, while some dark brown or black sherds exhibited a tendency to lighten in value. The overall preburn dark appearance of many of these sherds likely accounts for the lack of substantial color change. Scorching occurred on 50% of the Plot 4 items, 16.7% of those in Plot 1, and not at all in Plot 2. There is little indication, however, that scorching is highly correlated with color change (see Appendix 1).

A small number of sherds (n = 3, 3.3%) exhibited evidence of transverse fracture (Table 4). However, this attrition can not be positively linked to thermal stress. A more likely explanation may be inadvertent human trampling during the field experiment. Spalling or flaking did not occur.

Subsurface ceramics in Plot 3 did not appear to be affected adversely. Scorching was not observed on any sherds in the sample. The observed color change in a few sherds (Table 3) may be related to burial conditions rather than thermal exposure. Subtle color changes may be due to adsorption of minerals from the surrounding soil matrix.

Bone

The majority of bone fragments from surface plots exhibited color changes after burning as reflected in the incidence of scorching and charring (Table 3). Scorching was observed slightly more frequently in Plot 1 (100%) than in either Plot 2 (89.7%) and Plot 4 (89.3%). Charred and blackened surfaces were most frequent in Plot 4 (46.4%) followed by lower incidences in Plot 1 (20.0%) and Plot 2 (10.3%). The mean color value data support this pattern of scorching and charring. The largest mean change in Munsell value occurred in Plot 4 (-3.8), followed by Plot 1 (-3.0) and Plot 2 (-2.3).

Burning of bone remains in the surface plots also resulted in weight loss or a change in shape for specimens in two samples in Plot 4 and for one specimen in Plot 2 (Table 4). The bone breakage for one sample in Plot 2 does not appear to be heat related.

Bone remains in subsurface contexts were little affected by the burn compared to their surface counterparts. Scorching occurred infrequently (10%) with minimal impact to the surface of the bone; charring was not observed (Table 3). Some darkening of exposed surfaces occurred (Table 3), but we feel this probably resulted from the effect of soil chemistry on the organic matrix in the bone rather than thermal exposure.

Freshwater Mussel Shell

Shell remains were among the most severely affected materials in the surface plots. Burning resulted in a darkening of the nacre on the interior of the shell in many cases (Table 3), even though this surface was placed downward, away from the fire during the burn. The decrease in mean color value for the three plots (-2.1) supports this observation (Table 3). Scorching was a commonly noted feature, occurring on 87.5% of the surface specimens. In many cases the shell exterior was also darkened as a result of exposure to heat and flame (see Appendix 2).

Shell structure and morphology were also altered by burning. The greatest impacts were recorded in Plot 4 where 42.9% of the recovered specimens exhibited some form of structural or shape change (Table 4), including six examples of disintegration and another six instances of spall fractures. Heat related fractures were also reported in both Plots 1 and 2. Substantial weight losses accompanied this process in many instances.

Shell recovered from subsurface Plot 3 was not affected to nearly the same degree. Scorching was observed as small patches on the nacre in five cases (16.7%) (Table 3). No significant weight loss was indicated. Some attrition was observed on two shell fragments, but this damage does not appear to be heat related.

Wood Remains

The two groups of wood items were the most severely affected materials placed in the field burn. In each of the three surface plots, heat-related discoloration was noted on most of the recovered specimens (Table 3). Scorching was recorded on nearly 90% of the samples in Plots 1 and 2. Charring and potential consumption were evident on almost one-half of these cases, as well, and for 87.5% of the cases in Plot 4 (Tables 3,4). The degree of consumption was highest in Plot 4 (mean estimated volume loss of 29.5%), but was lesser in Plot 1 (13.1%) and Plot 2 (1.8%). Six wood segments in Plot 4 were lost and presumed to be 100% consumed; two were similarly missing from Plot 1 (Appendix 2).

Different burning effects were observed on balsa and birch samples in the surface plots. The softer balsa wood segments exhibited greater scorching and charring than their somewhat harder birch counterparts. Charring was reported on 78.4% of the recovered balsa pieces, but only on 46.7% of the birch samples (Appendix 2). The mean percentage of charring per piece was also greater for the balsa group (11.8%) compared to the birch group (1.0%). All of the missing and presumably fire-consumed pieces were balsa; no birch specimens were missing.

The wood samples in Plot 3 revealed little modification by fire. One balsa piece was lightly scorched and four birch specimens exhibited light scorching (Table 4). Charring was not observed on any specimen.

Charcoal

The sample of 40 charcoal sticks from surface and subsurface contexts did not exhibit any noticeable change in color or shape. This observation is surprising considering the scope of observed changes (color, structure, and shape) reported for the other organic materials in the surface aggregate, especially the wood remains. It is possible that minor undetected consumption or oxidation did take place during the burning episode, since the specimens were not weighed for minor weight changes or otherwise measured except for length.

Lead Objects

In Plots 1 and 2, most conical lead sinkers exhibited some color change (Table 3). The most common feature was a yellowish brown surface film probably resulting from smoke impregnation. This discoloration, recorded as scorching, occurred more frequently in Plot 2. In some cases, surfaces were blackened by smoke. Two lead cones in Plot 1 (6.7%) were fully deformed or melted as a result of heat exposure.

The winged lead sinkers in Plot 4 were more adversely affected by the burn. Five of the sinkers (19.2%) showed signs of deformation by heat (three partially melted, two fully melted; Table 4). Most of the others were either blackened or turned a yellowish brown by smoke impregnation.

In Plot 3, the buried lead specimens showed no effects of exposure to heat. The most common feature recorded there was the presence of a white film, a lead oxide rind, which had begun to develop in the moist subsurface context (cf. Schiffer 1987:195). These findings parallel those for most of the other previously discussed materials indicating little heat alteration to shallowly buried remains.

Glass Beads

Within the three surface plots, a color change was reported on 65.5% of the specimens (Table 3), with individual plot means ranging from 60.0% in Plot 1 to 73.3% in Plot 4. This change took two general forms: (1) a light yellowish brown smoke impregnation much like that reported on the lead objects, and (2) a blackened surface smoke residue.

Single occurrences of surface fusion or partial melting were observed on specimens in Plots 1 and 4 (Table 4). No heat related changes were recorded for the 60 specimens placed in the two subsurface sample locations in Plot 3.

Interplot Variation

To facilitate comparisons of burning effects among plots, we ranked the plots according to the relative degree of change evident in various dependent variables such as color, weight, and shape (Table 5). A plot ranking of 1 indicates that the plot exhibits the greatest amount or most severe degree of change for the particular dependent variable while a ranking of 4 indicates that the plot shows the least degree of postburn change for that variable.

For all materials except wood charcoal, the greatest frequency and degree of overall change related to burning occurred in Plot 4, followed in decreasing order by Plot 1, Plot 2, and Plot 3. The mean rank values for the various plots illustrate this pattern: Plot 4 - 1.39; Plot 1 - 2.06; Plot 2 - 2.78; and Plot 3 - 3.78 (Table 5).

The severity of burning impacts was influenced by relative fuel load and burn duration (Table 5). Plot 4, in which materials exhibited the most severe effects from the burn, had the highest fuel load and longest burn duration. This finding is generally in agreement with conclusions reached by other researchers (e.g., Pilles 1984:7; Thurman and Willmore 1980-81:282) that fuel load and duration of burn are critical variables in assessing the intensity of effects of fire on archeological materials. The maximum temperature recorded within a plot seems to be less clearly correlated with the severity of burn alterations to the artifacts. These correlations pinpoint details of prescribed burn plans where control can be applied to diminish negative effects on cultural resources.

Summary of Burning Experiment

We conducted two experimental burns on native prairie vegetation in North Dakota to determine potential effects (changes in color, weight, structure, morphology) on artifact materials common to KNRI. Two types of sample burning plots were used, each containing nearly identical groups of 10 different materials. The first type contained three plots of surface remains each with a differing fuel load. These were designed to simulate surface scatters of artifacts. A second sample type consisted of a single shallowly buried subsurface plot of sample materials simulating a buried cultural deposit. Maximum recorded air temperatures during two experimental burns reached 399°C.

Natural cobbles of granitic, basaltic, and limestone rocks were placed in each of four plots. Specimens in surface plots were often discolored by smoke impregnation. The greatest color change was recorded in the surface plots, especially in the plot with the largest fuel load and the longest burn duration (Plot 4). Subsurface rocks were only occasionally discolored, some of which may be due to contact with soil. Fracture or other heat related modifications were not observed on any of the stones. This observation suggests that temperatures within the stone objects themselves did not exceed the 250-300°C threshold suggested to be necessary to initiate fracture in coarse-grained rocks (cf. Blackwelder 1927:107;

Table 5. Summary of independent variables and rank ordering of burning plots by effects on material classes, Oakville Prairie Natural History Area prescribed burning experiment.

Material Class	Variable	Data Values or Rankings: ¹			
		Plot 1	Plot 2	Plot 3	Plot 4
Independent Variables:					
	Artifact Position	surface	surface	subsurface	surface
	Relative Fuel Load	high	medium	low	very high
	2 Cm Fire Temp. (°C)	177	399	316	121
	10 Cm Fire Temp. (°C)	343	399	288	399
	Burn Duration	0.5 min	0.5 min	0.5 min	1.0 min
Dependent Variables:					
Natural Rock	Mean Color Value Change	2	3	4	1
KRF Cobbles	Mean Color Value Change	2	3	4	1
KRF Flakes	Mean Color Value Change	1	2	4	2
Pottery	Mean Color Value Change	1	4	2	2
Bone	Mean Color Value Change	2	3	4	1

Table 5. Continued.

Material Class	Variable	Data Values or Rankings ¹			
		Plot 1	Plot 2	Plot 3	Plot 4
Shell	Mean Color Value Change	2	3	4	1
Lead	Color Change	3	1	4	2
Glass Bead	Color Change	3	2	4	1
KRF Cobble	Fracture	4	4	2	1
KRF Flake	Fracture	2	3	4	1
Shell	Fracture	2	3	4	1
Lead	Fracture	2	4	4	1
Glass Bead	Fracture	1	4	4	1
Bone	Scorching	1	2	4	3
Shell	Scorching	3	2	4	1
Wood	Scorching	2	1	4	3
Bone	Charring	2	3	4	1
Wood	Charring	2	3	4	1
Mean Ranking on Dependent Variables:		2.06	2.78	3.78	1.39

¹ Rankings for plots on dependent variables: 1 = most severe or frequent effects, to 4 = least severe or least frequent effects.

Tarr 1915:357). Consequently, we feel that natural fires in prairie/grassland settings probably will not ordinarily produce sufficient heat for long enough periods to fracture cobble-sized rocks in either surface or buried contexts. Perhaps just as important, it is highly likely that materials occurring in a prairie/grassland setting and classifiable by an archeologist as fire-cracked rocks are in fact the product of cultural rather than natural processes.

Like the natural rocks, the KRF cobbles exhibited substantial surface discoloration from smoke impregnation. One cobble from a surface plot exhibited heat related spalling. The damage to the stone was localized, however, and not uniform across the exposed surface. No evidence of crazing or more massive transverse fracture was recorded. Burned KRF identified in archeological contexts is often a shade of gray or reddish brown in color hue. It is unlikely that any of the cobbles tested in this study, if recovered from an archeological context, would be identified as intentionally thermally altered (cf. Ahler 1983). Lack of change in yellow and brown cortex colors indicates that temperatures within the cortical rind did not exceed 200°C (cf. Ahler 1983:4) in the cobbles tested. The scorching residue observed on the cobbles was not removed by a single washing with water. Because this trait has not been identified on archeological specimens, it seems unlikely that this is a permanent alteration to the surface of the stone. However, the length of time and the process by which such coloration may be naturally removed from fire-treated stones is unknown.

KRF flakes were substantially discolored by heat and smoke in the surface plots. This discoloration was often characterized as a blackened opaque sheen on the flake surface. The flint matrix itself does not appear to have been substantially altered in color. Based on experimental data (Ahler 1983:8), it appears that temperatures within the experimental flakes did not exceed 200-250°C. Burned KRF flakes from archeological contexts are identified by their reddish brown or gray color hue, traits that are absent in the experimental samples. Heat related potlid/spall fractures were also noted on specimens in the surface plots. Weight loss often accompanied this process of attrition. The spalls were usually visible as shallow localized pits near one end or along one edge of the artifacts rather than covering the entire flake surface, as is common in thermally altered debris from archeological contexts. This distinction could perhaps be used to separate culturally related burning from burning associated with natural grass fires or similar "flash-fire" situations.

The aboriginal pottery sherds employed in this experiment showed little evidence of thermal alteration in of color or structure as a result of the refiring process. It is doubtful that episodes of natural firing in grassland settings would have major impact on native ceramics. These findings are compatible with the relatively low maximum temperatures recorded in our burn experiments (ca. 399°C) and conclusions from experimental studies (e.g., Bennett and Kunzmann 1987:12) that temperatures above 600°C are necessary to cause major changes in pottery color.

Overall, there is a slight tendency for Munsell color values for the sherds to increase as a result of the burning process. Only additional experimentation can determine if multiple episodes of prairie fire exposure would eventually

transform the dark Knife River ware sherds into something significantly lighter in color and appearing to be atypical of pottery manufactured during the postcontact period at Knife River.

The bone remains from surface contexts were scorched and charred by thermal exposure in many cases, although this burning did not consume any significant portion of the exposed bone surface. The degree of alteration in bone is consistent with some of the range of alteration occurring in faunal materials classified as "burned bone" from regional archeological sites. Shallowly buried bones were not effected to any degree. The relatively severe impacts to surface bone samples is compatible with experimental studies which suggest that alteration in bone can begin at temperatures as low as 100°C (Von Endt and Ortnier 1984) and that temperatures on the order of 285-300°C are sufficient to produce charring (Shipman et al. 1984; Bennett and Kunzmann 1987).

Mussel shell in the surface plots was significantly altered. Fracture and structural disintegration were noted in several instances. Shell remains appear more susceptible to heat stress and structural change than most of the other material classes except for organics such as wood (see below). Shell in buried contexts was lightly scorched in several instances, but no observable structural change or heat induced fracture was indicated. These findings suggest that surface mussel shell may be severely affected by thermal exposure in certain instances; repeated burnings could remove shell completely from the surficial archeological record.

Wood was the most affected material class in the study. The denser birch wood was more resistant to scorching and charring than was balsa wood. However, in the surface plots both wood types exhibited some consumption resulting from burning. Subsurface samples were little affected; only light scorching of surfaces was detected.

Wood charcoal on the other hand appeared to be generally unaffected by the burn. No recognizable changes in color, structure, or morphology were noted for specimens in either the surface or subsurface plots. Existing archeological wood charcoal fragments in buried sediments do not appear to risk the possibility of reduction to mineral ash as the result of refiring during natural or prescribed burns.

Lead items placed in the surface plots were frequently discolored by smoke. Partial or complete melting was recorded in several instances in the two surface plots containing the greatest fuel loads, indicating that temperatures in some locations exceeded the 327.5°C melting point for lead (Waite 1976:Table 1). Metal items buried in shallow subsurface contexts were not affected by heat or smoke to any degree.

Finally, glass beads displayed the effects of the same types of impacts observed for lead items. Beads in the surface plots were frequently discolored by flame and smoke. A small fraction of the specimens exhibited some physical deformation from partial (surface fusion?) melting. Buried glass beads were not visibly impacted by the fire.

Conclusions

We offer the following conclusions regarding the effects of controlled or prescribed grass fires on archeological resources in the KNRI:

1. Impacts of grassland fires on artifacts and other materials in subsurface settings will be negligible, even if they are buried only a centimeter or less below the ground surface. This conclusion is based both on the experimental results from this study and the large body of empirical data gathered from many grassland fire studies (cf. Wright and Bailey and 1982:11; Vogl 1974: 152-156).

2. Fire-related impacts to surface-exposed artifacts will be substantial. The severity of the impact will vary according to artifact type and artifact size. Virtually all artifact types will be scorched and smoke-blackened. The permanency of this alteration is not known at the present time, but it is likely to be more permanent for combustible, organic items than for inorganic items. Bone and antler remains will be substantially altered by blackening and charring. Small items will be structurally altered to a greater degree than larger items. Shell will be fractured and in some cases disintegrated. Wood artifacts (a rare occurrence at the surface of a site) will be charred and in some cases consumed. A substantial percentage of chipped stone items (flaking debris and tools) will be spalled and potlidd fractured. Pottery will not be severely structurally damaged, although it is possible that repeated cycles of burning may permanently alter the surface color of pottery sherds (as yet untested). Larger stone items such as natural rock, fire-cracked rock, flint cobbles, and larger ground stone artifacts will not be structurally affected to a great degree. Localized spalling may occur rarely or occasionally on such specimens, but massive fracturing and breakdown will not occur. Small lead and glass items will be partially or fully fused and melted. If fully exposed on the surface, the smallest "seed beads" will be more severely altered than larger beads. Overall, these effects are considered to be quite negative and serious, and are to be avoided if at all possible in the management of the KNRI cultural resources.

3. The severity of fire-related effects can be controlled and diminished to some degree by controlling the environmental conditions at the time of burn. Lower burn duration and lower fuel loads are expected to lessen severity of fire-related impacts to cultural resources. The negative effects of prescribed burning can be diminished by burning under conditions of higher wind velocity (thereby decreasing burn duration) and by burning under conditions of artificially or naturally reduced fuel load.

4. The negative effects of prescribed burning in grassland settings at the KNRI can be alleviated to a great degree by collecting all sensitive surface- visible artifacts prior to the burn. The same solution has been offered by Bennett and Kunzmann (1987:16). Indirect negative effects, such as disturbance from fire-control equipment and personnel, must still be kept in mind and avoided if possible.

FIRE AS A VEGETATION MANAGEMENT TOOL FOR THE KNIFE RIVER INDIAN VILLAGES NHS

by

John T. Trevor and Nikki R. Seabloom

Introduction

As a guide for planning future burning programs, we reviewed available literature on effects of fire on selected plant species known to occur at KNRI. We examined standard bibliographic sources, major review articles and bibliographies on prairie fires (e.g., Higgins et al. 1988), and texts on fire management, to locate references on relevant plant species effects. From a working list of over 150 selected references, we located information about effects of fire on 85 of the 257 plant species listed in Clambey (1985). Most research on fire effects on vegetation refers to changes in biomass, canopy cover, frequency, or seed production. Occasionally, reference is simply made to 'increasers or decreaseers'. It was beyond the scope of this study to attempt a detailed discussion of all of these potential effects. However, a summary of this information is discussed for each of the major vegetation areas of KNRI and relevant information on these selected 85 plant species is provided in Table 6.

Effects on Major Vegetation Areas

Former Cropland

Former cropland on KNRI is classified into 5 distinct types based on dominant plant species: Crested Wheatgrass, Sideoats Grama-Western Wheatgrass, Smooth Brome grass, Western Wheatgrass, and Grass-Forb Mixture. The crested wheatgrass (*Agropyron cristatum*) type is expected to decrease after annual spring burns. In those areas dominated by both a mixture of sideoats grama (*Bouteloua curtipendula*) and western wheatgrass (*Agropyron smithii*) or western wheatgrass alone, annual spring burns would result in an increase of these species. Annual spring burns would decrease smooth brome grass (*Bromus inermis*). Finally, areas with a grass-forb mixture, consisting primarily of smooth brome grass, Kentucky bluegrass (*Poa pratensis*), and sweet clover (*Melilotus* spp.) , would be expected to decrease after annual spring burns.

Native Prairie

Because of the heterogeneous nature of the native prairie areas at KNRI, only species identified by Clambey (1985) as major constituents of a particular site will be addressed for predicted response to burning. Big Hidatsa, Grannis Uncultivated, Buchfink, and Sakakawea pastures are the four major areas of

Table 6. Summary of literature review on effects of fire on plants found at the Knife River Indian Villages National Historic Site.

Species (Common Name)	General Response After Fire	Comments And References ^a
<u>Grasses:</u>		
<i>Agropyron cristatum</i> (Crested Wheatgrass)	Decrease	Annual spring and fall burn (31)
<i>Agropyron smithii</i> (Western Wheatgrass)	Increase	Annual spring burns up to 24 years at one site (6, 7, 14, 15, 16, 17, 21, 34, 36)
<i>Andropogon gerardii</i> (Big Bluestem)	Increase	Annual and biennial burns, up to 13 years at two sites (1, 2, 7, 11, 12, 14, 20, 23, 24, 25, 26, 28, 33, 38, 40, 41, 42)
<i>Andropogon hallii</i> (Sand Bluestem)	Decrease	Late Spring burn (9)
<i>Andropogon scoparius</i> (Little Bluestem)	Increase	Annual spring burns up to 13 years at one site (2, 12, 15, 24, 26, 28, 38, 40, 41, 45)
<i>Bouteloua curtipendula</i> (Side-oats Grama)	Increase	Annual spring burns (24, 26, 30, 34)
<i>Bouteloua gracilis</i> (Blue Grama)	Increase	Annual spring burns up to 24 years at one site (3, 9, 15, 28, 30, 34, 36)
<i>Bromus ciliatus</i> (Fringed Brome)	Decrease	Annual spring burn for 24 years (3)
<i>Bromus inermis</i> (Smooth Brome)	Decrease	Annual spring and fall burn up to 24 years at one site (3, 18, 28, 30)
<i>Bromus japonicus</i> (Japanese Brome)	Decrease	Spring burn (16)
<i>Bromus tectorum</i> (Cheatgrass)	Decrease	Spring and summer burn (5, 34)
<i>Calamovilfa longifolia</i> (Prairie Sandreed)	Increase	Annual spring burns up to 24 years at one site (3, 28)
<i>Elymus canadensis</i> (Canada Wildrye)	No Effect	Spring burn (12)
<i>Eragrostis trichodes</i> (Sand Lovegrass)	Decrease	Late spring burn (9)
<i>Festuca octoflora</i> (Six-weeks Fescue)	Decrease	Late spring burn (9)
<i>Koeleria pyramidata</i> (Junegrass)	Increase	Spring burn (41)
<i>Muhlenbergia dungensis</i> (Sandhill Muhly)	Decrease	Late Spring burn (9)
<i>Muhlenbergia schreberi</i> (Nimblewill)	Increase	Early spring burn (18)
<i>Panicum virgatum</i> (Switchgrass)	No Effect	Annual spring burns up to 4 years at one site (2, 26, 32)
<i>Phleum pratense</i> (Timothy)	Decrease	Annual spring burn up to 3 years, only slight decrease (12)
<i>Poa pratensis</i> (Kentucky Bluegrass)	Decrease	Annual spring burns up to 13 years (1, 2, 7, 12, 13, 14, 15, 18, 20, 23, 24, 26, 28, 34, 35, 39, 41, 42, 45)
<i>Redfieldia flexuosa</i> (Blowout Grass)	Increase	Late spring burn (9)
<i>Sorghastrum nutans</i> (Indian Grass)	Increase	Annual spring burns up to 13 years (1, 2, 12, 20, 26, 40, 41, 42)
<i>Spartina pectinata</i> (Prairie Cordgrass)	Decrease	Spring burn (28)
<i>Setaria</i> spp. (Foxtail)	Decrease	Spring burn (18)
<i>Sporobolus asper</i> (Tall Dropseed)	Mixed	Spring and fall burn, increase after spring, decrease after fall burn (18)
<i>Sporobolus cryptandrus</i> (Sand Dropseed)	Increase	Spring burn (34)
<i>Stipa comata</i> (Needle-and-thread)	Increase	Spring burns (9, 17, 19, 28)
<i>Stipa spartea</i> (Needlegrass)	Mixed	Annual spring burns up to 24 years at one site (3, 7, 15, 19, 24, 28, 40, 42)
<i>Stipa viridula</i> (Green Needlegrass)	Mixed	Annual spring burns up to 24 years at one site (3, 14, 17, 28)
<i>Trifolium pratense</i> (Red Clover)	Increase	Spring, summer, and fall burn (18)
<u>Forbs, Shrubs, And Trees:</u>		
<i>Achillea millefolium</i> (Yarrow)	Increase	Annual spring burn for 24 years (3)
<i>Amaranthus</i> spp. (Pigweed)	Mixed	Spring burn, increased on some sites, decreased on others (44)
<i>Ambrosia psilostachya</i> (Western Ragweed)	Mixed	Annual spring burns up to 4 years, increases, decreases and no change noted in studies (1, 2, 9, 28, 29, 30, 44)
<i>Amelanchier alnifolia</i> (Juneberry)	No Effect	Annual spring and a fall burn (3, 26)
<i>Anemone canadensis</i> (Meadow Anemone)	Increase	Spring burn (28)
<i>Anemone cylindrica</i> (Candle Anemone)	Increase	Spring burn (28)

Table 6. Continued.

Species (Common Name)	General Response After Fire	Comments And References ^a
Forbs, Shrubs, And Trees (cont.):		
<i>Anemone patens</i> (Pasque-flower)	Decrease	Annual spring burns for 24 years (3)
<i>Artemisia absinthium</i> (Wormwood Sage)	Decrease	Summer burn (37)
<i>Artemisia cana</i> (Silver Sagebrush)	Decrease	Spring and fall burn (43)
<i>Artemisia dracunculus</i> (Silky Wormwood)	Increase	Spring burn (9)
<i>Artemisia frigida</i> (Fringed Sagebrush)	Mixed	Annual spring and summer burns up to 24 years at one site, increase after spring, decrease a summer burn (5, 6, 15, 28)
<i>Artemisia ludoviciana</i> (Pasture Sage)	Mixed	Annual spring burns up to 24 years at one site, increases, decreases, and no change noted in studies (2, 15, 28)
<i>Asclepias verticillata</i> (Whorled Milkweed)	Increase	Spring burn (24)
<i>Aster ericoides</i> (White Prairie Aster)	Mixed	Annual spring burns, summer, and fall burns; decreases and increases after spring burns,
<i>Carex filifolia</i> (Thread-leaved Sedge)	Mixed	Spring and summer burn, no change after spring, decrease after summer burn (11, 28)
<i>Carex heliophila</i> (Sun Sedge)	Increase	Annual spring burn for 24 years (3) increases after summer and fall burns (1, 2, 18, 28)
<i>Cirsium canadensis</i> (Canada Thistle)	Decrease	Spring burn (28)
<i>Conyza canadensis</i> (Horseweed)	No Effect	Spring burn (29)
<i>Corylus americana</i> (American Hazel)	Decrease	Annual spring burn for 4 years (2)
<i>Crataegus</i> spp. (Hawthorn)	No Effect	Annual spring, summer, and fall burns (18)
<i>Equisetum laevigatum</i> (Smooth horstail)	Decrease	Annual spring burn for 24 years (3)
<i>Fragaria virginiana</i> (Wild Strawberry)	No Effect	Annual spring burn for 24 years and fall burn (3, 8)
<i>Galium boreale</i> (Northern Bedstraw)	Mixed	Annual spring burns, for 24 years at one site, increase at 24 year site, no effect noted at other (3, 28)
<i>Gleditsia tricanthus</i> (Honey Locust)	Increase	Annual spring burn (18)
<i>Glycyrrhiza lepidota</i> (Wild Licorice)	No Effect	Spring burn (28)
<i>Helianthus maximiliani</i> (Maximilian Sunflower)	Increase	Spring burn (28)
<i>Ipomopsis longiflora</i> (White Flowered Gilia)	Decrease	Spring burn (9)
<i>Juncus balticus</i> (Baltic Rush)	Mixed	Annual spring burns up to 24 years, no change at 24 year site, decrease at other site (3, 28)
<i>Kuhnia eupatorioides</i> (False Boneset)	Increase	Spring burn (44)
<i>Lepidium</i> spp. (Pepperweedgrass)	Decrease	Spring burn (44)
<i>Liatris punctata</i> (Blazing Star)	Increase	Spring burn (44)
<i>Lithospermum incisum</i> (Narrow-leaved Puccoon)	Decrease	Spring burn (44)
<i>Melilotus</i> spp. (Sweet Clover)	Mixed	Spring and summer burns, increases and decreases noted after a spring burn, decrease after a summer burn (10, 15, 22, 34)
<i>Mentzelia nuda</i> (Bractless Mentzelia)	Decrease	Spring burn (9)
<i>Monarda fistulosa</i> (Wild Bergamot)	Increase	Annual spring burns for 24 years (3)
<i>Petalostemum purpureum</i> (Purple Prairie Clover)	Increase	Spring burn (28)
<i>Populus tremuloides</i> (Trembling Aspen)	Decrease	Annual and biennial spring burns (38)
<i>Prunus besseyi</i> (Sand Cherry)	No Effect	Fall burn (8)
<i>Prunus virginiana</i> (Chokecherry)	Mixed	Annual spring burns for 24 years, and fall burn; increase and no change noted in 24 year study, no effect noted after fall burn (3, 8)
<i>Psoralea</i> spp. (Scurfpea)	Mixed	Spring burns, increases noted in two studies, a decrease noted in the third (9, 15, 28)
<i>Ratibida columnifera</i> (Coneflower)	Decrease	Spring burn (44)

Table 6. Continued.

Species (Common Name)	General Response After Fire	Comments And References ^a
Forbs, Shrubs, And Trees (cont.):		
<i>Rhus glabra</i> (Smooth Sumac)	No Effect	Annual spring, summer and fall burn (18)
<i>Rosa arkansana</i> (Prairie Wild Rose)	No Effect	Spring and fall burn (8, 28)
<i>Salix</i> spp.	Decrease	Spring burn (35)
<i>Smilacina stellata</i> (False Solomon's Seal)	No Effect	Annual spring burns for 24 years (3)
<i>Solidago</i> spp. (Goldenrod)	Increase	Annual spring, summer, and fall burn (18)
<i>Solidago missouriensis</i> (Prairie Goldenrod)	Increase	Annual spring burns, for 24 years at one site (3, 44)
<i>Solidago rigida</i> (Rigid Goldenrod)	No Effect	Spring burn (28)
<i>Symphoricarpos orbiculatus</i> (Coralberry)	Increase	Annual spring burn (18)
<i>Symphoricarpos occidentalis</i> (Snowberry)	Mixed	Annual spring burns, and summer burn; increases, decreases, and no change noted after spring burns, no change noted after summer burn (3, 4, 6, 8, 27, 28)
<i>Toxicodendron rydbergii</i> (Poison Ivy)	No Effect	Fall burn (8)
<i>Ulmus</i> spp. (Elm)	Increase	Annual spring and fall burns (18)
<i>Vicia americana</i> (American Vetch)	Increase	Annual spring burns for 24 years (3)
<i>Viola nuttallii</i> (Nuttall's Violet)	Decrease	Summer burn (5)

^a References: 1 Abrams (1988), 2 Abrams and Hulbert (1987), 3 Anderson and Bailey (1980), 4 Anderson and Bailey (1979), 5 Antos et al. (1983), 6 Bird (1961), 7 Bock and Bock (1983), 8 Bock and Bock (1984), 9 Bragg (1978), 10 Curtis and Partch (1948), 11 Curtis and Partch (1950), 12 Ehrenreich and Aikman (1963), 13 Engle and Bultsma (1981), 14 Engle and Bultsma (1984), 15 Forde et al. (1984), 16 Gartner et al. (1978), 17 Gartner et al. (1986), 18 George et al. (1978), 19 Hadley (1970), 20 Hadley and Kieckhefer (1963), 21 Haupt (1985), 22 Heitlinger (1975), 23 Hill and Platt (1975), 24 Hover and Bragg (1981), 25 Hulbert (1969), 26 Hulbert (1988), 27 Keith and Surrendi (1971), 28 Kirsch and Kruse (1973), 29 Launchbaugh (1964), 30 Launchbaugh (1973), 31 Lodge (1960), 32 Ohr and Bragg (1985), 33 Peet et al. (1975), 34 Schacht and Stubbendieck (1985), 35 Smeins and Olsen (1970), 36 Smith et al. (1985), 37 Steuter (1983), 38 Svedarsky et al. (1986), 39 Tester (1965), 40 Tester and Marshall (1961), 41 Towne and Owensby (1984), 42 White (1983), 43 White and Currie (1983), 44 Wolfe (1973), 45 Zedler and Loucks (1969)

native prairie. The Grannis Hidatsa pasture and the lower portion of the Big Hidatsa pasture are contiguous in their vegetation patterns, and are dominated by western wheatgrass, green needlegrass (*Stipa viridula*), and Kentucky bluegrass. Annual spring burns on these areas would increase western wheatgrass and decrease the amount of Kentucky bluegrass. The response of green needlegrass to burning has been mixed; some studies have recorded an increase while others a decrease after spring burning.

The upper portion of the Big Hidatsa pasture, with its increased elevation, has more variation of soils and vegetation. The dominant species include Kentucky bluegrass, big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), needle-and-thread grass (*Stipa comata*), blue grama (*Bouteloua gracilis*), thread-leaved sedge (*Carex filifolia*), green sage (*Artemisia dracunculus*), and fringed sage (*Artemisia frigida*). Previous studies show that big bluestem, little bluestem, needle-and-thread grass, blue grama, green sage, and fringed sage would all increase after annual spring burns. However, Kentucky bluegrass would decrease, and thread-leaved sedge would not change after annual spring burns. If burning occurred in summer, thread-leaved sedge and fringed sage would be expected to decrease.

The dominant species on the Buchfink pasture are western wheatgrass, blue grama, needle-and-thread grass, Kentucky bluegrass, little bluestem, and sideoats grama. All of these species, except Kentucky bluegrass, would increase after an annual spring burn. Kentucky bluegrass, on the other hand, would decrease after a spring burn.

The Sakakawea pasture is divided into two areas, an upper and a lower region, based on distinctly different soil types. The dominant vegetation on both sites includes western wheatgrass, green needlegrass, blue grama, Kentucky bluegrass, needle-and-thread grass, and smooth brome grass. After a spring burn western wheatgrass, blue grama, and needle-and-thread grass would increase, while Kentucky bluegrass and smooth brome grass would both decrease. The exact response of green needlegrass is unknown.

Forested Areas

The dominant species of trees and shrubs occurring in forested areas include green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), boxelder (*Acer negundo*), poison ivy (*Toxicodendron rydbergii*), chokecherry (*Prunus virginiana*), snowberry (*Symphoricarpos occidentalis*), and western wild rose (*Rosa woodsii*). Little information is available on the response of these species to prescribed burns. One previous study noted that elm increased after both annual spring and fall burns (Table 6). The responses of both chokecherry and snowberry to burning are mixed. Both of these species exhibited increases, decreases, and no change after burning in various studies. Finally, because of the health hazard in burning poison ivy, few data are available regarding its response to burning. In one previous study, there was no effect after annual spring and fall burns (Table 6).

RECOMMENDED BURNING PROGRAM

by

Robert W. Seabloom, Stanley A. Ahler, Rodney D. Sayler

Land Management Objectives

The land and natural resource management goals of KNRI were outlined by Hellickson-Key (1984) and updated by Holm (1986a,b). Briefly, active vegetation management is desirable to create a natural setting resembling the time period of major village occupation (i.e. early 1800's). Thus, vegetation management should encourage native prairie species and discourage exotic and pest species. Riparian woodland zones should be restricted in size and limited to areas immediately adjacent to the river. Land management practices should not have a negative impact on preservation of the valuable archeological resources of KNRI.

The purpose of this plan is to provide a burn prescription for: 1) enhancing native vegetation on native prairie and artificially seeded grasslands, 2) reducing exotic plant species, and 3) reducing wildfire hazards by removal of accumulated fine fuels. Burning programs at KNRI should be consistent with sound vegetation management and minimize negative impacts on wildlife populations and visitor use. A burning program must also be consistent with available manpower and equipment constraints.

Minimizing or Mitigating Fire Effects on Cultural Resources:

Our results indicate that a variety of fire-related impacts will occur on various surface archeological materials at KNRI, primarily depending on artifact type and size, fuel loads, and burn duration. Minimally, it can be assumed that any artifact visible on the ground surface during a prescribed burn will be at risk of scorching, receiving structural damage, or being consumed. Consequently, we recommend a burning program that recognizes several categories of artifact densities and relative importance or sensitivity to burning. Specifically, we recommend that:

- 1) The village sites not be burned until a thorough and professional collection of surface-visible artifacts is completed that will preserve this valuable information for future analysis.
- 2) Archeological sites on KNRI with moderate artifact densities be surveyed to determine whether surface collection is warranted to mitigate fire damage.
- 3) Burning and other vegetation management programs may begin as soon as feasible on other areas and portions of the park which have low artifact densities,

archeological sites deemed not significant (with reference to criteria used for nomination to the National Register of Historic Places), or sites not susceptible to fire damage.

To help delineate potential burning zones within the park (Fig. 3), we categorized archeological sites within KNRI according to the preceding three levels of recommended treatment prior to prescribed burning. The boundaries of all archeological sites and non-site zones listed in the following sections have been marked on a series of twenty-two, 1:1000 scale cultural resource base maps previously submitted to the park (Lovick and Ahler 1982).

1) High Density Sites: Sites with high densities of visible surface artifacts and greatest susceptibility to impact from prescribed fires; sites at which intensive, controlled artifact collection should definitely occur prior to prescribed burning:

Sites¹ - 10, 11, 12, 366.

2) Moderate Density Sites: Potentially sensitive sites which exhibited moderate densities of surface-visible artifacts when examined during previous surveys and which are known to contain items, such as bone and chipped stone material, particularly sensitive to fire damage. These sites will require preburn surface examination to determine if artifacts are still visible at the surface now that vegetation has covered them more completely. These surveys are required to determine if such a surface collection program would effectively mitigate potential fire damage, and to determine how to conduct such a collection program if it is deemed necessary:

Sites² - 9, 310, 311, 312, 383, 407, 408, 409, 411, 412, 413, 414, 415, 416, 464, 465, 466, 473, 474, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 499

3) Low Density Sites: Sites and areas within KNRI where damage to cultural resources from prescribed burning is not believed to present a problem. This group includes: a) all non-site zones and sites identified as bone concentrations along the Knife River shoreline (presumably in an area where surface vegetation would not burn), b) Euroamerican historic sites which do not contribute to the cultural significance of the park, and c) archeological sites such as trails and cemeteries which exhibit surface ground features, but no artifacts known to be subject to fire damage:

Sites - 467, 468, 469, 470, 471, 472, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 787, and all designated non-site zones.

1 The prefix "32ME" has been dropped from the listed site numbers.

2 Sites 410, 497, and 498 are comparable to those in this group in terms of expression and content, but have been excluded from this group because they are located in the scenic easement for the park, presumably outside any burn zone.

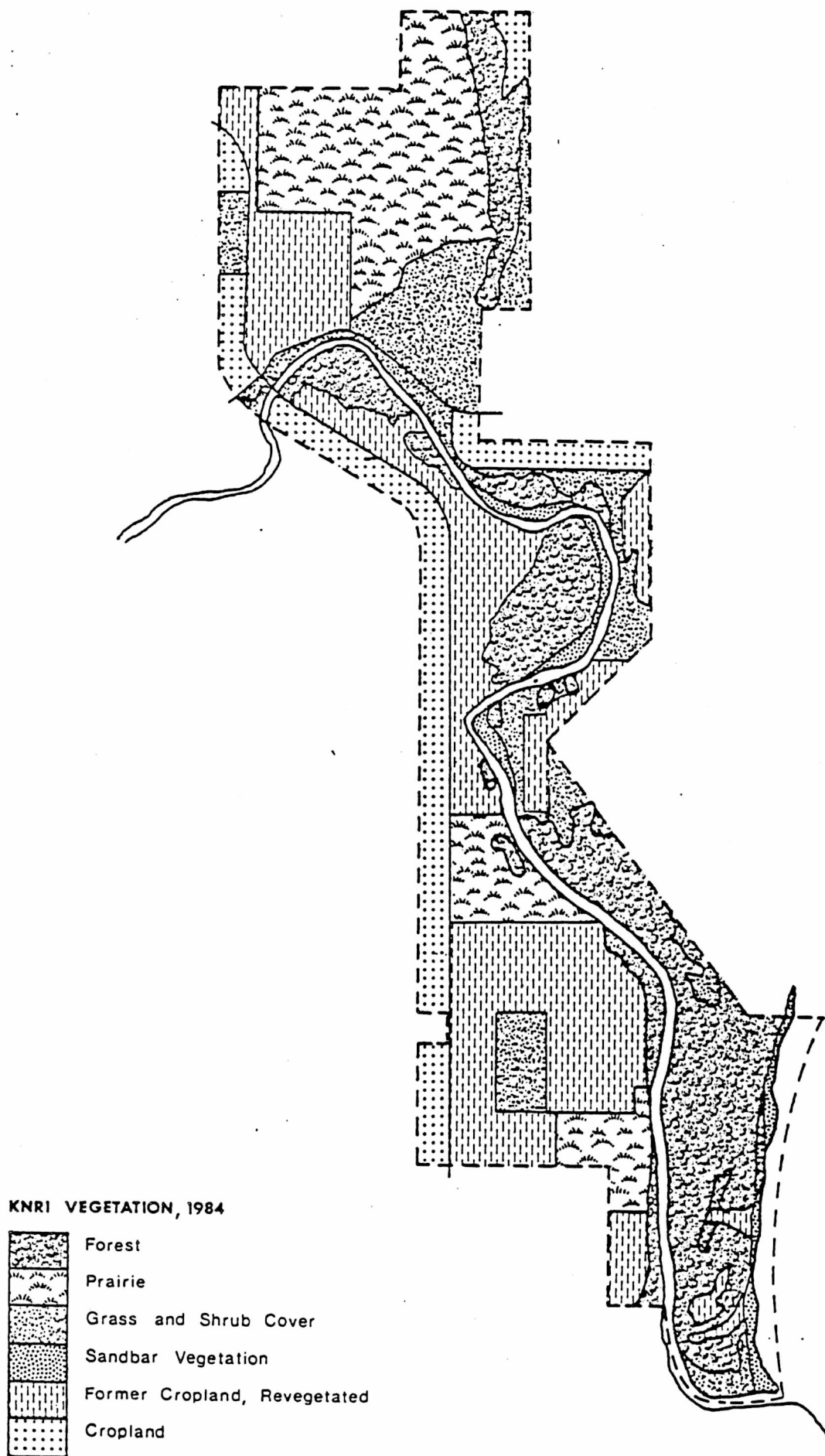


Fig. 3. Vegetation cover areas for burning zones at KNRI (from Clambey 1985).

Collecting Artifacts

Artifact collection should generally be scheduled during spring and early summer when ground surface visibility is maximal and the density of ground-obscuring vegetation is minimal. Intensive surface artifact collection should be carefully spatially controlled in order to increase the research value of the resulting collections. For the major village sites, collection should occur in 10 meter square grid units tied into the existing grid coordinate systems previously used at the sites. For cultivated sites and less prominent sites, collection grid units might be increased in size to 20-meter squares, also tied to previously applied grid coordinate systems.

Intensive surface artifact collection should be accompanied by proper cleaning, sorting, classification, cataloging, and curation of the materials to maximize their future analytical value. Artifact collections should be considered a valuable source of data about the cultural content of the sites as well as spatial structure within individual sites. Such information will prove useful in planning future subsurface or surface investigations at specific sites. Data presented in Ahler and Benz (1980:Tables 4 and 7) can be used as a guide concerning the types of artifacts expected to occur in major village locations. Similar data presented in Lovick and Ahler (1982:Table 9) provide relevant information for artifact content in less prominent villages and other types of sites. Because cultivation has not occurred for several years and previous surface collections have occurred, total artifact densities now present on the surface may be somewhat lower than the density values reported in Ahler and Benz (1980) and Lovick and Ahler (1982).

If a prescribed burn occurs at known archeological sites in the KNRI, detailed examination of the ground surface should be conducted after the burn and controlled postburn collection and attendant processing of visible artifacts should occur. Ideally, the collection process should be scheduled after one or more episodes of precipitation, which will tend to wash down the charred debris and enhance surface artifact visibility. Analysis of postburn artifacts should focus on evaluating the negative effects on the collected materials, relative to expectations outlined in this study and in other relevant information sources. Such before and after analysis of artifacts at KNRI can provide additional valuable information on fire impacts and guide fire management policy at specific sites by the National Park Service.

Other Treatment Considerations/Constraints

Environmental:

A major environmental constraint on a prescribed burn program at KNRI is air quality. The historic site is immediately north of and adjacent to Stanton, a town of slightly over 800 people. Prevailing northwesterly winds during most months of the year could create significant health and aesthetic problems during prescribed burns of tracts adjacent to the town.

It is possible that frequent burns immediately adjacent to the Knife River may result in somewhat accelerated bank erosion, primarily depending upon heavy precipitation during the postburn period.

Multiple Use:

The short-term impact on visual appeal and recreational activity at the site should be considered before determining the total amount of land to be burned during any season.

Economic:

Prescribed burning comprises one of the most economical tools available for land management. Investment in equipment is essentially not a consideration since it is the same as that required for fire suppression. If there is not adequate equipment for a burning program, then there is not adequate equipment for rapid, on-site fire suppression.

Personnel costs may be significant if burn crews are to be hired. However, this should be unnecessary if cooperative agreements can be negotiated with nearby federal, state, and local agencies.

Some initial costs may be entailed with construction of firebreaks. Our proposed burning plan uses existing roads, trails, and natural firebreaks wherever possible to avoid environmental impacts and reduce expenses.

Operational:

The gently rolling terrain and trail system of KNRI does not provide any significant constraints to access. The existing small staff and limited equipment at KNRI comprises an operational constraint which is inadequate to engage in a burn program and meet its normal operational responsibilities. Even with the proposed expanded staffing to 8.3 (Holm, 1986b), it will probably be necessary to "borrow" personnel and equipment from nearby agencies and facilities in order to safely conduct a burn program.

Administrative:

A prescribed burn program will be subject to constraints imposed by the primary mission of KNRI and existing policy of the National Park Service regarding fire and archeological resources.

Legal:

Open burning in North Dakota is subject to regulation by the State Health Department. An open burning variance must be obtained from that department prior to any prescribed burn operation (See Appendix 6 - Sample permit application and variance)

Vegetation Management Objectives

- 1) Remove natural fuels accumulating since establishment of KNRI, thus reducing wildfire risk to the park and adjacent private property.
- 2) Encourage development of native prairie vegetation similar to that at the time of Mandan/Hidatsa occupancy, especially on the major village sites (Big Hidatsa, Lower Hidatsa, Sakakawea).
- 3) Discourage further development of riparian woodland, established exotic cool season grasses, and noxious plant species (i.e., poison ivy).
- 4) Prepare exposed sites for possible reseeding of native grasses.
- 5) Minimize negative impacts on resident wildlife.

Fire Prescription

Residual fuel loads, consisting mainly of down and dead grasses, were measured on grassland tracts at KNRI during August, 1988 (Table 7). Average fuel loads varied from 3488 (SD = 1113, range 2292 - 5612) kg/ha in crested wheatgrass (Sakakawea Pasture) to 6926 (SD = 1833, range 4792 - 9792) kg/ha in smooth brome (Borner Cultivated). Total herbage and mulch accumulations on other unburned grasslands in western North Dakota have ranged from 7280 to 9408 kilograms per hectare. (Dix, 1960). Consequently, we recommend the following specific vegetation management goals:

Specific Goals

- 1) Remove litter accumulations of 3000 - 6000 kg/ha.
- 2) Create conditions encouraging development of native prairie grasses such as big bluestem, sideoats grama, and green needlegrass.
- 3) Reduce exotic cool season grasses such as Kentucky blue grass and smooth brome.
- 4) Discourage reproduction of weedy annuals on former village sites, possibly by encouraging replacement with native species to some extent.
- 5) Discourage further development of riparian forest dominated by cottonwood, green ash and American elm. Discourage encroachment of woody shrubs, especially buffaloberry, chokecherry, western snowberry, and wild rose into adjacent grassland.

Table 7. Fine fuel loads (kg/ha) from vegetation clippings at Knife River Indian Villages NHS, Fall, 1988.

Location	Mean	Range	95% CI	N
Borner Cultivated (Smooth Brome)	6926	4812-9712	3331-10521	10
Big Hidatsa Pasture (Native Prairie)	3968	1612-7466	781-7156	10
Smith-Russell (Crested Wheat)	3498	2292-5612	1334-5662	10
Buchfink Cultivated (Brome/Alfalfa)	5944	3732-10132	1521-10367	10

Desired Fire Behavior:

Desired fire behavior at KNRI is based on the assumption that a relatively quick (but hot) burn will minimize impact on surface archeological resources, and also accomplish the desired impact on vegetation. This, of course, is contingent on conditions warranting safe control as well. The major features of a desirable fire, as discussed in Pyne (1984) and Andrews and Rothermel (1982), results in minimum heat production at the soil surface:

Rate-of-Spread - 200-800 feet per minute
 Fire Intensity - Under 300 Btu/ft/s
 Heat per Unit Area - Under 200 Btu/sq ft
 Flame Length - Under 8 ft

The lower range of conditions (e.g., flame length under 4 ft) can be expected in grass cover under light wind conditions. However, fire behavior will be more extreme with higher temperatures and winds, along with heavier fuels (e.g., shrub patches).

Required Environmental Conditions

Season:

Most prescribed burning of grasslands in the northern Great Plains has been conducted during spring, usually April to June (Kirsch and Kruse 1972, Fritzell 1975, Kruse and Piehl 1985, Higgins 1986). Such burns result in a certain amount of nest destruction for ground-nesting birds. However, many avian species readily reneest and excessive mortality of eggs and young can be alleviated by burning as early in the season as possible, burning smaller blocks, and avoiding annual burns of the same tract.

May-June burns tend to invigorate native grasses and suppress woody shrubs. Towne and Owensby (1984) reported that early spring burns will tend to increase species diversity, while late spring burns will increase total herbage and encourage big bluestem and indiangrass. Svedarsky et al. (1986) indicated that late spring burns are more injurious to Kentucky bluegrass (*Poa pratensis*) and trembling aspen (*Populus tremuloides*) because their carbohydrate reserves are lower at that time.

Weather:

1) Prescribed burns should be conducted under conditions most likely to result in desired and controllable fire behavior (See Desired Fire Behavior). Thus, wind and humidity conditions which promote a relatively fast, hot fire will have the desired impact on vegetation while minimizing exposure of heat to surface archeological resources. Fire under a no-wind condition would increase burn duration, increase labor costs, and potentially damage non-target biota and archeological resources (Higgins et al. 1989a). Furthermore, experience indicates

that under such conditions, there is greater probability of fire-generated wind, changes in fire direction, and firewhirls.

2) Burns should normally be conducted during the early afternoon. Although winds are generally higher, they also tend to be more constant and predictable than in early morning.

3) Burns should not be conducted when a frontal passage is forecast for anytime during the planned fire. Such conditions, with accompanying wind changes, can result in backfires turning into uncontrolled headfires with dangerous safety implications.

4) Recommended weather conditions for prescribed burns at KNRI are based on discussions in Svedarsky and Sando (1977), Wright and Bailey (1980), and current practices on regional natural areas and refuges (Higgins et al. 1989a), with slight modification to minimize exposure of archeological resources to heat. These conditions are:

Wind: 16 - 32 km/hr (10 - 20 MPH)

Humidity: 20 - 40%

Temperature: 20 - 34 C (70 - 90 F)

5) Fuel moisture is generally minimal during mid-afternoon. Wright and Bailey (1982:392) recommend a preferred range of fine fuel moisture of 7 to 20 percent. Such conditions should be monitored if significant precipitation has occurred recently and there are doubts about fuel moisture. However, in grassland, fine-fuel moisture may reach equilibrium in as little as one hour following precipitation (Britton et al. 1973).

Burning Procedures

Preburn Tasks:

1) Conduct survey of tract(s) under consideration for surface artifact collection. The length of time required for a thorough survey and collection should be considered in the burning program.

2) Obtain burn permit from Environmental Health Section, North Dakota State Department of Health, Missouri Office Building, 1200 Missouri Avenue, Bismarck, North Dakota 58505.

3) Prepare news release on burn program and/or specific burn plans and dates (optional - consistent with NPS policy).

4) Notify local law enforcement agencies, fire department, and adjacent landowners on specific burn plans and dates.

5) Construct adequate firebreaks. Existing roads and trails at KNRI may be used as firebreaks (Figure 2). Large tracts of continuous grassland may be

subdivided with mowed firebreaks or by burning out strips between twin wetlines (Martin et al., 1977). These strips, generally 20-50 feet wide, can be established the preceeding fall or in early spring while the ground is still frozen and not as subject to excessive vehicle damage. Mowed firebreaks should be thoroughly wetted down just prior to the burn (Martin et al., 1977).

Ignition Technique:

Prescribed burning in grasslands generally involves use of back fires and flank fires along firebreaks. After the back and flank fires have burned in 100-150 feet, a head fire may be set (Kruse and Piehl, 1985; Svedarsky et al., 1986; Wright and Bailey, 1980).

Ignition Methods:

The drip torch is the most commonly used ignition method in grassland burning. Other methods, e.g. flares, flamethrowers, may be equally acceptable. The main principle is to complete the back and flank firing as quickly as possible, thus surrounding the treatment area with a black, unburnable barrier. The more quickly and efficiently this task is accomplished, the fewer containment problems there will be with a wind shift.

Burning Frequency:

Frequency of burns will depend on fuel loads and vegetative composition. Well-drained native prairie (Big Hidatsa Pasture, Grannis Uncultivated, Sakakawea Pasture, Buchfink Pasture) may not require burning at intervals greater than 4 - 5 years unless there is significant invasion of shrubs. Revegetated cropland, e.g. Borner, Smith-Russell, should be subjected to more frequent burns (possibly every 2 - 4 years) in order to reduce established exotic species. Tracts with significant invasion of shrubs should be burned annually to semiannually, contingent on adequate fuel accumulation, in order to ensure topkills and inhibit suckering.

Pre-Burn Monitoring:

The success of a prescribed burn program can be evaluated by establishing permanent plots or line transects to be sampled annually. The experimental and adjacent control (unburned) plots can be sampled annually in the fall to monitor both the effects of prior burns, and provide pre-burn data for the following spring. Specific types of vegetation data to be taken would include plant cover, plant density, plant frequency, plant mortality, plant biomass, and fuel load. Specific methodologies for such sampling can be found in Bunting et al. (1987) and Gysell and Lyon (1980).

If vegetative data have been acquired the preceeding fall, they should suffice for spring pre-burn monitoring. The only additional spring vegetation data needed would be fuel moisture. This may be especially important in tracts with significant woody growth and should be measured a day or two prior to the proposed burn. Fuel moisture may be determined by taking weights of clipped

samples, oven-drying, and weighing again. Weather forecasts and meteorological conditions must be monitored prior to the proposed burn (See Required Environmental Conditions).

Burning Plan and Report

A burning plan should be prepared prior to each prescribed burn. This is a written document outlining what needs to be done to yield a successful project conforming to the overall fire management plan. It may also include a section on postburn evaluation which discusses what the fire accomplished, actual fire behavior, fuel moisture and weather conditions, costs, and general observations and future recommendations. Appendix 6 includes a combined burn plan and report form modified from a plan developed for prescribed burns by the Minnesota Department of Natural Resources.

Evaluation

A burn report should be prepared following the fire. This should include information on what the fire accomplished, e.g. exposure of mineral soil, percent of treated area affected, top kill of shrubs. A series of photo stations, both closeup and landscape portraits, may be extremely useful in documenting habitat changes due to fire. General fire behavior should be recorded, i.e. approximate average flame height, average flame length (distance between tip of flame and ground midway in the zone of flaming), and rate of spread (Rothermel and Rinehart, 1983). Fall vegetation sampling (See Pre-Burn Monitoring) will be important in providing trend data requisite to long-term evaluation. Parameters to be considered would include plant cover, plant density, plant frequency, plant mortality, plant biomass, and fuel load.

An archeological reconnaissance should be conducted after each burn to assess the impact on surface artifacts (See Treatment Considerations/Constraints). This will be especially important for burns conducted at the major village sites. Such comparisons of large samples of artifacts from pre- and post-burn periods can provide additional valuable information on burning impacts that can guide future management decisions.

Alternatives to Burning Programs

Given present environmental conditions at KNRI, it is unlikely that prescribed burning can accomplish all of the necessary or desirable vegetation management goals throughout the entire site without some negative impacts. We note several situations where fire probably is not a good tool to use at the present time. First, the fuel loads in the riparian woodland areas are high enough to be difficult to control safely unless large firebreaks are constructed with associated damage to surface soils. Furthermore, these areas contain large stands of poison ivy, which should not be burned because of safety and legal considerations. Given these

limitations or unknowns, we recommend that several alternatives to large-scale burning be considered for these sites:

1) Small tracts dominated by exotic species may be subjected to chemical treatment and reseeded with native grasses.

2) Riparian woodland, or the encroachment of woody vegetation on uplands may be reduced, if desired, by logging. Areas cleared of trees and shrubs should discourage growth of poison ivy, which appears to do best in partial shade or along edges of woodland openings. However, the riparian area is an important wildlife habitat at KNRI and may also reduce bank erosion. Consequently, efforts to reduce woodland habitat should be considered carefully before large-scale changes are made.

3) Regrowth of woody vegetation may be reduced by the introduction of grazing by species compatible to the theme of KNRI - horses or bison. However, the trampling activities of large animals (e.g., cattle, horses, bison) are capable of causing substantial damage to chipped stone artifacts (cf. Knudson 1979) and presumably could severely damage less durable artifacts such as bone and pottery. For this reason, large animals should be restricted at least from the major villages sites where artifact densities are highest.

4) Weedy annuals on the major village sites may be reduced by less frequent mowing and by cutting at a greater height to avoid disturbing the soil surface (Clambey 1985)

5) Areas of dense poison ivy stands may be reduced by clearing or thinning riparian woodlands and repeated treatment by chemical herbicides. The extent of chemical use can be minimized by spot-spraying individual plants or areas over several years, particularly in areas where plants may be stressed by exposure to full sunlight and competition with invading grasses.

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APPENDIX 1

RECORDED VARIABLES

This section outlines: (1) the variables employed for artifacts in the preburn and postburn data collection phases of this study, and (2) the data coding and reporting format.

Preburn, burn, and postburn data were systematically recorded for each item used in the controlled burn experiment. These data were first recorded by hand on paper and later were entered into a microcomputer database program for purposes of summarization and analysis. The complete data set collected on the test materials is reproduced in Appendix 2. A series of 21 variables is incorporated into the coded data set. The full list is provided below, with the variable name presented first followed by the variable label used in the data file and in Appendix 1b in parentheses:

Independent Variables:

- site number (SITE)
- plot number (PLOT)
- sample number (SAMPLE)
- material code (MATCODE)
- material name (MATNAME)
- unique number (UNIQUE)
- 2 cm temperature (2CMTEMP)
- 10 cm temperature (10CMTEMP)
- burn duration (DURA)

Dependent Variables:

- color before (COLBEFORE)
- color after (COLAFTER)
- color change (COLCHANGE)
- weight before (WTBEF)
- weight after (WTAFT)
- weight change (WTCHA)
- fracture (FRACT)
- fracture type (FRTYP)
- scorching (SCORCH)
- charring (CHARR)
- recovery (LOSS)
- commentary (COMMENT)

The first six variables serve as a means of describing and organizing the sample materials. The site number (SITE) refers to the location of the experiment (i.e., at Oakville Prairie tract coded as 1). The plot number (PLOT) designates the

particular subdivision of the larger site (i.e., the Oakville Prairie experimental burn plots 1-4). Within each plot, artifacts were arranged within a series of 30 batches or samples, each containing one artifact of each type. Each sample location was assigned a discrete sample number (SAMPLE) identifying its precise location within the larger site and plot (see Figure 1) (Oakville Prairie samples were numbered sequentially 001-120). Each of the raw materials was assigned both a numeric material code (MATCODE) and material name (MATNAME) (e.g., natural rock cobbles were coded 01 for NATROCK). Finally, a six-digit unique number designation (UNIQUE) combining both the sample number and material code number (e.g., 001- 01) serves to identify each individual item placed in the burn experiment.

The next three independent variables provide data regarding specific burn conditions within each plot. Maximum recorded temperature values for each plot in degrees Celsius (°C) at 2 cm above ground (2CMTEMP) and at 10 cm above ground (10CMTEMP) were assigned and coded for each item according to its plot association. An estimate of the burn duration (DURA), in minutes, was made for an unspecified point location within each sample plot, and this value was assigned to each item according to its plot association.

The following is a list of variable names, variable labels, variable codes, and code format explanation used in the KNRI prescribed burning experiment:

Variable Name (Variable Label)		Code and Explanation
Site Number (SITE)	1	Oakville Prairie tract
Plot Number (PLOT)	1	Burn Plot 1 (SE, surface)
	2	Burn Plot 2 (NE, surface)
	3	Burn Plot 3 (NW, subsurface)
	4	Burn Plot 4 (SW, surface, enhanced fuel load)
Sample Number (SAMPLE)	001-120	assigned sample numbers in four burn plots
Material Code (MATCODE)	01	natural rock cobble (NATROCK)
	02	Knife River flint cobble (KRFCOBBLE)
	03	Knife River flint flake (KRFFLAKE)
	04	Knife River ware body sherd (POTTERY)
	05	<i>Bos</i> sp. rib fragments (BONE)
	06	mussel shell fragments (SHELL)
	07	balsa wood (WOODBALSA)
	08	birch wood (WOODBIRCH)
	09	wood charcoal (CHARCOAL)

10	conical lead fishing sinker (LEADCONE)
11	winged lead fishing sinker (LEADWING)
12	No. 10 "Crow" glass bead (GLASSBEAD)
Material Name (MATNAME)	see names and labels associated with the codes, above
Unique Number (UNIQUE)	xxx-xx unique identification number produced by combining three digit sample number with two material code number (e.g., 001-01, 001-02, 001-03, etc.)
2 Cm Temperature (2CMTEMP)	xxx maximum fire temperature reached at 2 cm above level in burn plot recorded in degrees Celsius (°C)
10 Cm Temperature (10CMTEMP)	xxx maximum fire temperature reached at 10 cm above ground surface in burn plot recorded in degrees Celsius (°C)
Burn Duration (DURA)	xxx estimated maximum burn duration time in minutes for a point location within the plot
Color Before	preburn Munsell soil color or rock color (COLBEFORE) designation (e.g., 10YR6/6) for the surface of the artifact; in cases where multiple colors are present, the predominant ones are recorded as a color string (used for material codes 01-06)
Color After	postburn Munsell soil color or rock color (COLAFTER) designation (e.g., 10YR6/6) for the surface of the artifact; in cases where multiple colors are present, the predominant ones are recorded as a color string (used for material codes 01-06)
Color Change (COLCHA)	blank no data 0 no change in Munsell color value +/- 1-7 maximum positive (+, lighter) or negative (-, negative) change in Munsell color value in preburn and postburn data sets (used for material codes 01-06); 0 color change absent, or 1 color change present (for material codes 07-12)
Weight Before (WTBEF)	blank no data xxx.x preburn artifact weight (0.1 g) (used for materials codes 01-06)
Weight After	blank no data

(WTAFT)	xxx.x postburn weight (0.1 g) (used for material codes 01-06)
Weight Change (WTCHA)	blank no data 0 weight change absent (<0.2 g change) 1 weight change present (>0.2 g change) (used for material codes 01-06)
Fracture (FRACT)	blank no data 0 fracture absent 1 fracture present
Fracture Type (FRYTP)	blank no data 0 none 1 crazing/shrinkage cracks 3 potlidding/spalling 5 disintegration (structural breakdown) 6 melting (slight deformation) 7 melting (full deformation) 8 miscellaneous (usually a simple transverse break)
Scorching (SCORCH)	blank no data 0 none 1-100 estimated percentage of exposed artifact surface discolored (toward brown) or altered (subtractive process for material codes 05-09) (additive process for material codes 01-04 and 10-12)
Charring (CHARR)	blank no data 0 none 1-100 estimated percentage of exposed artifact surface blackened (material class 05); estimated percentage of exposed artifact surface blackened and volume lost (material class 07-08), estimated volume lost (material class 09)
Recovery (LOSS)	blank no data 0 artifact found 1 artifact absent and presumed lost 2 artifact absent and presumed consumed by fire
Commentary (COMMENT)	salient information concerning preburn or postburn artifact condition

APPENDIX 2

RAW DATA FOR ARTIFACT MATERIALS INCLUDED IN THE
EXPERIMENTAL PRESCRIBED BURN AT THE OAKVILLE
PRAIRIE NATURAL HISTORY AREA, NORTH DAKOTA

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988.

PL	SAM	MAT	2CM	10CM							COL	WT	WT	WT	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR	BEFORE	COLOR	AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
1	001	01	NATROCK	177	343	0.5	10YR7/1,7/5,8/6		10YR6/6		-2	2025	2025	0	0	0	100	0	0	smoke glazing top surface
1	002	01	NATROCK	177	343	0.5	5Y3/1,4/1		10YR3/1		-1	1735	1735	0	0	0	80	0	0	smoke glazing top surface
1	003	01	NATROCK	177	343	0.5	10YR8/3,5/1,7/6		10YR5/6		-3	1161	1161	0	0	0	100	0	0	smoke glazing top surface
1	004	01	NATROCK	177	343	0.5	5Y3/1,4/1		10YR3/1,5/8		-1	1330	1330	0	0	0	100	0	0	smoke blackening glaze
1	005	01	NATROCK	177	343	0.5	10YR8/3,5/1,3/1		10YR4/4		-4	1634	1634	0	0	0	100	0	0	smoke blackening glaze
1	006	01	NATROCK	177	343	0.5	5Y2.5/2,10YR5/3		10YR3/1		-2	2684	2684	0	0	0	0	0	0	only slight color change
1	007	01	NATROCK	177	343	0.5	10YR8/4,5/1,7/6		10YR5/8,5/4,3/2		-5	1634	1634	0	0	0	100	0	0	smoke glazing
1	008	01	NATROCK	177	343	0.5	5Y6/1,6/2		2.5Y5/4		-1	822	822	0	0	0	100	0	0	grass impr.,olive smoke
1	009	01	NATROCK	177	343	0.5	5Y4/1		5Y4/2		0	1334	1334	0	0	0	50	0	0	more olive gray
1	010	01	NATROCK	177	343	0.5	10YR8/3,5/1,7/6		10YR3/4,4/2		-5	2497	2496	0	0	0	100	0	0	smoke glaze
1	011	01	NATROCK	177	343	0.5	5Y3/1,10YR6/8		5Y3/1,10YR6/8		0	1407	1407	0	0	0	20	0	0	one patch smoke glaze
1	012	01	NATROCK	177	343	0.5	2.5Y5/1		5Y4/1		-1	1854	1854	0	0	0	100	0	0	darker gray
1	013	01	NATROCK	177	343	0.5	10YR7/4,8/4		10YR5/4		-3	2437	2437	0	0	0	100	0	0	dark yellow brown
1	014	01	NATROCK	177	343	0.5	10YR8/2,6/1,7/6		10YR4/6		-4	2136	2136	0	0	0	95	0	0	yellow brown glaze
1	015	01	NATROCK	177	343	0.5	10YR8/4,6/1		10YR6/4		-2	1873	1873	0	0	0	75	0	0	yellow brown glaze
1	016	01	NATROCK	177	343	0.5	10YR8/2,7/4		10YR4/4		-4	2834	2834	0	0	0	95	0	0	grass impress., y/b smoke
1	017	01	NATROCK	177	343	0.5	5Y4/1		5Y3/1		-1	1812	1812	0	0	0	100	0	0	smoke glaze
1	018	01	NATROCK	177	343	0.5	5Y5/2		10YR3/2,3/3		-2	4106	4106	0	0	0	100	0	0	blackening,grass impress.
1	019	01	NATROCK	177	343	0.5	5Y4/1		5Y3/1,3/2,4/2		-1	1789	1789	0	0	0	100	0	0	olive gray smoke
1	020	01	NATROCK	177	343	0.5	10YR8/3,7/6,5/1		10YR4/4		-4	3632	3632	0	0	0	100	0	0	y/b smoke top
1	021	01	NATROCK	177	343	0.5	5Y4/1		5Y4/2		0	3472	3472	0	0	0	100	0	0	olive gray,black soot
1	022	01	NATROCK	177	343	0.5	10YR4/1,7/3		10YR4/3		-3	2465	2465	0	0	0	20	0	0	small patch glaze
1	023	01	NATROCK	177	343	0.5	10YR8/4,7/1,2.5YR6/6		10YR4/4		-4	1925	1925	0	0	0	90	0	0	10YR4/4 glaze
1	024	01	NATROCK	177	343	0.5	5Y4/1		5Y4/1		0	1045	1045	0	0	0	0	0	0	no apparent change
1	025	01	NATROCK	177	343	0.5	5Y4/1,4/2		5Y4/1,4/2		0	2167	2167	0	0	0	20	0	0	5Y2.5/2 smoke blackening
1	026	01	NATROCK	177	343	0.5	10YR4/1,7/2,8/6		10YR4/1,7/2,8/6		0	2504	2504	0	0	0	10	0	0	10YR3/2 smoke blackening
1	027	01	NATROCK	177	343	0.5	10YR8/4,5/2		10YR4/4		-4	2303	2303	0	0	0	100	0	0	smoke blackening,glaze
1	028	01	NATROCK	177	343	0.5	5Y4/1		5Y3/2,4/2		-1	2639	2639	0	0	0	80	0	0	olive gray smoking
1	029	01	NATROCK	177	343	0.5	10YR4/1,8/3		10YR5/6		-3	1525	1525	0	0	0	100	0	0	y/b smoke glaze
1	030	01	NATROCK	177	343	0.5	10YR6/1,8/4		10YR4/3,4/4		-4	1984	1984	0	0	0	100	0	0	y/b smoke, ochre st. dim.
2	031	01	NATROCK	399	399	0.5	5Y4/1		5Y4/2,10YR4/2		0	2924	2923	0	0	0	100	0	0	gray/brown smoking
2	032	01	NATROCK	399	399	0.5	10YR6/1,8/4		10YR4/3,5/1,5/3		-4	3226	3225	0	0	0	80	0	0	smoked
2	033	01	NATROCK	399	399	0.5	5Y3/1,4/1		10YR3/1,3/2		-1	3023	3023	0	0	0	90	0	0	olive smoked
2	034	01	NATROCK	399	399	0.5	10YR5/1,8/3		10YR5/1,8/3		0	2456	2456	0	0	0	0	0	0	smoke glaze hard to detect
2	035	01	NATROCK	399	399	0.5	10YR6/1,8/3		10YR6/1,8/3		0	1597	1597	0	0	0	0	0	0	smoke glaze hard to detect
2	036	01	NATROCK	399	399	0.5	10YR8/4,8/6,6/1		10YR5/6		-3	1780	1779	0	0	0	100	0	0	y/b smoke glazing
2	037	01	NATROCK	399	399	0.5	5Y3/1,4/1		5Y3/1,4/1,10YR3/2		0	2340	2340	0	0	0	50	0	0	slt. dk. one cort. surf.
2	038	01	NATROCK	399	399	0.5	10YR7/2,5/1,8/6		10YR6/6		-2	2020	2020	0	0	0	100	0	0	lt. smoke glaze
2	039	01	NATROCK	399	399	0.5	5Y3/2		5Y3/2,2.5/2		0	2196	2196	0	0	0	0	0	0	hard to detect color change
2	040	01	NATROCK	399	399	0.5	5Y3/1		5Y3/1,2.5/2		0	2113	2113	0	0	0	100	0	0	darker,smoking
2	041	01	NATROCK	399	399	0.5	5Y4/1		5Y4/1		0	3543	3543	0	0	0	0	0	0	no apparent change
2	042	01	NATROCK	399	399	0.5	10YR8/2,8/3		10YR5/4		-3	2049	2049	0	0	0	100	0	0	brown smoke glazing
2	043	01	NATROCK	399	399	0.5	5Y4/1		10YR3/2,4/1		-1	3608	3608	0	0	0	100	0	0	gray smoke glazing
2	044	01	NATROCK	399	399	0.5	10YR7/4,8/4		10YR4/4		-4	2784	2784	0	0	0	100	0	0	dk. smoke glazing/blacken
2	045	01	NATROCK	399	399	0.5	10YR8/4,5/1,5/8		10YR7/4		-1	3357	3357	0	0	0	100	0	0	sl. darker, smoke
2	046	01	NATROCK	399	399	0.5	10YR8/3,7/2,6/8		10YR5/4		-3	2802	2802	0	0	0	50	0	0	sl. smoke tint
2	047	01	NATROCK	399	399	0.5	5Y4/1		5Y4/1		0	1666	1666	0	0	0	0	0	0	no apparent change
2	048	01	NATROCK	399	399	0.5	10YR5/1,6/6		10YR5/1,6/6,6/8		0	2508	2508	0	0	0	5	0	0	lt. black soot,sm.gl.?

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT	2CM 10CM		DURA	COLOR BEFORE	COLOR AFTER	COL	WT	WT	WT	FR	FR	SCO	CHA	LO	COMMENT
OT	PLE	CODE	MATNAME	TEMP	TEMP			CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	
2	049	01	NATROCK	399	399	0.5	5Y3/1,10YR3/1	5Y2.5/2	0	3416	3416	0	0	0	0	0	0 v. slt. color darkening
2	050	01	NATROCK	399	399	0.5	10YR7/3,4/1	10YR7/3,4/1	0	1958	1958	0	0	0	0	0	0 no apparent change
2	051	01	NATROCK	399	399	0.5	10YR8/4,6/1	10YR5/4	-3	2248	2248	0	0	0	100	0	0 y/b smoke glaze
2	052	01	NATROCK	399	399	0.5	10YR3/1,4/1	10YR3/1,4/1	0	1383	1383	0	0	0	0	0	0 sl. sm. gl. hard to detect
2	053	01	NATROCK	399	399	0.5	10YR6/2,8/3,8/6	10YR5/4	-3	2190	2189	0	0	0	100	0	0 smoke glazing
2	054	01	NATROCK	399	399	0.5	10YR4/1,5/1	10YR3/1	-2	1901	1901	0	0	0	100	0	0 smoke blackening
2	055	01	NATROCK	399	399	0.5	10YR6/1,8/2	10YR6/1,8/2	0	1984	1984	0	0	0	0	0	0 lt. sm. on carbonate
2	056	01	NATROCK	399	399	0.5	10YR8/3,6/1	10YR8/3,6/1,5/4	-3	2387	2387	0	0	0	90	0	0 soot and smoke
2	057	01	NATROCK	399	399	0.5	10YR7/4,5/1	10YR7/4,5/1	0	1425	1425	0	0	0	0	0	0 sm. haze, no color change
2	058	01	NATROCK	399	399	0.5	10YR5/1	10YR4/1	-1	1355	1355	0	0	0	60	0	0 lightly smoked
2	059	01	NATROCK	399	399	0.5	10YR7/4,4/1	10YR7/4,4/1	0	2477	2477	0	0	0	0	0	0 no apparent change
2	060	01	NATROCK	399	399	0.5	10YR5/1	10YR4/2	-1	2641	2641	0	0	0	50	0	0 smoke blackening
3	061	01	NATROCK	316	288	0.5	10YR4/1	10YR5/2	+1	4462	4462	0	0	0	40	0	0 lt. smoke glazing?
3	062	01	NATROCK	316	288	0.5	10YR6/2,7/3	10YR6/2,7/3,5/4	-2	2062	2062	0	0	0	75	0	0 smoke glazing
3	063	01	NATROCK	316	288	0.5	10YR7/3,5/1	10YR7/3,5/1	0	2520	2520	0	0	0	0	0	0 no apparent change
3	064	01	NATROCK	316	288	0.5	10YR7/3,5/1	10YR7/3,5/1	0	2715	2715	0	0	0	0	0	0 no apparent change
3	065	01	NATROCK	316	288	0.5	10YR7/3,4/1	10YR7/3,4/1	0	1657	1657	0	0	0	0	0	0 no apparent change
3	066	01	NATROCK	316	288	0.5	10YR7/3,4/1	10YR7/3,4/1	0	2519	2519	0	0	0	0	0	0 no apparent change
3	067	01	NATROCK	316	288	0.5	10YR4/1,7/4,8/6	10YR4/1,7/4,8/6	0	2133	2133	0	0	0	0	0	0 no apparent change
3	068	01	NATROCK	316	288	0.5	10YR5/1	10YR4/1	-1	1281	1281	0	0	0	0	0	0 shade darker smoke/soil?
3	069	01	NATROCK	316	288	0.5	10YR6/2,7/4	10YR6/2,7/4	0	3053	3053	0	0	0	0	0	0 no apparent change
3	070	01	NATROCK	316	288	0.5	10YR7/4,8/2,5/1	10YR7/4,8/2,5/1	0	1665	1665	0	0	0	0	0	0 no apparent change
3	071	01	NATROCK	316	288	0.5	10YR5/1,5/2	10YR5/1,5/2	0	2257	2257	0	0	0	0	0	0 no apparent change
3	072	01	NATROCK	316	288	0.5	10YR7/4,8/4,5/1	10YR7/4,8/4,5/1	0	1959	1959	0	0	0	0	0	0 no apparent change
3	073	01	NATROCK	316	288	0.5	10YR4/1,4/2	10YR4/1,4/2	0	1471	1471	0	0	0	0	0	0 no apparent change
3	074	01	NATROCK	316	288	0.5	10YR8/3,7/4,5/1	10YR8/3,7/4,5/1	0	1444	1444	0	0	0	0	0	0 no apparent change
3	075	01	NATROCK	316	288	0.5	10YR5/1,5/2	10YR5/1,5/2,3/1	-2	2359	2359	0	0	0	0	0	0 30% smoke blackening
3	076	01	NATROCK	316	288	0.5	10YR5/1	10YR5/1	0	3483	3483	0	0	0	0	0	0 no apparent change
3	077	01	NATROCK	316	288	0.5	10YR8/4,8/6,5/1	10YR8/4,8/6,5/1	0	2320	2320	0	0	0	0	0	0 no apparent change
3	078	01	NATROCK	316	288	0.5	10YR8/4,5/1	10YR8/4,5/1	0	1482	1482	0	0	0	0	0	0 no apparent change
3	079	01	NATROCK	316	288	0.5	10YR6/6,6/2	10YR6/6,6/2	0	1246	1246	0	0	0	0	0	0 no apparent change
3	080	01	NATROCK	316	288	0.5	10YR7/6,7/2,5/1	10YR7/6,7/2,5/1	0	3826	3826	0	0	0	0	0	0 no apparent change
3	081	01	NATROCK	316	288	0.5	10YR4/1,8/2	10YR5/4	-3	2561	2561	0	0	0	60	0	0 60% smoke glaze
3	082	01	NATROCK	316	288	0.5	10YR5/1,8/2,2.5Y5/8	10YR5/1,8/2,2.5Y5/8	0	2119	2119	0	0	0	0	0	0 no apparent change
3	083	01	NATROCK	316	288	0.5	10YR8/2,7/6	10YR8/2,7/6	0	1827	1826	0	0	0	0	0	0 no apparent change
3	084	01	NATROCK	316	288	0.5	10YR8/4,2/2	10YR8/4,2/2	0	3245	3245	0	0	0	0	0	0 no apparent change
3	085	01	NATROCK	316	288	0.5	10YR3/1,8/3	10YR3/1,8/3	0	2346	2346	0	0	0	0	0	0 no apparent change
3	086	01	NATROCK	316	288	0.5	2.5Y5/2	2.5Y5/2	0	1375	1375	0	0	0	0	0	0 no apparent change
3	087	01	NATROCK	316	288	0.5	10YR5/1	10YR5/1	0	1126	1126	0	0	0	0	0	0 no apparent change
3	088	01	NATROCK	316	288	0.5	2.5Y4/0,5/0	2.5Y4/0,5/0	0	1741	1741	0	0	0	0	0	0 no apparent change
3	089	01	NATROCK	316	288	0.5	10YR8/2,2/1	10YR8/2,2/1	0	1906	1906	0	0	0	0	0	0 no apparent change
3	090	01	NATROCK	316	288	0.5	10YR6/1,8/1,2.5YR6/6	10YR6/1,8/1,2.5YR6/6	0	1667	1667	0	0	0	0	0	0 no apparent change
4	091	01	NATROCK	121	399	1.0	10YR4/1,7/1	10YR4/1,7/1	0	2015	2015	0	0	0	0	0	0 no apparent change
4	092	01	NATROCK	121	399	1.0	10YR4/1,8/1	10YR4/1,8/1	0	1707	1707	0	0	0	0	0	0 no apparent change
4	093	01	NATROCK	121	399	1.0	10YR5/1	10YR4/2	-1	808	808	0	0	0	40	0	0 smoke glaze 40%
4	094	01	NATROCK	121	399	1.0	10YR6/1	10GY5/2	-1	2579	2579	0	0	0	10	0	0 smoke glaze along edges
4	095	01	NATROCK	121	399	1.0	2.5YR6/6,10YR3/1,8/1	2.5YR6/6,10YR3/1,8/1	0	2439	2439	0	0	0	0	0	0 diff. to tell due to rkco
4	096	01	NATROCK	121	399	1.0	2.5YR6/6,10YR3/1,8/1	2.5YR6/6,10YR3/1,8/1	0	1758	1758	0	0	0	0	0	0 diff. to tell due to rkco

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT	2CM	10CM				COL	WT	WT	WT	FR	FR	SCO	CHA	LO		
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR BEFORE	COLOR AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
4	097	01	NATROCK	121	399	1.0	5YR8/2,2.5YR6/0	5YR8/2,2.5YR6/0	0	1504	1504	0	0	0	0	0	0	diff. to tell due to rkco
4	098	01	NATROCK	121	399	1.0	10YR8/1,6/2	10YR8/1,6/2	0	1304	1304	0	0	0	0	0	0	no apparent change
4	099	01	NATROCK	121	399	1.0	10YR2/1,5/1,8/1	10YR2/1,5/1,8/1	0	1324	1324	0	0	0	10	0	0	10% patch of smoke glaze
4	100	01	NATROCK	121	399	1.0	7.5YR4/0,5/0	7.5YR4/0,5/0,10YR3/3	-2	1016	1016	0	0	0	10	0	0	10% smoke blackening
4	101	01	NATROCK	121	399	1.0	2.5YR3/0,4/0	2.5YR3/0,4/0,10YR2/1,3/2	-2	2147	2147	0	0	0	10	0	0	10% smoke blackening
4	102	01	NATROCK	121	399	1.0	10YR6/3,7/3	10YR6/3,7/3	0	2413	2413	0	0	0	0	0	0	no apparent change
4	103	01	NATROCK	121	399	1.0	10YR3/1,4/1	10YR3/1,4/1,10YR3/3	0	1692	1692	0	0	0	20	0	0	20% smoke blackening
4	104	01	NATROCK	121	399	1.0	10YR8/1,3/1	10YR2/2	-6	965	965	0	0	0	80	0	0	80% smoke blackening
4	105	01	NATROCK	121	399	1.0	10YR8/1,3/1	10YR4/4	-4	1489	1489	0	0	0	100	0	0	100 smoke browning
4	106	01	NATROCK	121	399	1.0	10YR5/1,8/1	10YR5/1,8/1,10YR3/2	-5	1424	1424	0	0	0	40	0	0	40% smoke blackening
4	107	01	NATROCK	121	399	1.0	10YR8/1,8/4	10YR8/1,8/4,10YR4/6	-4	1097	1097	0	0	0	20	0	0	20% smoke browning
4	108	01	NATROCK	121	399	1.0	7.5YR4/0,10YR8/1	7.5YR4/0,10YR8/1,3/1	-5	2272	2272	0	0	0	30	0	0	30% smoke browning
4	109	01	NATROCK	121	399	1.0	10YR4/1,5/1	10YR4/1,5/1,10YR3/2	-2	1199	1198	0	0	0	20	0	0	20% smoke browning
4	110	01	NATROCK	121	399	1.0	10YR4/1,5/1	10YR4/1,5/1,10YR3/2	-2	1286	1286	0	0	0	15	0	0	15% smoke browning edges
4	111	01	NATROCK	121	399	1.0	10YR8/1,8/4	10YR8/1,8/4,10YR3/1,3/2	-5	1441	1441	0	0	0	60	0	0	60% smoke blackened/brown
4	112	01	NATROCK	121	399	1.0	10YR5/1,8/1	10YR3/2,4/4	-5	1821	1821	0	0	0	80	0	0	80% smoke browned
4	113	01	NATROCK	121	399	1.0	10YR5/2,8/1	10YR5/2,8/1,10YR4/1	-4	1422	1422	0	0	0	60	0	0	60% smoke browning
4	114	01	NATROCK	121	399	1.0	10YR5/1,8/1	10YR5/2,8/1,10YR3/2	-5	2614	2614	0	0	0	60	0	0	60% smoke browning
4	115	01	NATROCK	121	399	1.0	7.5YR5/0,6/0	7.5YR5/0,6/0,10YR4/2	-2	1213	1213	0	0	0	20	0	0	diffuse smoke
4	116	01	NATROCK	121	399	1.0	10YR6/1,5/1	10YR6/1,5/1,10YR3/4	-3	2683	2683	0	0	0	30	0	0	30% smoke glaze one edge
4	117	01	NATROCK	121	399	1.0	10YR4/1,5/1	10YR4/1,5/1,10YR3/2	-2	1885	1885	0	0	0	10	0	0	10% lt. smoke browning
4	118	01	NATROCK	121	399	1.0	10YR6/1,5/1	10YR6/1,5/1,10YR3/2	-3	1788	1788	0	0	0	40	0	0	smoke browning,grass impr
4	119	01	NATROCK	121	399	1.0	10YR8/4,4/1	10YR8/4,4/1,10YR5/4	-3	1884	1884	0	0	0	60	0	0	lt. browning,hard detect
4	120	01	NATROCK	121	399	1.0	10R6/6,10YR3/1,8/1	10R6/6,10YR3/1,8/1,3/3	-5	1177	1177	0	0	0	30	0	0	30% smoke browning
1	001	02	KRFOBBLE	177	343	0.5	10YR8/1	10YR6/6,6/8	-2	1198	1198	0	0	0	90	0	0	smoke glaze on wh. pat.
1	002	02	KRFOBBLE	177	343	0.5	10YR6/6,5/8,8/8	10YR6/1,4/6	-4	1683	1683	0	0	0	80	0	0	dk. y/b smoke glaze
1	003	02	KRFOBBLE	177	343	0.5	10YR8/1,N8	10YR4/2,7/6	-4	672	672	0	0	0	25	0	0	y/b smoke glaze
1	004	02	KRFOBBLE	177	343	0.5	10YR5/6	10YR4/6	-1	1807	1807	0	0	0	20	0	0	slightly darker, smoke
1	005	02	KRFOBBLE	177	343	0.5	10YR7/6	10YR5/6	-2	2683	2683	0	0	0	100	0	0	smoke glazing
1	006	02	KRFOBBLE	177	343	0.5	10YR6/6 Rock	10YR4/6,6/6	-2	1482	1482	0	0	0	100	0	0	smoke glazing,darker br.
1	007	02	KRFOBBLE	177	343	0.5	10YR8/2,6/8	10YR6/6,7/6	-2	1624	1624	0	0	0	60	0	0	y/b smoke glaze on wh pat
1	008	02	KRFOBBLE	177	343	0.5	10YR8/1,N8	10YR7/6	-1	359	359	0	0	0	100	0	0	y/b smoking on wh. pat.
1	009	02	KRFOBBLE	177	343	0.5	10YR8/2,6/8	10YR7/3,8/3	-1	641	641	0	0	0	100	0	0	lt. br. smoke tint
1	010	02	KRFOBBLE	177	343	0.5	10YR8/1,N9	10YR7/4,6/6	-3	1274	1274	0	0	0	100	0	0	y/b smoke, lt gray noncor
1	011	02	KRFOBBLE	177	343	0.5	10YR8/2,7/8	10YR8/2,5/6	-3	998	998	0	0	0	50	0	0	sl. more br.,smoke
1	012	02	KRFOBBLE	177	343	0.5	10YR7/8	10YR5/4	-2	1301	1301	0	0	0	100	0	0	sl. more br.,smoke
1	013	02	KRFOBBLE	177	343	0.5	10YR8/2	10YR7/3,6/6	-2	2280	2280	0	0	0	100	0	0	y/b smoking
1	014	02	KRFOBBLE	177	343	0.5	10YR6/8,5B7/1	10YR7/3,4/4	-3	1374	1374	0	0	0	100	0	0	y/b smoke glaze,gr. nocor
1	015	02	KRFOBBLE	177	343	0.5	10YR5/8,8/2	10YR8/4	0	2028	2028	0	0	0	30	0	0	sl. color change,sm. gl.?
1	016	02	KRFOBBLE	177	343	0.5	10YR8/4,6/8	10YR5/4,4/4	-4	2759	2759	0	0	0	100	0	0	y/b smoke glaze,soot
1	017	02	KRFOBBLE	177	343	0.5	10YR6/6 Rock	10YR6/6 Rock,10YR4/4	-2	1398	1398	0	0	0	10	0	0	lt. smoke haze
1	018	02	KRFOBBLE	177	343	0.5	10YR6/6 Rock,N8	10YR3/2,3/4,8/3	-5	622	622	0	0	0	100	0	0	smoke browning
1	019	02	KRFOBBLE	177	343	0.5	10YR6/6 Rock	10YR6/6 Rock	0	738	738	0	0	0	0	0	0	no apparent change
1	020	02	KRFOBBLE	177	343	0.5	10YR5/6	10YR4/6,5/6	-1	841	841	0	0	0	50	0	0	dk. br. smoke glazing
1	021	02	KRFOBBLE	177	343	0.5	10YR7/6	10YR6/4,6/6	-1	943	943	0	0	0	20	0	0	sl. dk. br. smoke
1	022	02	KRFOBBLE	177	343	0.5	10YR8/2,6/8	10YR8/3,5/8	-3	1046	1046	0	0	0	20	0	0	sl. dk. br. smoke
1	023	02	KRFOBBLE	177	343	0.5	N8	10YR8/3	0	1990	1989	0	0	0	100	0	0	smoke glaze
1	024	02	KRFOBBLE	177	343	0.5	10YR2/2,7/8	10YR2/2,3/2	-4	1678	1678	0	0	0	15	0	0	sm. glaze on edges,soot

PL	SAM	MAT		20M	100M					COL	WT	WT	WT	FR	FR	SCO	CHA	LO	
OT	PLe	CODE	MATNAME	TEMP	TEMP	DURA	COLOR BEFORE		COLOR AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
1	025	02	KRFCOBBLE	177	343	0.5	10YR2/2		10YR2/2,3/2	+1	967	967	0	0	0	40	0	0	y/b smoke haze
1	026	02	KRFCOBBLE	177	343	0.5	10YR6/8,10YR6/6 Rock		10YR5/6	-1	2620	2620	0	0	0	50	0	0	s.l. dk. br.,smoke
1	027	02	KRFCOBBLE	177	343	0.5	10YR5/8,N8		10YR4/4	-4	1047	1047	0	0	0	100	0	0	gray smoke haze,sm. glaze
1	028	02	KRFCOBBLE	177	343	0.5	10YR8/4,8/6		10YR6/4	-2	1195	1195	0	0	0	100	0	0	cortex darkened by smoke
1	029	02	KRFCOBBLE	177	343	0.5	10YR6/8,N8		10YR4/3,6/6	-4	1069	1069	0	0	0	50	0	0	smoked,soot, darkened
1	030	02	KRFCOBBLE	177	343	0.5	10YR8/8,10YR6/6 Rock		10YR4/3,4/4	-4	920	920	0	0	0	100	0	0	y/b sm. glaze,ochre dimini
2	031	02	KRFCOBBLE	399	399	0.5	10YR8/1,N8		10YR7/6	-1	580	579	0	0	0	100	0	0	lt. y/b sm. glaze on pat.
2	032	02	KRFCOBBLE	399	399	0.5	10YR7/8,2/2		10YR4/4,2/2	-3	612	612	0	0	0	15	0	0	15% cortex, no other chng
2	033	02	KRFCOBBLE	399	399	0.5	10YR3/2		10YR4/3,3/3,ctx;2/1,3/1	-1	1616	1616	0	0	0	50	0	0	lt. sm. glaze
2	034	02	KRFCOBBLE	399	399	0.5	10YR6/8,5B8/1		10YR6/8;10YR5/6	-3	770	770	0	0	0	5	0	0	lt. sm. glaze one patch
2	035	02	KRFCOBBLE	399	399	0.5	10YR6/8		10YR6/8	0	951	951	0	0	0	0	0	0	no apparent change
2	036	02	KRFCOBBLE	399	399	0.5	10YR6/8,2/2		10YR6/8,2/2	0	1636	1636	0	0	0	0	0	0	no apparent change
2	037	02	KRFCOBBLE	399	399	0.5	10YR5/8,6/8		10YR5/8,6/8	0	1309	1309	0	0	0	0	0	0	no apparent change
2	038	02	KRFCOBBLE	399	399	0.5	10YR8/3		10YR8/3,6/6	-2	1661	1661	0	0	0	10	0	0	10% lt. sm. glaze
2	039	02	KRFCOBBLE	399	399	0.5	10YR7/8		10YR7/8,6/6	-1	1759	1759	0	0	0	0	0	0	diffuse smoke haze
2	040	02	KRFCOBBLE	399	399	0.5	10YR6/8,10YR6/6 Rock		10YR6/8	0	2501	2501	0	0	0	0	0	0	no apparent change
2	041	02	KRFCOBBLE	399	399	0.5	10YR5/6,7/8,7/2		10YR5/6,7/8,7/2	0	1722	1722	0	0	0	0	0	0	no apparent change
2	042	02	KRFCOBBLE	399	399	0.5	10YR8/3		10YR8/3,7/6	-1	1444	1443	0	0	0	50	0	0	50% y/b smoke glaze
2	043	02	KRFCOBBLE	399	399	0.5	10YR2/2		10YR3/3	+1	2696	2696	0	0	0	100	0	0	dk. brown smoke glaze
2	044	02	KRFCOBBLE	399	399	0.5	10YR8/3		10YR8/3,6/4,6/6	-2	1008	1008	0	0	0	50	0	0	y/b smoke glaze
2	045	02	KRFCOBBLE	399	399	0.5	10YR2/2,7/8		10YR2/2,7/8	0	948	948	0	0	0	0	0	0	no apparent change
2	046	02	KRFCOBBLE	399	399	0.5	10YR2/2,7/6,7/8		10YR4/4	-3	1589	1589	0	0	0	100	0	0	y/b smoke glaze
2	047	02	KRFCOBBLE	399	399	0.5	10YR8/1,6/8		10YR8/3,6/8	0	2277	2277	0	0	0	20	0	0	s.l. dk. on cortex,no oth
2	048	02	KRFCOBBLE	399	399	0.5	10YR4/3,7/6		10YR4/3,7/6	0	1297	1297	0	0	0	0	0	0	lt. soot on edges
2	049	02	KRFCOBBLE	399	399	0.5	10YR5/8,6/3		10YR4/4,5/8,6/3	-2	866	866	0	0	0	20	0	0	cortex s.l. smoked
2	050	02	KRFCOBBLE	399	399	0.5	10YR2/2,6/8		10YR2/2,6/8	0	2126	2126	0	0	0	0	0	0	smoked one edge?
2	051	02	KRFCOBBLE	399	399	0.5	10YR2/2		10YR2/2,7.5YR3/0	+1	1826	1826	0	0	0	30	0	0	lt. smoked
2	052	02	KRFCOBBLE	399	399	0.5	10YR8/2,7/8		10YR4/4,7/6	-4	1574	1574	0	0	0	90	0	0	y/b smoke glaze
2	053	02	KRFCOBBLE	399	399	0.5	10YR2/2,8/4		10YR2/2,6/4	-2	882	882	0	0	0	30	0	0	30% cotrex dk.
2	054	02	KRFCOBBLE	399	399	0.5	10YR8/4,8/5		10YR7/4,6/6	-2	480	480	0	0	0	100	0	0	dk. cortex,y/b smoke glaz
2	055	02	KRFCOBBLE	399	399	0.5	10YR6/6,3/6		10YR6/6,3/6	0	2062	2062	0	0	0	0	0	0	no apparent change
2	056	02	KRFCOBBLE	399	399	0.5	10YR8/2,6/8		10YR4/4	-4	784	784	0	0	0	100	0	0	y/b smoking on cortex
2	057	02	KRFCOBBLE	399	399	0.5	10YR8/2,6/8		10YR8/2,6/8	0	701	701	0	0	0	0	0	0	no apparent change
2	058	02	KRFCOBBLE	399	399	0.5	10YR6/8,7/8		10YR5/4	-2	1078	1078	0	0	0	100	0	0	cortex dk. by smoke
2	059	02	KRFCOBBLE	399	399	0.5	10YR8/3,6/8		10YR8/3,6/8	0	1848	1848	0	0	0	0	0	0	smoked? hard to detect
2	060	02	KRFCOBBLE	399	399	0.5	N9		10YR8/4,7/6	-2	1680	1679	0	0	0	90	0	0	y/b smoke glaze on pat.
3	061	02	KRFCOBBLE	316	288	0.5	10YR5/8,7/8		10YR5/8,7/8,4/4	-3	1187	1187	0	0	0	40	0	0	40% smoke haze cortex
3	062	02	KRFCOBBLE	316	288	0.5	10YR6/6 Rock		10YR6/6 Rock	0	2089	2089	0	0	0	0	0	0	no apparent change
3	063	02	KRFCOBBLE	316	288	0.5	10YR8/1,N9		10YR8/1,N9	0	895	895	0	0	0	0	0	0	no apparent change
3	064	02	KRFCOBBLE	316	288	0.5	10YR8/8,N9		10YR8/8,N9	0	1524	1524	0	0	0	0	0	0	no apparent change
3	065	02	KRFCOBBLE	316	288	0.5	10YR7/8		10YR7/8	0	1405	1405	0	0	0	0	0	0	no apparent change
3	066	02	KRFCOBBLE	316	288	0.5	10YR8/2		10YR8/2	0	636	636	0	0	0	0	0	0	no apparent change
3	067	02	KRFCOBBLE	316	288	0.5	10YR8/2,7/6		10YR8/2,7/6	0	1054	1053	0	1	8	0	0	0	no apparent change
3	068	02	KRFCOBBLE	316	288	0.5	10YR8/2		10YR8/2	0	1043	1043	0	0	0	0	0	0	no apparent change
3	069	02	KRFCOBBLE	316	288	0.5	10YR5/8,N0		10YR5/8,N0	0	1673	1673	0	0	0	0	0	0	no apparent change
3	070	02	KRFCOBBLE	316	288	0.5	7.5YR4/6,10YR8/2		7.5YR4/6,10YR8/2	0	1608	1608	0	0	0	0	0	0	no apparent change
3	071	02	KRFCOBBLE	316	288	0.5	7.5YR4/6,10YR2/2		7.5YR4/6,10YR2/2	0	1734	1734	0	0	0	0	0	0	no apparent change
3	072	02	KRFCOBBLE	316	288	0.5	10YR2/2,5/8		10YR2/2,5/8	0	1710	1710	0	0	0	0	0	0	no apparent change

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT	2CM 10CM			DURA	COLOR BEFORE	COLOR AFTER	COL	WT	WT	WT	FR	FR	SCO	CHA	LO	COMMENT
OT	PLE	CODE	MATNAME	TEMP	TEMP				CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	
3	073	02	KRFCOBBLE	316	288	0.5	10YR4/4,6/8	10YR4/4,6/8	0	2203	2203	0	0	0	0	0	0	no apparent change
3	074	02	KRFCOBBLE	316	288	0.5	10YR8/1,N9	10YR8/1,N9	0	1478	1478	0	0	0	0	0	0	no apparent change
3	075	02	KRFCOBBLE	316	288	0.5	10YR8/1,N9	10YR8/1,N9	0	1184	1184	0	0	0	0	0	0	no apparent change
3	076	02	KRFCOBBLE	316	288	0.5	10YR8/1,N9	10YR8/1,N9	0	1756	1756	0	0	0	0	0	0	no apparent change
3	077	02	KRFCOBBLE	316	288	0.5	7.5YR4/6	7.5YR4/6	0	1301	1301	0	0	0	0	0	0	no apparent change
3	078	02	KRFCOBBLE	316	288	0.5	10YR2/2,6/8	10YR2/2,6/8	0	2129	2129	0	0	0	0	0	0	no apparent change
3	079	02	KRFCOBBLE	316	288	0.5	7.5YR4/6,10YR8/2	7.5YR4/6,10YR8/2	0	1655	1655	0	0	0	0	0	0	no apparent change
3	080	02	KRFCOBBLE	316	288	0.5	10YR2/2,7/2	10YR2/2,7/2	0	1225	1225	0	0	0	0	0	0	no apparent change
3	081	02	KRFCOBBLE	316	288	0.5	10YR3/4,7/8,8/8	10YR3/4,7/8,8/8	0	993	993	0	0	0	0	0	0	no apparent change
3	082	02	KRFCOBBLE	316	288	0.5	10YR6/8	10YR6/8	0	1677	1677	0	0	0	0	0	0	no apparent change
3	083	02	KRFCOBBLE	316	288	0.5	10YR6/8,8/4	10YR6/8,8/4	0	1896	1896	0	0	0	0	0	0	no apparent change
3	084	02	KRFCOBBLE	316	288	0.5	10YR5/8,7/8	10YR5/8,7/8	0	1610	1610	0	0	0	0	0	0	no apparent change
3	085	02	KRFCOBBLE	316	288	0.5	10YR6/8,7/8	10YR6/8,7/8	0	713	713	0	0	0	0	0	0	no apparent change
3	086	02	KRFCOBBLE	316	288	0.5	10YR8/4,3/1	10YR8/4,3/1	0	1214	1214	0	0	0	0	0	0	no apparent change
3	087	02	KRFCOBBLE	316	288	0.5	10YR5/8,7/8,4/4	10YR5/8,7/8,4/4	0	1413	1413	0	0	0	0	0	0	no apparent change
3	088	02	KRFCOBBLE	316	288	0.5	10YR8/1,6/8	10YR8/1,6/8	0	967	967	0	0	0	0	0	0	no apparent change
3	089	02	KRFCOBBLE	316	288	0.5	10YR6/8,8/4	10YR6/8,8/4	0	2015	2015	0	0	0	0	0	0	no apparent change
3	090	02	KRFCOBBLE	316	288	0.5	10YR8/8,6/6,3/1	10YR8/8,6/6,3/1	0	1448	1448	0	0	0	0	0	0	no apparent change
4	091	02	KRFCOBBLE	121	399	1.0	10YR7/1,7/2	10YR7/1,7/2,8/6	+1	481	481	0	0	0	15	0	0	smoke glaze along edges
4	092	02	KRFCOBBLE	121	399	1.0	10YR6/8,7/8	10YR6/8,7/8,2/1	-5	648	648	0	0	0	5	0	0	grass sheen
4	093	02	KRFCOBBLE	121	399	1.0	10YR6/8	10YR6/8	0	908	908	0	0	0	0	0	0	y/b pat. obscures smoking
4	094	02	KRFCOBBLE	121	399	1.0	10YR6/8,2/2	10YR6/8,2/2,3/3	-3	1402	1402	0	0	0	10	0	0	dk. smoke glazing
4	095	02	KRFCOBBLE	121	399	1.0	10YR8/2,5/8	10YR8/2,5/8,3/2	-5	1783	1783	0	0	0	40	0	0	sm. gl./bl. cortex,edges
4	096	02	KRFCOBBLE	121	399	1.0	10YR4/6	10YR4/6	0	1061	1061	0	0	0	0	0	0	cortex color may mask sm.
4	097	02	KRFCOBBLE	121	399	1.0	10YR7/2,2/2	10YR7/2,2/2,3/3	-4	1275	1275	0	0	0	20	0	0	sm. glaze on pat.
4	098	02	KRFCOBBLE	121	399	1.0	10YR8/2	10YR8/2,6/6	-2	866	866	0	0	0	10	0	0	sm. glaze on pat.
4	099	02	KRFCOBBLE	121	399	1.0	10YR7/4,7/6	10YR7/4,7/6,2/1	-5	1422	1422	0	0	0	20	0	0	scorching along edge
4	100	02	KRFCOBBLE	121	399	1.0	10YR6/8,3/1	10YR6/8,3/1	0	1986	1986	0	0	0	0	0	0	5% smoke,no color change
4	101	02	KRFCOBBLE	121	399	1.0	10YR3/1,6/8,7/8	10YR3/1,6/8,7/8,6/3	-1	1615	1615	0	0	0	10	0	0	10% smoke glaze cortex
4	102	02	KRFCOBBLE	121	399	1.0	10YR8/4,6/8	10YR8/4,6/8	0	2875	2875	0	0	0	0	0	0	no apparent change
4	103	02	KRFCOBBLE	121	399	1.0	10YR5/8,6/8	10YR5/8,6/8,4/6	-2	2150	2149	0	0	0	10	0	0	smoke glaze on cortex
4	104	02	KRFCOBBLE	121	399	1.0	10YR8/3	10YR5/3	-3	1141	1141	0	0	0	60	0	0	smoke glaze and blacken
4	105	02	KRFCOBBLE	121	399	1.0	10YR6/8,10YR6/6	10YR3/0,2.5Y2.5/0	-3	1043	1043	0	0	0	100	0	0	scorched,smoke blackened
4	106	02	KRFCOBBLE	121	399	1.0	10YR5/8	10YR2/2,4/6	-3	1329	1329	0	0	0	100	0	0	smoke blackening
4	107	02	KRFCOBBLE	121	399	1.0	10YR6/8,10YR6/6	10YR6/8,10YR6/6	-2	932	932	0	0	0	20	0	0	20% on edges
4	108	02	KRFCOBBLE	121	399	1.0	10YR6/8,7/8	10YR6/8,7/8,2/2	-5	1081	1081	0	0	0	30	0	0	smoke glazing
4	109	02	KRFCOBBLE	121	399	1.0	10YR8/2,6/6	10YR8/2,6/6	0	2716	2716	0	0	0	0	0	0	faint smoking?
4	110	02	KRFCOBBLE	121	399	1.0	10YR8/2,7/6	10YR2/1,3/3	-6	2397	2388	1	1	3	100	0	0	fracture, blackening
4	111	02	KRFCOBBLE	121	399	1.0	10YR8/4,8/6,3/1	10YR8/4,8/6,3/1	0	604	604	0	0	0	10	0	0	10% smoke,no color change
4	112	02	KRFCOBBLE	121	399	1.0	10YR5/8	10YR3/2,4/2	-2	1149	1149	0	0	0	100	0	0	darkening,smoke
4	113	02	KRFCOBBLE	121	399	1.0	10YR3/1,7/8	10YR4/1,4/2	-3	1352	1352	0	0	0	100	0	0	smoke glaze,gray soot
4	114	02	KRFCOBBLE	121	399	1.0	10YR7/6,7/8	10YR7/6,7/8	0	944	944	0	0	0	5	0	0	v. lt. scorch one edge
4	115	02	KRFCOBBLE	121	399	1.0	10YR5/8,6/8	10YR5/8,6/8,4/2	-2	1288	1288	0	0	0	10	0	0	gr./br. sm. gl. one edge
4	116	02	KRFCOBBLE	121	399	1.0	10YR6/8,8/1	10YR6/8,8/1	0	1510	1510	0	0	0	0	0	0	darker brown?,hard to det
4	117	02	KRFCOBBLE	121	399	1.0	10YR3/1,5/8,6/8	10YR3/1,5/8,6/8,4/4	-2	1715	1714	0	0	0	25	0	0	browning on gold cortex
4	118	02	KRFCOBBLE	121	399	1.0	10YR5/8,6/8	10YR2/1,4/4	-4	1388	1388	0	0	0	100	0	0	smoke glazed,blackened
4	119	02	KRFCOBBLE	121	399	1.0	10YR6/8,4/6	10YR6/8,4/6,4/4,2/1	-4	833	833	0	0	0	20	0	0	20% smoke glaze,5% black
4	120	02	KRFCOBBLE	121	399	1.0	10YR8/1,8/2	10YR8/1,8/2,4/6	-4	1361	1361	0	0	0	5	0	0	lt.scorch 1 edge,sl. smk.

PL	SAM	MAT		2CM	10CM					COL	WT	WT	WT	FR	FR	SCO	CHA	LO	
OT	PLe	CODE	MATNAME	TEMP	TEMP	DURA	COLOR BEFORE	COLOR AFTER		CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
1	001	03	KRFFLAKE	177	343	0.5	7.5YR3/2	7.5YR3/2		0	40	40	0	0	0	0	0	0	no apparent change
1	002	03	KRFFLAKE	177	343	0.5	7.5YR3/2,3/3	7.5YR3/2		0	40	40	0	0	0	0	0	0	no apparent change
1	003	03	KRFFLAKE	177	343	0.5	7.5YR3/2	7.5YR3/2		0	24	24	0	0	0	0	0	0	no apparent change
1	004	03	KRFFLAKE	177	343	0.5	7.5YR3/2,3/3	7.5YR3/1		0	54	53	0	1	3	50	0	0	smoke glazing
1	005	03	KRFFLAKE	177	343	0.5	7.5YR3/2,3/3	7.5YR3/1		0	33	33	0	1	2	100	0	0	smoke glazing,scorching
1	006	03	KRFFLAKE	177	343	0.5	7.5YR3/2,3/1	7.5YR3/2		0	57	57	0	0	0	0	0	0	no apparent change
1	007	03	KRFFLAKE	177	343	0.5	7.5YR3/2,3/1	10YR2/2		-1	33	33	0	0	0	75	0	0	smoke glaze
1	008	03	KRFFLAKE	177	343	0.5	7.5YR3/2,3/3	7.5YR3/2,3/1		0	28	28	0	0	0	20	0	0	20% smoke glaze
1	009	03	KRFFLAKE	177	343	0.5	7.5YR3/1,3/2	7.5YR3/1,3/2		0	57	57	0	0	0	0	0	0	no apparent change
1	010	03	KRFFLAKE	177	343	0.5	7.5YR3/3	10YR2/1,2/2		-1	35	35	0	0	0	100	0	0	smoke glaze
1	011	03	KRFFLAKE	177	343	0.5	7.5YR3/2,3/3	7.5YR3/2		0	47	47	0	0	0	0	0	0	no apparent change
1	012	03	KRFFLAKE	177	343	0.5	7.5YR3/3	7.5YR3/3		0	20	20	0	0	0	0	0	0	no apparent change
1	013	03	KRFFLAKE	177	343	0.5	7.5YR3/3	10YR2/1		-1	44	44	0	0	0	100	0	0	smoke glaze
1	014	03	KRFFLAKE	177	343	0.5	7.5YR3/3	10YR2/2		-1	50	50	0	1	3	100	0	0	smoke glaze
1	015	03	KRFFLAKE	177	343	0.5	7.5YR3/3	7.5YR3/3		0	19	19	0	0	0	0	0	0	no apparent change
1	016	03	KRFFLAKE	177	343	0.5	7.5YR3/2	7.5YR3/2,3/1		0	97	97	0	0	0	15	0	0	lt. sm. glaze,sl. darken
1	017	03	KRFFLAKE	177	343	0.5	7.5YR3/3	7.5YR3/3,3/2		0	37	37	0	0	0	40	0	0	lt. sm. glaze,sl. darken
1	018	03	KRFFLAKE	177	343	0.5	5YR3/1	10YR2/1,2/2		-1	97	97	0	0	0	100	0	0	smoke glaze
1	019	03	KRFFLAKE	177	343	0.5	7.5YR3/3	7.5YR3/3,3/2		0	62	62	0	0	0	30	0	0	smoke glaze
1	020	03	KRFFLAKE	177	343	0.5	7.5YR3/3	7.5YR3/3,3/2		0	33	33	0	0	0	20	0	0	smoke glaze
1	021	03	KRFFLAKE	177	343	0.5	7.5YR3/1	7.5YR3/1		0	115	115	0	0	0	10	0	0	lt. sm. edge,no col chng
1	022	03	KRFFLAKE	177	343	0.5	7.5YR3/3	7.5YR3/3		0	60	60	0	0	0	0	0	0	no apparent change
1	023	03	KRFFLAKE	177	343	0.5	5YR3/1	10YR2/2		-1	94	94	0	0	0	100	0	0	smoke gl.,scorch
1	024	03	KRFFLAKE	177	343	0.5	7.5YR3/1	10YR2/1		-1	31	31	0	0	0	100	0	0	smoke gl.,scorch
1	025	03	KRFFLAKE	177	343	0.5	7.5YR3/1	7.5YR3/1		0	67	67	0	1	8	20	0	0	lt. scorch,no col change
1	026	03	KRFFLAKE	177	343	0.5	7.5YR3/1	10YR2/1		-1	41	41	0	0	0	100	0	0	smoke hazing
1	027	03	KRFFLAKE	177	343	0.5	7.5YR3/1	7.5YR3/1,3/2		0	57	57	0	0	0	50	0	0	smoke glazing, scorch
1	028	03	KRFFLAKE	177	343	0.5	7.5YR3/1	7.5YR3/1		0	58	58	0	0	0	0	0	0	no apparent change
1	029	03	KRFFLAKE	177	343	0.5	7.5YR3/3	10YR2/2		-1	68	68	0	0	0	50	0	0	smoke glaze,scorch
1	030	03	KRFFLAKE	177	343	0.5	7.5YR3/1	10YR2/2		-1	37	37	0	0	0	50	0	0	smoke glaze,scorch
2	031	03	KRFFLAKE	399	399	0.5	7.5YR3/3	7.5YR3/3,3/2		0	20	20	0	0	0	20	0	0	smoke glaze
2	032	03	KRFFLAKE	399	399	0.5	7.5YR3/3	7.5YR3/3,3/1		0	34	34	0	0	0	5	0	0	smoke glaze 5%, edge
2	033	03	KRFFLAKE	399	399	0.5	7.5YR3/2	7.5YR3/2		0	30	30	0	0	0	0	0	0	sm. haze ?,no color chng.
2	034	03	KRFFLAKE	399	399	0.5	7.5YR3/2,3/3	7.5YR3/2,3/1		0	26	26	0	0	0	90	0	0	sm. glaze,scorching
2	035	03	KRFFLAKE	399	399	0.5	7.5YR3/3	7.5YR3/3,3/2		0	19	19	0	0	0	20	0	0	smoke glaze along edge
2	036	03	KRFFLAKE	399	399	0.5	7.5YR3/3	7.5YR3/3		0	23	23	0	0	0	0	0	0	no apparent change
2	037	03	KRFFLAKE	399	399	0.5	7.5YR3/1	7.5YR3/1		0	59	59	0	0	0	0	0	0	no apparent change
2	038	03	KRFFLAKE	399	399	0.5	7.5YR3/3	7.5YR3/3		0	22	22	0	0	0	0	0	0	no apparent change
2	039	03	KRFFLAKE	399	399	0.5	10YR3/2	10YR3/2		0	28	28	0	0	0	10	0	0	lt.sm. edge,no color chng
2	040	03	KRFFLAKE	399	399	0.5	10YR3/2	10YR3/2		0	51	51	0	0	0	0	0	0	no apparent change
2	041	03	KRFFLAKE	399	399	0.5	10YR3/1	10YR3/1		0	64	64	0	0	0	0	0	0	no apparent change
2	042	03	KRFFLAKE	399	399	0.5	10YR3/2	10YR3/2		0	23	23	0	0	0	0	0	0	no apparent change
2	043	03	KRFFLAKE	399	399	0.5	10YR3/2	10YR3/2,10YR2/1		-1	38	38	0	0	0	50	0	0	heavy scorch
2	044	03	KRFFLAKE	399	399	0.5	10YR3/4	10YR3/4		0	31	31	0	0	0	0	0	0	lt. sm. smudge,no col chg
2	045	03	KRFFLAKE	399	399	0.5	7.5YR3/1	7.5YR3/1		0	64	64	0	0	0	0	0	0	no apparent change
2	046	03	KRFFLAKE	399	399	0.5	7.5YR3/2	7.5YR3/2,3/1		0	25	25	0	0	0	5	0	0	lt. scorch along edge
2	047	03	KRFFLAKE	399	399	0.5	7.5YR3/1	7.5YR3/1		0	60	60	0	0	0	5	0	0	5% smoke glaze near plat.
2	048	03	KRFFLAKE	399	399	0.5	7.5YR3/2	7.5YR3/2		0	54	54	0	0	0	0	0	0	sm.?,no color change

PL	SAM	MAT	20M	100M						COL	WT	WT	WT	FR	FR	SCO	CHA	LO		
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR	BEFORE	COLOR	AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
2	049	03	KRFFLAKE	399	399	0.5	7.5YR3/2		7.5YR3/2		0	29	29	0	0	0	5	0	0	5% lt. scorch edges
2	050	03	KRFFLAKE	399	399	0.5	7.5YR3/2		10YR3/1,2/1		-1	31	31	0	0	0	20	0	0	scorching lat. margins
2	051	03	KRFFLAKE	399	399	0.5	7.5YR3/2		7.5YR3/2		0	20	20	0	0	0	15	0	0	lat. margins, no col. chg
2	052	03	KRFFLAKE	399	399	0.5	7.5YR3/2,3/1		7.5YR3/2,3/1		0	40	40	0	0	0	0	0	0	no apparent change
2	053	03	KRFFLAKE	399	399	0.5	7.5YR3/3		7.5YR3/3		0	18	18	0	0	0	0	0	0	no apparent change
2	054	03	KRFFLAKE	399	399	0.5	7.5YR3/2		7.5YR3/2		0	21	21	0	0	0	0	0	0	sl. hint of sm.?
2	055	03	KRFFLAKE	399	399	0.5	7.5YR3/1		7.5YR3/1,10YR2/2		-1	33	33	0	0	0	10	0	0	scorching near bulb
2	056	03	KRFFLAKE	399	399	0.5	7.5YR3/2		10YR3/2		0	14	13	0	1	3	10	0	0	potlidding
2	057	03	KRFFLAKE	399	399	0.5	7.5YR3/2		10YR2/1,2/2		-1	58	58	0	0	0	30	0	0	sm. glazing,scorching
2	058	03	KRFFLAKE	399	399	0.5	7.5YR3/2		7.5YR3/2,3/1		0	47	47	0	0	0	5	0	0	lt. scorch along edge
2	059	03	KRFFLAKE	399	399	0.5	7.5YR3/1		7.5YR3/1		0	42	42	0	0	0	0	0	0	no apparent change
2	060	03	KRFFLAKE	399	399	0.5	7.5YR3/1		7.5YR3/1,10YR2/1		-1	67	67	0	0	0	100	0	0	dk. scorching
3	061	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1		0	92	92	0	0	0	0	0	0	no apparent change
3	062	03	KRFFLAKE	316	288	0.5	7.5YR3/2,3/3		7.5YR3/2,3/3		0	20	20	0	0	0	0	0	0	no apparent change
3	063	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	29	29	0	0	0	0	0	0	no apparent change
3	064	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	25	25	0	0	0	0	0	0	no apparent change
3	065	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1		0	46	46	0	0	0	0	0	0	no apparent change
3	066	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1		0	32	32	0	0	0	0	0	0	no apparent change
3	067	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1		0	70	70	0	0	0	0	0	0	no apparent change
3	068	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1,10YR3/2		0	48	48	0	0	0	5	0	0	5% scorch along edge
3	069	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	22	22	0	0	0	0	0	0	no apparent change
3	070	03	KRFFLAKE	316	288	0.5	7.5YR3/2,3/1		7.5YR3/2,3/1		0	35	35	0	0	0	0	0	0	no apparent change
3	071	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	56	56	0	0	0	1	0	0	sm. scorch one corner?
3	072	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	28	28	0	0	0	0	0	0	no apparent change
3	073	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1		0	60	60	0	0	0	0	0	0	no apparent change
3	074	03	KRFFLAKE	316	288	0.5	7.5YR3/1,3/2		7.5YR3/1,3/2		0	26	26	0	0	0	0	0	0	no apparent change
3	075	03	KRFFLAKE	316	288	0.5	7.5YR3/1,3/2		7.5YR3/1,3/2		0	40	40	0	0	0	0	0	0	no apparent change
3	076	03	KRFFLAKE	316	288	0.5	7.5YR3/1,3/2		7.5YR3/1,3/2		0	71	71	0	0	0	0	0	0	no apparent change
3	077	03	KRFFLAKE	316	288	0.5	7.5YR3/3		7.5YR3/3		0	19	19	0	0	0	0	0	0	no apparent change
3	078	03	KRFFLAKE	316	288	0.5	7.5YR3/1,3/2		7.5YR3/1,3/2		0	31	31	0	0	0	0	0	0	no apparent change
3	079	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1		0	28	28	0	0	0	0	0	0	no apparent change
3	080	03	KRFFLAKE	316	288	0.5	7.5YR3/1		7.5YR3/1		0	24	24	0	0	0	0	0	0	no apparent change
3	081	03	KRFFLAKE	316	288	0.5	7.5YR3/1,3/2		7.5YR3/1,3/2		0	28	28	0	0	0	0	0	0	no apparent change
3	082	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	25	25	0	0	0	0	0	0	no apparent change
3	083	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	25	25	0	0	0	0	0	0	no apparent change
3	084	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	43	43	0	0	0	0	0	0	no apparent change
3	085	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	37	37	0	0	0	0	0	0	no apparent change
3	086	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	40	40	0	0	0	0	0	0	no apparent change
3	087	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2,3/1		0	19	18	0	1	8	10	0	0	fr. post burn?,scorch cor
3	088	03	KRFFLAKE	316	288	0.5	7.5YR3/3		7.5YR3/3		0	26	26	0	0	0	0	0	0	no apparent change
3	089	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	24	24	0	0	0	0	0	0	no apparent change
3	090	03	KRFFLAKE	316	288	0.5	7.5YR3/2		7.5YR3/2		0	25	25	0	0	0	0	0	0	no apparent change
4	091	03	KRFFLAKE	121	399	1.0	7.5YR3/2,3/1		7.5YR3/2,3/1		0	32	32	0	0	0	0	0	0	no apparent change
4	092	03	KRFFLAKE	121	399	1.0	7.5YR3/2,3/1		7.5YR3/2,3/1		0	37	37	0	0	0	10	0	0	lt.scorch edges,no col.ch
4	093	03	KRFFLAKE	121	399	1.0	7.5YR3/2		7.5YR3/2		0	29	29	0	0	0	0	0	0	no apparent change
4	094	03	KRFFLAKE	121	399	1.0	7.5YR3/2		5YR2.5/1		0	58	58	0	1	3	60	0	0	potlidding on surface
4	095	03	KRFFLAKE	121	399	1.0	7.5YR3/2,3/3		7.5YR3/2,3/3		0	27	27	0	0	0	5	0	0	lt. scorch edges,no colch
4	096	03	KRFFLAKE	121	399	1.0	7.5YR3/2,8/2		7.5YR3/2,8/2		0	78	78	0	0	0	0	0	0	no apparent change

PL	SAM	MAT		2CM	10CM					COL	WT	WT	WT	FR	FR	SOO	CHA	LO	
OT	PLe	CODE	MATNAME	TEMP	TEMP	DURA	COLOR BEFORE		COLOR AFTER	CHA	Bef	Aft	CHA	ACT	TYP	RCH	RR	SS	COMMENT
4 097	03	KRFFLAKE		121	399	1.0	7.5YR3/1		7.5YR3/1	0	60	60	0	0	0	5	0	0	v. lt. sc. edges,no colch
4 098	03	KRFFLAKE		121	399	1.0	7.5YR3/1,3/2,3/3		7.5YR3/1,3/2,3/3	0	61	61	0	0	0	10	0	0	v. lt. sc. edges,no colch
4 099	03	KRFFLAKE		121	399	1.0	7.5YR3/1		10YR2/1,3/2	-1	59	59	0	0	0	10	0	0	scorching on edge
4 100	03	KRFFLAKE		121	399	1.0	7.5YR3/2		7.5YR3/2	0	49	49	0	0	0	5	0	0	lt. sc. edges,no col. ch.
4 101	03	KRFFLAKE		121	399	1.0	7.5YR3/2		7.5YR3/2	0	33	33	0	0	0	20	0	0	7.5YR7/6 sm. glaze cortex
4 102	03	KRFFLAKE		121	399	1.0	7.5YR3/2		7.5YR3/2,10YR3/4	0	77	77	0	0	0	15	0	0	10YR3/4 cortex,edge
4 103	03	KRFFLAKE		121	399	1.0	7.5YR3/2		7.5YR3/2	0	33	33	0	0	0	5	0	0	10YR2/1 scorch edge marg.
4 104	03	KRFFLAKE		121	399	1.0	7.5YR2/1		10YR2/1	0	92	89	1	1	3	100	0	0	potlidding,some lost
4 105	03	KRFFLAKE		121	399	1.0	7.5YR3/2		10YR2/2	-1	49	44	1	1	3	100	0	0	potlidding,some lost
4 106	03	KRFFLAKE		121	399	1.0	7.5YR3/2		7.5YR3/2,3/1	0	63	63	0	0	0	10	0	0	edge smoked, blackened
4 107	03	KRFFLAKE		121	399	1.0	7.5YR3/3,3/4		7.5YR3/3,3/4	0	16	16	0	0	0	5	0	0	v. lt. scorch,no col. chg
4 108	03	KRFFLAKE		121	399	1.0	7.5YR3/2		7.5YR3/1	0	40	37	1	1	3	100	0	0	potlidding
4 109	03	KRFFLAKE		121	399	1.0	7.5YR3/2		7.5YR3/2,10YR2/1	-1	39	39	0	0	0	20	0	0	smoked, blakened
4 110	03	KRFFLAKE		121	399	1.0	7.5YR3/2		10YR3/2	0	33	31	1	1	3	100	0	0	spalling,gr.br.no red
4 111	03	KRFFLAKE		121	399	1.0	7.5YR3/3		7.5YR3/3	0	30	30	0	0	0	10	0	0	smoked, no color change
4 112	03	KRFFLAKE		121	399	1.0	7.5YR3/2		10YR3/2	0	49	49	0	0	0	80	0	0	smoked
4 113	03	KRFFLAKE		121	399	1.0	7.5YR3/2,3/3		5YR3/2,2.5/0	0	21	20	0	1	3	100	0	0	reddish tint,potlidded
4 114	03	KRFFLAKE		121	399	1.0	7.5YR3/1		7.5YR3/1,10YR2/2,3/2	-1	70	70	0	0	0	20	0	0	smoked
4 115	03	KRFFLAKE		121	399	1.0	7.5YR3/2		10Y3/4,5YR3/2	0	21	18	1	1	3	100	0	0	potlidding,dusky red
4 116	03	KRFFLAKE		121	399	1.0	7.5YR3/3		10YR3/1	0	33	32	0	1	3	100	0	0	no red,sm. resin
4 117	03	KRFFLAKE		121	399	1.0	7.5YR3/3		7.5YR3/3	0	27	27	0	0	0	20	0	0	scorch edges,no color chg
4 118	03	KRFFLAKE		121	399	1.0	7.5YR3/2		10YR3/3	0	35	30	1	1	3	100	0	0	smoked, blackened sheen
4 119	03	KRFFLAKE		121	399	1.0	7.5YR3/2		10YR3/2,2/1	-1	69	69	0	0	0	30	0	0	scorching,blackened sheen
4 120	03	KRFFLAKE		121	399	1.0	7.5YR3/1		7.5YR3/1,5YR3/3	0	57	57	0	0	0	10	0	0	10YR8/1 cortex, scorch
1 001	04	POTTERY		177	343	0.5	10YR4/1,5/1		10YR4/1	+1	75	75	0	0	0	10	0	0	lt. br. scorch ext.
1 002	04	POTTERY		177	343	0.5	10YR3/1		10YR3/1	0	27	27	0	0	0	0	0	0	no apparent change
1 003	04	POTTERY		177	343	0.5	10YR3/1		10YR3/1	0	32	32	0	0	0	0	0	0	no apparent change
1 004	04	POTTERY		177	343	0.5	10YR4/1		10YR3/1	-1	37	37	0	0	0	50	0	0	sl. darker,sm. glaze ext.
1 005	04	POTTERY		177	343	0.5	10YR3/1		10YR3/1	0	36	36	0	0	0	50	0	0	lt. smoke,no color chng.
1 006	04	POTTERY		177	343	0.5	10YR3/1,4/1		10YR3/1,4/1	0	58	58	0	0	0	0	0	0	no apparent change
1 007	04	POTTERY		177	343	0.5	10YR3/1		10YR3/1	0	34	34	0	0	0	0	0	0	no apparent change
1 008	04	POTTERY		177	343	0.5	10YR3/1,4/1		10YR3/1,4/1	0	30	30	0	0	0	0	0	0	no apparent change
1 009	04	POTTERY		177	343	0.5	10YR4/1,4/2		10YR4/1,4/2	0	47	47	0	0	0	0	0	0	no apparent change
1 010	04	POTTERY		177	343	0.5	10YR3/1,4/1		10YR3/1,4/1	0	40	40	0	0	0	0	0	0	no apparent change
1 011	04	POTTERY		177	343	0.5	10YR2/1		10YR3/1,4/1	+2	81	81	0	0	0	0	0	0	ext. lighter gray smoke
1 012	04	POTTERY		177	343	0.5	10YR4/1		10YR4/1	0	19	19	0	0	0	0	0	0	no apparent change
1 013	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR3/1	+1	26	26	0	0	0	50	0	0	lt. gray ext., 50%
1 014	04	POTTERY		177	343	0.5	10YR4/1		10YR4/1	0	27	27	0	0	0	0	0	0	no apparent change
1 015	04	POTTERY		177	343	0.5	10YR2/1,2/2		10YR2/1,2/2	0	40	40	0	0	0	0	0	0	no apparent change
1 016	04	POTTERY		177	343	0.5	10YR2/1		10YR2/1,3/1	+1	58	58	0	0	0	0	0	0	ext. sl. lighter,soot
1 017	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR2/1,3/1	0	60	60	0	0	0	0	0	0	soot 10%,no other effect
1 018	04	POTTERY		177	343	0.5	10YR2/1		10YR2/1	0	37	37	0	0	0	0	0	0	no apparent change
1 019	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR2/1,3/1	0	46	46	0	0	0	0	0	0	no apparent change
1 020	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR2/1,3/1	0	29	29	0	0	0	0	0	0	no apparent change
1 021	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR2/1,3/1	0	41	41	0	0	0	0	0	0	no apparent change
1 022	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR4/1	+2	60	60	0	0	0	0	0	0	ext. lighter
1 023	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR2/1,3/1	0	65	65	0	0	0	0	0	0	lt. scorch edges?
1 024	04	POTTERY		177	343	0.5	10YR2/1,3/1		10YR2/1,3/1	0	49	49	0	0	0	0	0	0	no apparent change

PL	SAM	MAT		2CM	10CM																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
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Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT	2CM 10CM							COL	WT	WT	WT	FR	FR	SCO	CHA	LO		
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR	BEFORE	COLOR	AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
3	073	04	POTTERY	316	288	0.5	10YR2/1,3/1		10YR2/1,3/1		0	38	38	0	0	0	0	0	0	no apparent change
3	074	04	POTTERY	316	288	0.5	10YR3/1		10YR3/1		0	49	49	0	0	0	0	0	0	no apparent change
3	075	04	POTTERY	316	288	0.5	10YR3/1		10YR3/1		0	54	54	0	0	0	0	0	0	no apparent change
3	076	04	POTTERY	316	288	0.5	10YR3/1,2.5Y3/4		10YR3/1,2.5Y3/4		0	31	31	0	0	0	0	0	0	no apparent change
3	077	04	POTTERY	316	288	0.5	10YR3/1,2.5YR3/4		10YR3/1,2.5YR3/4		0	52	52	0	0	0	0	0	0	no apparent change
3	078	04	POTTERY	316	288	0.5	10YR3/1		10YR3/1		0	30	30	0	0	0	0	0	0	no apparent change
3	079	04	POTTERY	316	288	0.5	10YR4/2,5YR5/6		10YR4/1,4/2,5YR5/6		0	50	50	0	0	0	0	0	0	lightening due to soil?
3	080	04	POTTERY	316	288	0.5	10YR2/1,3/1		10YR2/1,3/1		0	57	57	0	0	0	0	0	0	no apparent change
3	081	04	POTTERY	316	288	0.5	10YR3/1		10YR3/1,6/2		+3	105	105	0	0	0	0	0	0	ext. gr. br. haze, soil?
3	082	04	POTTERY	316	288	0.5	10YR3/1,3/2		10YR4/1,4/2		+1	54	54	0	0	0	0	0	0	soil related lightening
3	083	04	POTTERY	316	288	0.5	10YR3/1		10YR3/1		0	52	51	0	1	8	0	0	0	attrition fracture
3	084	04	POTTERY	316	288	0.5	10YR5/1,5/2		10YR5/1,5/2		0	60	60	0	0	0	0	0	0	int. lighter, soil?
3	085	04	POTTERY	316	288	0.5	10YR3/1,3/2		10YR3/1,3/2		0	53	53	0	0	0	0	0	0	int. lighter, soil?
3	086	04	POTTERY	316	288	0.5	10YR2/1,3/1		10YR2/1,3/1		0	26	26	0	0	0	0	0	0	no apparent change
3	087	04	POTTERY	316	288	0.5	10YR2/1,3/1		10YR2/1,3/1		0	43	43	0	0	0	0	0	0	no apparent change
3	088	04	POTTERY	316	288	0.5	10YR2/1		10YR2/1		0	65	65	0	0	0	0	0	0	no apparent change
3	089	04	POTTERY	316	288	0.5	10YR4/1,5/1		10YR4/1,5/1		0	35	35	0	0	0	0	0	0	no apparent change
3	090	04	POTTERY	316	288	0.5	10YR3/1		10YR3/1		0	33	33	0	0	0	0	0	0	no apparent change
4	091	04	POTTERY	121	399	1.0	10YR5/1,5/2		10YR5/1,5/2		0	75	75	0	0	0	0	0	0	no apparent change
4	092	04	POTTERY	121	399	1.0	10YR3/1,2.5YR3/4		10YR3/1,2.5YR5/6		+2	27	27	0	0	0	0	0	0	ext. lighter,red residue
4	093	04	POTTERY	121	399	1.0	10YR5/3		10YR5/3		0	40	40	0	0	0	10	0	0	sm. glaze int.,one edge
4	094	04	POTTERY	121	399	1.0	10YR2/1,3/1		10YR3/1,3/2,6/3		+4	48	48	0	0	0	30	0	0	lighter brown ext. scorch
4	095	04	POTTERY	121	399	1.0	10YR3/2,5YR4/6		10YR3/1,2.5YR4/6		0	53	53	0	0	0	30	0	0	lt. scorching,patchy
4	096	04	POTTERY	121	399	1.0	10YR4/1,4/2		10YR4/1,4/2,3/2		-1	44	44	0	0	0	10	0	0	smoke glaze edge
4	097	04	POTTERY	121	399	1.0	10YR2/1		10YR2/1		0	72	72	0	0	0	0	0	0	original color dark
4	098	04	POTTERY	121	399	1.0	10YR3/1,3/2		10YR3/1,3/2		0	75	75	0	0	0	10	0	0	smoke glaze,no color chng
4	099	04	POTTERY	121	399	1.0	10YR3/1		10YR3/1		0	103	103	0	0	0	20	0	0	smoke glaze,no color chng
4	100	04	POTTERY	121	399	1.0	10YR2/1,3/1		10YR2/1,3/1		0	43	43	0	0	0	40	0	0	black ext. residue to gry
4	101	04	POTTERY	121	399	1.0	10YR2/1,3/1		10YR2/1,3/1		0	42	42	0	0	0	0	0	0	no apparent change
4	102	04	POTTERY	121	399	1.0	10YR2/1		10YR2/1		0	22	22	0	0	0	0	0	0	no apparent change
4	103	04	POTTERY	121	399	1.0	10YR3/1		10YR3/1		0	41	41	0	0	0	50	0	0	smoke smudged interior
4	104	04	POTTERY	121	399	1.0	10YR3/1		2.5YR5/0		+2	46	46	0	0	0	100	0	0	graying due to heat,smoke
4	105	04	POTTERY	121	399	1.0	10YR4/2		10YR3/1,4/2		-1	36	36	0	0	0	40	0	0	smoke glazing
4	106	04	POTTERY	121	399	1.0	10YR2/1		10YR2/1		0	54	54	0	0	0	0	0	0	dk. color, hard to detect
4	107	04	POTTERY	121	399	1.0	10YR2/1		10YR2/1		0	42	42	0	0	0	0	0	0	dk. color, hard to detect
4	108	04	POTTERY	121	399	1.0	10YR5/2,5/3		10YR4/1,5/2,5/3		-1	36	36	0	0	0	20	0	0	20% scorched exterior
4	109	04	POTTERY	121	399	1.0	10YR3/1		10YR3/1		0	75	75	0	0	0	20	0	0	20% scorched interior
4	110	04	POTTERY	121	399	1.0	10YR3/1		2.5YR2.5/0,10YR2/1		-1	25	25	0	0	0	100	0	0	smoke blackened
4	111	04	POTTERY	121	399	1.0	10YR2/1,3/1		10YR2/1,3/1		0	105	105	0	0	0	100	0	0	ext. sm. resin,no col.ch.
4	112	04	POTTERY	121	399	1.0	10YR5/2,5/3		10YR5/2,5/3,3/1		-2	16	16	0	0	0	10	0	0	sm. smudge edge,ext.
4	113	04	POTTERY	121	399	1.0	10YR3/1,3/2		10YR4/1,4/2		+1	45	45	0	0	0	0	0	0	ext. shade lighter
4	114	04	POTTERY	121	399	1.0	10YR3/1,3/2		10YR3/1,3/2		0	54	54	0	0	0	0	0	0	no apparent change
4	115	04	POTTERY	121	399	1.0	10YR3/1,3/2		10YR3/1,3/2		0	76	76	0	0	0	0	0	0	int. shade lighter,smoke?
4	116	04	POTTERY	121	399	1.0	10YR2/1		10YR2/1		0	63	63	0	0	0	0	0	0	no apparent change
4	117	04	POTTERY	121	399	1.0	10YR3/1		10YR3/1		0	37	37	0	0	0	0	0	0	no apparent change
4	118	04	POTTERY	121	399	1.0	10YR3/1		10YR3/1		0	79	79	0	0	0	0	0	0	no apparent change
4	119	04	POTTERY	121	399	1.0	10YR3/1,2.5YR4/4		10YR3/1,2.5YR4/4		0	67	67	0	0	0	0	0	0	no apparent change
4	120	04	POTTERY	121	399	1.0	10YR2/1,2.5YR4/6		10YR2/1,2.5YR4/6		0	76	76	0	0	0	0	0	0	no apparent change

PL	SAM	MAT	2CM		10CM				COL	WT	WT	WT	FR	FR	SCO	CHA	LO			
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR	BEFORE	COLOR	AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
1	001	05	BONE	177	343	0.5	5Y8/1		10YR6/6,3/4		-5	77	77	0	0	0	30	0	0	scorching
1	002	05	BONE	177	343	0.5	5Y8/1		10YR6/6		-2	46	46	0	0	0	30	0	0	scorching
1	003	05	BONE	177	343	0.5	5Y8/1		10YR5/6		-3	45	45	0	0	0	20	0	0	scorching
1	004	05	BONE	177	343	0.5	5Y8/1		10YR6/8,5/3,2/2		-6	31	31	0	0	0	75	5	0	scorching, charring
1	005	05	BONE	177	343	0.5	5Y8/1		10YR4/4,5/4,5/6		-4	67	67	0	0	0	50	0	0	scorching
1	006	05	BONE	177	343	0.5	5Y8/1		10YR7/4		-1	53	53	0	0	0	100	0	0	scorching
1	007	05	BONE	177	343	0.5	5Y8/1		10YR5/4,6/4		-3	164	164	0	0	0	90	0	0	scorching
1	008	05	BONE	177	343	0.5	5Y8/1		10YR5/6,3/2		-5	61	61	0	0	0	100	0	0	scorching
1	009	05	BONE	177	343	0.5	5Y8/1		10YR7/4,5/6		-3	38	38	0	0	0	100	0	0	scorching
1	010	05	BONE	177	343	0.5	5Y8/1		10YR6/6,5/3		-3	50	50	0	0	0	100	0	0	scorching
1	011	05	BONE	177	343	0.5	5Y8/1		10YR8/4		0	38	38	0	0	0	90	0	0	smoked
1	012	05	BONE	177	343	0.5	5Y8/1		10YR8/3		0	91	91	0	0	0	100	0	0	smoked
1	013	05	BONE	177	343	0.5	5Y8/1		10YR8/4,6/6		-2	38	38	0	0	0	100	0	0	scorching
1	014	05	BONE	177	343	0.5	5Y8/1		10YR3/4,4/4		-5	65	65	0	0	0	100	0	0	scorching
1	015	05	BONE	177	343	0.5	5Y8/1		10YR7/4		-1	23	23	0	0	0	75	0	0	scorching
1	016	05	BONE	177	343	0.5	5Y8/1		10YR7/4,7/6,7/8		-1	105	105	0	0	0	100	0	0	scorching
1	017	05	BONE	177	343	0.5	5Y8/1		10YR6/6,7/6		-2	71	71	0	0	0	100	0	0	scorching
1	018	05	BONE	177	343	0.5	5Y8/1		10YR7/6		-1	83	83	0	0	0	100	0	0	scorching
1	019	05	BONE	177	343	0.5	5Y8/1		10YR6/4,8/4		-2	101	101	0	0	0	80	0	0	scorching
1	020	05	BONE	177	343	0.5	5Y8/1		10YR8/3,7/6,2/2		-6	30	30	0	0	0	75	5	0	scorching, charring
1	021	05	BONE	177	343	0.5	5Y8/1		10YR5/6,3/2		-5	51	51	0	0	0	80	0	0	scorching
1	022	05	BONE	177	343	0.5	5Y8/1		10YR8/2,8/4		0	85	85	0	0	0	80	0	0	smoked
1	023	05	BONE	177	343	0.5	5Y8/1		10YR4/6,2/2		-6	83	83	0	0	0	95	5	0	scorching, charring
1	024	05	BONE	177	343	0.5	5Y8/1		10YR6/4,2/2		-6	72	72	0	0	0	85	5	0	scorching, charring, sm. gl
1	025	05	BONE	177	343	0.5	5Y8/1		10YR7/2,7/3		-1	76	76	0	0	0	100	0	0	smoke staining
1	026	05	BONE	177	343	0.5	5Y8/1		10YR8/2,6/4		-2	143	143	0	0	0	50	0	0	smoke staining
1	027	05	BONE	177	343	0.5	5Y8/1		10YR4/2,2/2		-6	92	92	0	0	0	95	5	0	scorching, charring, sm. gl
1	028	05	BONE	177	343	0.5	5Y8/1		10YR8/3,7/8		-1	161	161	0	0	0	20	0	0	scorching on edges
1	029	05	BONE	177	343	0.5	5Y8/1		10YR6/3,6/6		-2	72	72	0	0	0	100	0	0	smoke staining
1	030	05	BONE	177	343	0.5	5Y8/1		10YR3/3,2/2		-6	47	47	0	0	0	90	10	0	scorching, charring, sm. gl
2	031	05	BONE	399	399	0.5	5Y8/1		10YR8/3,6/6		-2	48	48	0	1	8	80	0	0	Spall due to heat?
2	032	05	BONE	399	399	0.5	5Y8/1		10YR8/3,5/4,5/6		-3	44	44	0	0	0	40	0	0	scorching
2	033	05	BONE	399	399	0.5	5Y8/1		10YR7/6		-1	58	58	0	0	0	20	0	0	lt. scorching
2	034	05	BONE	399	399	0.5	5Y8/1		10YR4/4		-4	43	43	0	0	0	40	0	0	scorching
2	035	05	BONE	399	399	0.5	5Y8/1		10YR8/3		0	44	44	0	0	0	0	0	0	darker, due to organic st.
2	036	05	BONE	399	399	0.5	5Y8/1		10YR4/6,2/1		-6	44	44	0	0	0	10	5	0	scorching, charring edge
2	037	05	BONE	399	399	0.5	5Y8/1		10YR4/4		-4	122	122	0	0	0	10	0	0	min. scorching
2	038	05	BONE	399	399	0.5	5Y8/1		10YR7/4		-1	38	38	0	0	0	100	0	0	lt. scorching
2	039	05	BONE	399	399	0.5	5Y8/1		10YR7/4		-1	66	66	0	0	0	80	0	0	lt. brown smoke glaze
2	040	05	BONE	399	399	0.5	5Y8/1		10YR4/4		-4	70	70	0	0	0	80	0	0	scorching, smoke glaze
2	041	05	BONE	399	399	0.5	5Y8/1		10YR8/4,7/4		-1	72	72	0	0	0	90	0	0	smoke glaze
2	042	05	BONE	399	399	0.5	5Y8/1		10YR8/4,6/4		-2	51	51	0	0	0	40	0	0	scorching
2	043	05	BONE	399	399	0.5	5Y8/1		10YR4/3,2/1		-6	39	39	0	0	0	80	20	0	scorching, charring
2	044	05	BONE	399	399	0.5	5Y8/1		10YR4/4,8/4,2/1		-6	36	36	0	0	0	60	10	0	scorching, charring
2	045	05	BONE	399	399	0.5	5Y8/1		10YR8/4		0	44	44	0	0	0	100	0	0	smoke glaze
2	046	05	BONE	399	399	0.5	5Y8/1		10YR8/4		0	52	52	0	0	0	50	0	0	lt. smoke glaze
2	047	05	BONE	399	399	0.5	5Y8/1		10YR8/6		0	69	69	0	0	0	10	0	0	10% not readily apparent
2	048	05	BONE	399	399	0.5	5Y8/1		10YR8/3		0	50	50	0	0	0	0	0	0	organic staining

[illegible]

PL	SAM	MAT		20M	10CM					COL	WT	WT	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR BEFORE	COLOR AFTER		CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS COMMENT
4	097	05	BONE	121	399	1.0	5Y8/1	10YR6/3		-2	25	25	0	0	0	0	0	organic,smoke?
4	098	05	BONE	121	399	1.0	5Y8/1	10YR7/8		-1	35	35	0	0	0	10	0	lt. scorching one face
4	099	05	BONE	121	399	1.0	5Y8/1	10YR7/8		-1	30	30	0	0	0	5	0	v. lt. scorching
4	100	05	BONE	121	399	1.0	5Y8/1	10YR3/4		-5	22	22	0	0	0	50	0	scorching over organic st
4	101	05	BONE	121	399	1.0	5Y8/1	10YR3/2		-5	56	56	0	0	0	0	0	smoke smudge 10%
4	102	05	BONE	121	399	1.0	5Y8/1	5Y8/1		0	40	40	0	0	0	0	0	no apparent change,weath.
4	103	05	BONE	121	399	1.0	5Y8/1	10YR7/6		-1	24	24	0	0	0	80	0	scorching
4	104	05	BONE	121	399	1.0	5Y8/1	10YR6/6,2/1		-6	26	24	1	1	3	60	40	scorched,charned,fracture
4	105	05	BONE	121	399	1.0	5Y8/1	10YR6/8,2/1		-6	30	30	0	0	0	80	20	scorched,charned
4	106	05	BONE	121	399	1.0	5Y8/1	10YR8/6,5/4,3/2		-5	84	84	0	0	0	90	10	scorched,charned
4	107	05	BONE	121	399	1.0	5Y8/1				43							1 would likely be scorched
4	108	05	BONE	121	399	1.0	5Y8/1	10YR2/1,5/4		-6	88	86	1	0	0	50	40	charned,scorched
4	109	05	BONE	121	399	1.0	5Y8/1	10YR5/6		-3	28	28	0	0	0	90	0	scorching
4	110	05	BONE	121	399	1.0	5Y8/1	10YR3/2,3/1		-5	83	83	0	0	0	80	20	scorching,lt. charring
4	111	05	BONE	121	399	1.0	5Y8/1	10YR4/4		-4	35	35	0	0	0	95	0	dk. scorching
4	112	05	BONE	121	399	1.0	5Y8/1	10YR3/2,3/1		-5	76	76	0	0	0	90	10	dk. scorching,lt. char
4	113	05	BONE	121	399	1.0	5Y8/1	10YR4/6,2/1		-6	30	30	0	0	0	10	5	lt. scorching,lt. char
4	114	05	BONE	121	399	1.0	5Y8/1	10YR5/3,4/4,7/4		-4	48	48	0	0	0	30	0	lt. scorching
4	115	05	BONE	121	399	1.0	5Y8/1	10YR5/4,2/1		-6	20	20	0	0	0	30	10	lt. scorching,lt. char
4	116	05	BONE	121	399	1.0	5Y8/1	10YR6/6,3/2		-5	134	134	0	0	0	80	20	lt. scorch, lt. charring
4	117	05	BONE	121	399	1.0	5Y8/1	10YR4/4		-4	65	65	0	0	0	60	0	scorching
4	118	05	BONE	121	399	1.0	5Y8/1	10YR7/6		-1	49	49	0	0	0	30	0	scorching
4	119	05	BONE	121	399	1.0	5Y8/1	10YR4/4,7/6,2/1		-6	103	103	0	0	0	80	10	scorching,lt. char
4	120	05	BONE	121	399	1.0	5Y8/1				65							1 likely be scorched,char
1	001	06	SHELL	177	343	0.5	N8	10YR5/6,3/2		-5	18	18	0	0	0	30	0	scorching nacre
1	002	06	SHELL	177	343	0.5	N8	10YR5/8		-3	58	58	0	0	0	40	0	scorching nacre
1	003	06	SHELL	177	343	0.5	N8	10YR8/2		0	34	34	0	0	0	90	0	nearing disintegration
1	004	06	SHELL	177	343	0.5	N8	10YR4/3,3/2		-5	24	24	0	0	0	75	0	scorching nacre
1	005	06	SHELL	177	343	0.5	N8	10YR3/3		-5	28	28	0	0	0	40	0	scorching nacre,sm. glaze
1	006	06	SHELL	177	343	0.5	N8	N8		0	49	49	0	0	0	0	0	no apparent change
1	007	06	SHELL	177	343	0.5	N8	N8		0	34	34	0	0	0	0	0	no apparent change
1	008	06	SHELL	177	343	0.5	N8	10YR8/3		0	15	15	0	0	0	100	0	sm. glaze ext.,blackening
1	009	06	SHELL	177	343	0.5	N8	10YR5/2		-3	29	29	0	0	0	20	0	scorching
1	010	06	SHELL	177	343	0.5	N8	10YR4/6,3/4		-5	39	39	0	0	0	80	0	scorching,sm. glaze ext.
1	011	06	SHELL	177	343	0.5	N8	N8		0	52	52	0	0	0	0	0	no change int.,lt. sm. ex
1	012	06	SHELL	177	343	0.5	N8	N8		0	30	30	0	0	0	0	0	poss. friability edge <5%
1	013	06	SHELL	177	343	0.5	N8	10YR7/4,5/4		-3	26	26	0	0	0	100	0	scorching,sm. glaze
1	014	06	SHELL	177	343	0.5	N8	10YR5/6		-3	46	45	0	1	8	100	0	scorching,smoke glaze
1	015	06	SHELL	177	343	0.5	N8	10YR5/6		-3	17	17	0	0	0	25	0	scorching,smoke glaze
1	016	06	SHELL	177	343	0.5	N8	10YR3/6		-5	18	18	0	0	0	20	0	scorching,smoke glaze
1	017	06	SHELL	177	343	0.5	N8	10YR8/6,N8		0	57	57	0	0	0	5	0	lt. scorch one edge only
1	018	06	SHELL	177	343	0.5	N8	10YR4/6		-4	24	24	0	0	0	20	0	scorching,smoke glaze
1	019	06	SHELL	177	343	0.5	N8	10YR8/3		0	51	51	0	0	0	80	0	lt. smoke glazing
1	020	06	SHELL	177	343	0.5	N8	10YR5/3		-3	25	25	0	1	8	50	0	scorching,attrition edge
1	021	06	SHELL	177	343	0.5	N8	N8		0	20	20	0	0	0	5	0	1 scorched edge
1	022	06	SHELL	177	343	0.5	N8	N8		0	68	68	0	0	0	0	0	no apparent change
1	023	06	SHELL	177	343	0.5	N8	10YR5/6		-3	45	45	0	0	0	80	0	scorching
1	024	06	SHELL	177	343	0.5	N8	10YR2/2,3/2		-6	20	13	1	1	5	80	0	fragmentation, blackening

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT	2CM	10CM			COL	WT	WT	WT	FR	FR	SCO	CHA	LO			
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR BEFORE	COLOR AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
1	025	06	SHELL	177	343	0.5	N8	10YR8/1,7/1	-1	27	27	0	0	0	100	0	0	ext. charred,int. scorch
1	026	06	SHELL	177	343	0.5	N8	10YR7/6	-1	19	19	0	0	0	5	0	0	lt. scorching one edge
1	027	06	SHELL	177	343	0.5	N8	10YR4/3	-4	27	26	0	1	3	50	0	0	dk. scorching,edge frac.
1	028	06	SHELL	177	343	0.5	N8	10YR6/4	-2	52	52	0	0	0	50	0	0	lt. scorching
1	029	06	SHELL	177	343	0.5	N8	10YR4/6	-4	11	11	0	0	0	20	0	0	lt. scorching
1	030	06	SHELL	177	343	0.5	N8	10YR6/1	-2	45	45	0	0	0	10	0	0	lt. scorching, ext. col.2
2	031	06	SHELL	399	399	0.5	N8	10YR5/6	-3	23	23	0	0	0	30	0	0	lt. scorching
2	032	06	SHELL	399	399	0.5	N8	10YR7/6	-1	39	39	0	0	0	40	0	0	lt. scorching
2	033	06	SHELL	399	399	0.5	N8	N8	0	16	16	0	0	0	1	0	0	scorch edge,no color chng
2	034	06	SHELL	399	399	0.5	N8	10YR5/6	-3	17	16	0	1	3	100	0	0	lost nacre luster
2	035	06	SHELL	399	399	0.5	N8	N8	0	14	14	0	0	0	0	0	0	no apparent change
2	036	06	SHELL	399	399	0.5	N8	10YR8/3	0	73	73	0	0	0	20	0	0	lt. scorching edge
2	037	06	SHELL	399	399	0.5	N8	10YR8/3	0	47	47	0	0	0	1	0	0	lt. scorching edge,no ch.
2	038	06	SHELL	399	399	0.5	N8	10YR8/3	0	16	16	0	0	0	15	0	0	lt. scorching
2	039	06	SHELL	399	399	0.5	N8	N8	0	19	19	0	0	0	0	0	0	no apparent change
2	040	06	SHELL	399	399	0.5	N8	10YR8/3	0	43	43	0	0	0	5	0	0	lt. scorching edges
2	041	06	SHELL	399	399	0.5	N8	N8	0	38	38	0	0	0	1	0	0	lt. scorching edges, no c
2	042	06	SHELL	399	399	0.5	N8	N8	0	23	23	0	0	0	1	0	0	lt. scorching edges, no c
2	043	06	SHELL	399	399	0.5	N8	10YR5/6	-3	64	64	0	0	0	40	0	0	scorching
2	044	06	SHELL	399	399	0.5	N8	10YR4/4	-4	24	24	0	0	0	60	0	0	scorching
2	045	06	SHELL	399	399	0.5	N8	N8	0	53	53	0	0	0	1	0	0	lt. scorch edges,no col c
2	046	06	SHELL	399	399	0.5	N8	10YR5/3	-3	17	17	0	0	0	40	0	0	scorching
2	047	06	SHELL	399	399	0.5	N8	10YR8/3	0	36	36	0	0	0	5	0	0	ext. col. ch.,int. scorch
2	048	06	SHELL	399	399	0.5	N8	N8	0	26	26	0	0	0	0	0	0	nacre no change
2	049	06	SHELL	399	399	0.5	N8	10YR7/6	-1	22	22	0	1	8	30	0	0	attrition one edge
2	050	06	SHELL	399	399	0.5	N8	10YR8/3	0	29	29	0	0	0	50	0	0	sm. glaze, nacre luster
2	051	06	SHELL	399	399	0.5	N8	N8	0	28	28	0	0	0	0	0	0	nacre structure weathered
2	052	06	SHELL	399	399	0.5	N8	10YR7/6	-1	30	30	0	0	0	75	0	0	ext. charred, eroded too
2	053	06	SHELL	399	399	0.5	N8	10YR8/4	0	33	33	0	0	0	20	0	0	scorching,sm. glaze
2	054	06	SHELL	399	399	0.5	N8	10YR6/4,6/6	-2	26	26	0	0	0	100	0	0	nacre scorched,ext. smoke
2	055	06	SHELL	399	399	0.5	N8	10YR4/6	-4	17	17	0	0	0	20	0	0	ext. and nacre edge scor
2	056	06	SHELL	399	399	0.5	N8	10YR7/6	-1	54	54	0	0	0	30	0	0	nacre scorched
2	057	06	SHELL	399	399	0.5	N8	10YR6/3	-2	16	16	0	0	0	30	0	0	nacre scorched
2	058	06	SHELL	399	399	0.5	N8	10YR8/4	0	37	37	0	0	0	5	0	0	lt. scorching
2	059	06	SHELL	399	399	0.5	N8	10YR8/3	0	27	27	0	0	0	5	0	0	lt. scorching
2	060	06	SHELL	399	399	0.5	N8	10YR5/8	-3	42	42	0	0	0	90	0	0	nacre scorched,ext. scor
3	061	06	SHELL	316	288	0.5	N8	10YR8/4	0	37	37	0	0	0	5	0	0	v. lt. scorching edge
3	062	06	SHELL	316	288	0.5	N8	N8	0	38	38	0	0	0	0	0	0	no change
3	063	06	SHELL	316	288	0.5	N8	N8	0	19	19	0	0	0	1	0	0	v. lt. scorch one edge
3	064	06	SHELL	316	288	0.5	N8	10YR7/6	-1	76	76	0	0	0	0	0	0	soil related?
3	065	06	SHELL	316	288	0.5	N8	N8	0	24	24	0	0	0	0	0	0	no change
3	066	06	SHELL	316	288	0.5	N8	N8	0	30	30	0	0	0	0	0	0	no change
3	067	06	SHELL	316	288	0.5	N8	N8	0	31	31	0	0	0	0	0	0	no change
3	068	06	SHELL	316	288	0.5	N8	10YR8/4	0	47	47	0	0	0	30	0	0	scorch on beak, nacre
3	069	06	SHELL	316	288	0.5	N8	N8	0	49	49	0	0	0	0	0	0	no apparent change
3	070	06	SHELL	316	288	0.5	N8	10YR8/3	0	36	36	0	0	0	0	0	0	soil related
3	071	06	SHELL	316	288	0.5	N8	N8	0	53	53	0	0	0	0	0	0	no change
3	072	06	SHELL	316	288	0.5	N8	N8	0	24	24	0	0	0	0	0	0	no change

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT	2CM	10CM				COL	WT	WT	WT	FR	FR	SCO	CHA	LO		
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	COLOR BEFORE	COLOR AFTER	CHA	BEF	AFT	CHA	ACT	TYP	RCH	RR	SS	COMMENT
3	073	06	SHELL	316	288	0.5	N8	N8	0	67	66	0	1	8	0	0	0	0 snap fracture
3	074	06	SHELL	316	288	0.5	N8	N8	0	30	29	0	1	8	0	0	0	0 attrition, not ht. relate
3	075	06	SHELL	316	288	0.5	N8	N8	0	15	15	0	0	0	0	0	0	0 nacre weathered?
3	076	06	SHELL	316	288	0.5	N8	10YR8/3	0	38	38	0	0	0	0	0	0	0 soil related
3	077	06	SHELL	316	288	0.5	N8	N8	0	42	42	0	0	0	0	0	0	0 no apparent change
3	078	06	SHELL	316	288	0.5	N8	N8	0	54	54	0	0	0	0	0	0	0 no apparent change
3	079	06	SHELL	316	288	0.5	N8	10YR8/4	0	42	42	0	0	0	0	0	0	0 soil related
3	080	06	SHELL	316	288	0.5	N8	N8	0	11	11	0	0	0	0	0	0	0 no apparent change
3	081	06	SHELL	316	288	0.5	N8	10YR8/6,6/1	-2	56	56	0	0	0	5	0	0	0 scorching,gray cast edge
3	082	06	SHELL	316	288	0.5	N8	10YR8/2	0	42	42	0	0	0	0	0	0	0 75% nacre staining,soil?
3	083	06	SHELL	316	288	0.5	N8	10YR8/4	0	43	43	0	0	0	0	0	0	0 40% nacre staining,soil?
3	084	06	SHELL	316	288	0.5	N8	10YR8/3	0	18	18	0	0	0	0	0	0	0 90% nacre staining,soil?
3	085	06	SHELL	316	288	0.5	N8	10YR7/6	-1	37	37	0	0	0	5	0	0	0 v. lt. scorching one edge
3	086	06	SHELL	316	288	0.5	N8	10YR8/3	0	18	18	0	0	0	0	0	0	0 30% nacre haze,soil?
3	087	06	SHELL	316	288	0.5	N8	10YR8/3	0	55	55	0	0	0	15	0	0	0 scorching along beak,ext.
3	088	06	SHELL	316	288	0.5	N8	10YR7/2	-1	47	47	0	0	0	0	0	0	0 100% haze nacre,soil?
3	089	06	SHELL	316	288	0.5	N8	10YR8/2	0	25	25	0	0	0	0	0	0	0 50% haze nacre,soil?
3	090	06	SHELL	316	288	0.5	N8	N8	0	19	19	0	0	0	0	0	0	0 no apparent change
4	091	06	SHELL	121	399	1.0	N8	N8,5RP6/2	-2	16	16	0	1	3	10	0	0	0 valve margins,not due ht?
4	092	06	SHELL	121	399	1.0	N8	N8,10YR8/2	0	19	19	0	0	0	5	0	0	0 v. lt. scorch
4	093	06	SHELL	121	399	1.0	N8	10YR8/4	0	55	54	0	1	3	100	0	0	0 nacre cloudy,ext. scorch
4	094	06	SHELL	121	399	1.0	N8	10YR7/4	-1	51	51	0	0	0	40	0	0	0 nacre scorched
4	095	06	SHELL	121	399	1.0	N8			17								1 not placed in exp.
4	096	06	SHELL	121	399	1.0	N8	N8	0	16	16	0	0	0	0	0	0	0 nacre looks weathered
4	097	06	SHELL	121	399	1.0	N8	N8	0	45	45	0	0	0	0	0	0	0 no apparent change
4	098	06	SHELL	121	399	1.0	N8	10YR3/6	-5	14	14	0	0	0	25	0	0	0 scorching nacre, exterior
4	099	06	SHELL	121	399	1.0	N8	10YR3/1	-5	26	24	1	1	5	30	0	0	0 dk. scorch, charred ext.
4	100	06	SHELL	121	399	1.0	N8	10YR3/4	-5	43	43	0	0	0	30	0	0	0 scorch,nacre,ext.
4	101	06	SHELL	121	399	1.0	N8	10YR4/4	-4	19	19	0	0	0	40	0	0	0 scorch,nacre,ext. edges
4	102	06	SHELL	121	399	1.0	N8	10YR8/4	0	12	12	0	0	0	5	0	0	0 lt. scorch nacre,edge
4	103	06	SHELL	121	399	1.0	N8	10YR5/6	-3	23	23	0	0	0	15	0	0	0 lt. scorch nacre,edge
4	104	06	SHELL	121	399	1.0	N8	10YR2/1,7/6	-6	24	8	1	1	5	100	0	0	0 disintegration,blackening
4	105	06	SHELL	121	399	1.0	N8	10YR2/1	-6	19	7	1	1	5	100	0	0	0 disintegration,blackening
4	106	06	SHELL	121	399	1.0	N8	10YR4/4,5/4	-4	37	37	0	0	0	100	0	0	0 scorching nacre,ext.
4	107	06	SHELL	121	399	1.0	N8	10YR3/4	-5	31	30	0	1	3	70	0	0	0 nacre scorched,ext. char
4	108	06	SHELL	121	399	1.0	N8	10YR7/6	-1	53	37	1	1	5	100	0	0	0 disintegration
4	109	06	SHELL	121	399	1.0	N8	10YR8/6	0	34	34	0	0	0	100	0	0	0 nacre,ext. heavy scorch
4	110	06	SHELL	121	399	1.0	N8	10YR5/2	-3	10	7	1	1	3	100	0	0	0 nacre,ext. damaged
4	111	06	SHELL	121	399	1.0	N8	10YR4/4	-4	35	34	0	1	3	50	0	0	0 nacre 20%,ext. 90%,spall
4	112	06	SHELL	121	399	1.0	N8	10YR8/1	0	16	16	0	0	0	100	0	0	0 ext. scorched 5YR3/3
4	113	06	SHELL	121	399	1.0	N8	10YR4/4	-4	45	45	0	0	0	10	0	0	0 scorching nacre,100% ext.
4	114	06	SHELL	121	399	1.0	N8	10YR8/4,7/6,2/1	-6	35	35	0	0	0	100	0	0	0 hvy. scorching nacre,ext.
4	115	06	SHELL	121	399	1.0	N8	10YR4/1,4/2	-4	25	25	0	0	0	70	0	0	0 hvy. scorching nacre,ext.
4	116	06	SHELL	121	399	1.0	N8	10YR8/3,3/2	-5	23	23	0	1	3	60	0	0	0 hvy. scorching nacre,ext.
4	117	06	SHELL	121	399	1.0	N8			16								2 presumed consumed?
4	118	06	SHELL	121	399	1.0	N8	10YR7/1	-1	13	5	1	1	5	100	0	0	0 disintegration
4	119	06	SHELL	121	399	1.0	N8	10YR7/1,4/4	-4	27	25	1	1	5	65	0	0	0 disintegration, scorching
4	120	06	SHELL	121	399	1.0	N8	10YR4/4	-4	21	21	0	0	0	10	0	0	0 scorching nacre,20% ext.

Appendix 2. Raw data for materials included in the experimental prescribed burn at
the Oakville Prairie, November 1988, continued.

PL	SAM	MAT		5CM	10CM		COL	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	TYP	RCH	RR	SS	COMMENT
1	002	07	WOODBALSA	177	343	0.5	1	0	0	5	0	0	scorch
1	004	07	WOODBALSA	177	343	0.5	1	0	0	40	5	0	charred 5% lost
1	006	07	WOODBALSA	177	343	0.5	1	0	0	5	0	0	scorch
1	008	07	WOODBALSA	177	343	0.5	1	0	0	30	1	0	charred 1% lost
1	010	07	WOODBALSA	177	343	0.5	1	0	0	10	20	0	charred, 20% lost
1	012	07	WOODBALSA	177	343	0.5	1	0	0	5	0	0	scorched
1	014	07	WOODBALSA	177	343	0.5	1	0	0	10	5	0	charred, 5% lost
1	016	07	WOODBALSA	177	343	0.5	1	0	0	0	60	0	charred 60% lost
1	018	07	WOODBALSA	177	343	0.5	1	0	0	50	10	0	charred 10% lost
1	020	07	WOODBALSA	177	343	0.5	1	0	0	0	80	0	charred 80% lost
1	022	07	WOODBALSA	177	343	0.5	0	0	0	0	0	0	no apparent change
1	024	07	WOODBALSA	177	343	0.5						2	presumed consumed
1	026	07	WOODBALSA	177	343	0.5	1	0	0	20	5	0	charred 5% lost
1	028	07	WOODBALSA	177	343	0.5	1	0	0	20	1	0	charred 1% lost
1	030	07	WOODBALSA	177	343	0.5						2	presumed consumed
2	032	07	WOODBALSA	399	399	0.5	1	0	0	30	5	0	charring 5% lost, scorched
2	034	07	WOODBALSA	399	399	0.5	1	0	0	20	5	0	charring 5% lost, scorched
2	036	07	WOODBALSA	399	399	0.5	0	0	0	0	0	0	no apparent change
2	038	07	WOODBALSA	399	399	0.5	1	0	0	5	0	0	lt. scorching
2	040	07	WOODBALSA	399	399	0.5	1	0	0	30	5	0	charred 5% lost, scorched
2	042	07	WOODBALSA	399	399	0.5	1	0	0	20	1	0	charred 1% lost, scorched
2	044	07	WOODBALSA	399	399	0.5	1	0	0	60	5	0	charred 5% lost, scorched
2	046	07	WOODBALSA	399	399	0.5	1	0	0	30	0	0	scorching
2	048	07	WOODBALSA	399	399	0.5	1	0	0	10	1	0	charring 1% lost, scorched
2	050	07	WOODBALSA	399	399	0.5	1	0	0	20	5	0	charring 5% lost, scorched
2	052	07	WOODBALSA	399	399	0.5	1	0	0	10	0	0	scorched
2	054	07	WOODBALSA	399	399	0.5	1	0	0	40	10	0	charred 10% lost, scorched
2	056	07	WOODBALSA	399	399	0.5	1	0	0	20	1	0	charred 1% lost, scorched
2	058	07	WOODBALSA	399	399	0.5	1	0	0	10	1	0	charred 1% lost, scorched
2	060	07	WOODBALSA	399	399	0.5	1	0	0	40	10	0	charred 10% lost, scorched
3	062	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	064	07	WOODBALSA	316	288	0.5	1	0	0	1	0	0	lt. scorch one edge
3	066	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	068	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	070	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	072	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	074	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	076	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	078	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	080	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	082	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	084	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	086	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	088	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
3	090	07	WOODBALSA	316	288	0.5	0	0	0	0	0	0	no apparent change
4	092	07	WOODBALSA	121	399	1.0	1	0	0	0	20	0	charred, 20% lost
4	094	07	WOODBALSA	121	399	1.0	1	0	0	0	15	0	charred, 15% lost
4	096	07	WOODBALSA	121	399	1.0	1	0	0	0	15	0	charred, 15% lost

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT		5CM	10CM		COL	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	TYP	RCH	RR	SS	COMMENT
4	098	07	WOODBALSA	121	399	1.0	1	0	0	5	25	0	charred, 25% lost
4	100	07	WOODBALSA	121	399	1.0	1	0	0	0	30	0	charred, 30% lost
4	102	07	WOODBALSA	121	399	1.0	1	0	0	5	15	0	charred, 15% lost
4	104	07	WOODBALSA	121	399	1.0						2	presumed consumed
4	106	07	WOODBALSA	121	399	1.0						2	presumed consumed
4	108	07	WOODBALSA	121	399	1.0						2	presumed consumed
4	110	07	WOODBALSA	121	399	1.0	1	0	0	0	90	0	charred, 90% lost
4	112	07	WOODBALSA	121	399	1.0						2	presumed consumed
4	114	07	WOODBALSA	121	399	1.0						2	presumed consumed
4	116	07	WOODBALSA	121	399	1.0	1	0	0	0	10	0	charred, 10% lost
4	118	07	WOODBALSA	121	399	1.0						2	presumed consumed
4	120	07	WOODBALSA	121	399	1.0	1	0	0	0	15	0	charred, 15% lost
1	001	08	WOODBIRCH	177	343	0.5	1	0	0	20	1	0	charred 1% lost, scorched
1	003	08	WOODBIRCH	177	343	0.5	1	0	0	30	0	0	scorching
1	005	08	WOODBIRCH	177	343	0.5	1	0	0	30	0	0	scorching
1	007	08	WOODBIRCH	177	343	0.5	1	0	0	20	1	0	charred 1% lost
1	009	08	WOODBIRCH	177	343	0.5	0	0	0	0	0	0	lt. scorch?
1	011	08	WOODBIRCH	177	343	0.5	0	0	0	0	0	0	lt. scorch?
1	013	08	WOODBIRCH	177	343	0.5	1	0	0	30	1	0	charred 1% lost
1	015	08	WOODBIRCH	177	343	0.5	1	0	0	1	0	0	lt. scorch
1	017	08	WOODBIRCH	177	343	0.5	1	0	0	20	0	0	scorched
1	019	08	WOODBIRCH	177	343	0.5	1	0	0	20	1	0	scorched, charred 1% lost
1	021	08	WOODBIRCH	177	343	0.5	1	0	0	5	0	0	lt. scorch
1	023	08	WOODBIRCH	177	343	0.5	1	0	0	40	1	0	charred 1% lost
1	025	08	WOODBIRCH	177	343	0.5	1	0	0	20	0	0	scorched
1	027	08	WOODBIRCH	177	343	0.5	1	0	0	40	1	0	scorched, charred 1% lost
1	029	08	WOODBIRCH	177	343	0.5	1	0	0	20	0	0	scorched
2	031	08	WOODBIRCH	399	399	0.5	1	0	0	30	0	0	scorched
2	033	08	WOODBIRCH	399	399	0.5	1	0	0	5	0	0	lt. scorching
2	035	08	WOODBIRCH	399	399	0.5	1	0	0	40	0	0	scorching
2	037	08	WOODBIRCH	399	399	0.5	1	0	0	5	0	0	lt. scorching
2	039	08	WOODBIRCH	399	399	0.5	1	0	0	5	0	0	lt. scorching
2	041	08	WOODBIRCH	399	399	0.5	1	0	0	5	0	0	lt. scorching
2	043	08	WOODBIRCH	399	399	0.5	1	0	0	40	1	0	charring 1% lost, scorched
2	045	08	WOODBIRCH	399	399	0.5	1	0	0	30	1	0	charring 1% lost, scorched
2	047	08	WOODBIRCH	399	399	0.5	1	0	0	5	0	0	lt. scorching
2	049	08	WOODBIRCH	399	399	0.5	1	0	0	10	0	0	lt. scorching
2	051	08	WOODBIRCH	399	399	0.5	1	0	0	40	0	0	scorching
2	053	08	WOODBIRCH	399	399	0.5	1	0	0	30	0	0	scorching
2	055	08	WOODBIRCH	399	399	0.5	1	0	0	10	1	0	charred 1% lost, scorched
2	057	08	WOODBIRCH	399	399	0.5	1	0	0	30	0	0	scorched
2	059	08	WOODBIRCH	399	399	0.5	1	0	0	5	0	0	lt. scorching
3	061	08	WOODBIRCH	316	288	0.5	1	0	0	5	0	0	v. lt. scorch
3	063	08	WOODBIRCH	316	288	0.5	1	0	0	5	0	0	v. lt. scorch
3	065	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	067	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	069	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	071	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change

Appendix 2. Raw data for materials included in the experimental prescribed burn at the Oakville Prairie, November 1988, continued.

PL	SAM	MAT		5CM	10CM	COL	FR	FR	SCO	CHA	LO		
QT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	TYP	RCH	RR	SS	COMMENT
3	073	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	075	08	WOODBIRCH	316	288	0.5	1	0	0	10	0	0	scorched
3	077	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	079	08	WOODBIRCH	316	288	0.5	1	0	0	10	0	0	v. lt. scorching
3	081	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	083	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	085	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	087	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
3	089	08	WOODBIRCH	316	288	0.5	0	0	0	0	0	0	no apparent change
4	091	08	WOODBIRCH	121	399	1.0	1	0	0	5	0	0	lt. scorch edge
4	093	08	WOODBIRCH	121	399	1.0	1	0	0	10	0	0	lt. scorch edge
4	095	08	WOODBIRCH	121	399	1.0	1	0	0	30	5	0	charred, 5% lost
4	097	08	WOODBIRCH	121	399	1.0	1	0	0	5	0	0	lt. scorch
4	099	08	WOODBIRCH	121	399	1.0	1	0	0	10	1	0	scorched,charred 1% lost
4	101	08	WOODBIRCH	121	399	1.0	1	0	0	10	1	0	scorched,charred 1% lost
4	103	08	WOODBIRCH	121	399	1.0	1	0	0	10	1	0	scorch,charred 1% lost
4	105	08	WOODBIRCH	121	399	1.0	1	0	0	0	10	0	charred,10% consumed
4	107	08	WOODBIRCH	121	399	1.0	1	0	0	20	1	0	scorched,charred 1% lost
4	109	08	WOODBIRCH	121	399	1.0	1	0	0	30	5	0	scorched,charred 5% lost
4	111	08	WOODBIRCH	121	399	1.0	1	0	0	20	1	0	scorched,charred 1% lost
4	113	08	WOODBIRCH	121	399	1.0	1	0	0	30	5	0	scorched,charred 5% lost
4	115	08	WOODBIRCH	121	399	1.0	1	0	0	5	1	0	scorched,charred 1% lost
4	117	08	WOODBIRCH	121	399	1.0	1	0	0	0	10	0	charred,10% lost
4	119	08	WOODBIRCH	121	399	1.0	1	0	0	0	5	0	charred, 5% lost
1	003	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	006	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	009	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	012	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	015	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	018	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	021	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	024	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	027	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
1	030	09	CHARCOAL	177	343	0.5	0	0	0	0	0	0	no apparent change
2	033	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	036	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	039	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	042	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	045	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	048	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	051	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	054	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	057	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
2	060	09	CHARCOAL	399	399	0.5	0	0	0	0	0	0	no apparent change
3	063	09	CHARCOAL	316	288	0.5						1	not placed in experiment
3	066	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
3	069	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
3	072	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change

Appendix 2. Raw data for materials included in the experimental prescribed burn at
the Oakville Prairie, November 1988, continued.

PL	SAM	MAT		5CM	10CM		COL	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	TYP	RCH	RR	SS	COMMENT
3	075	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
3	078	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
3	081	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
3	084	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
3	087	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
3	090	09	CHARCOAL	316	288	0.5	0	0	0	0	0	0	no apparent change
4	093	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	096	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	099	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	102	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	105	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	108	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	111	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	114	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	117	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
4	120	09	CHARCOAL	121	399	1.0	0	0	0	0	0	0	no apparent change
1	001	10	LEADCONE	177	343	0.5	1	0	0	10	0	0	yellow brown, smoked
1	002	10	LEADCONE	177	343	0.5	1	0	0	10	0	0	yellow brown, smoked
1	003	10	LEADCONE	177	343	0.5	1	0	0	5	0	0	diffuse yellow smoke
1	004	10	LEADCONE	177	343	0.5	1	0	0	60	0	0	yellow brown, smoked
1	005	10	LEADCONE	177	343	0.5	1	0	0	50	0	0	yellow brown, smoked
1	006	10	LEADCONE	177	343	0.5	0	0	0	0	0	0	no apparent change
1	007	10	LEADCONE	177	343	0.5	1	1	7	100	0	0	deformed, blackened
1	008	10	LEADCONE	177	343	0.5	1	0	0	40	0	0	yellow brown, smoked
1	009	10	LEADCONE	177	343	0.5	0	0	0	0	0	0	no apparent change
1	010	10	LEADCONE	177	343	0.5	1	0	0	40	0	0	yellow brown, smoked
1	011	10	LEADCONE	177	343	0.5	0	0	0	0	0	0	no apparent change
1	012	10	LEADCONE	177	343	0.5	0	0	0	0	0	0	no apparent change
1	013	10	LEADCONE	177	343	0.5	1	0	0	50	0	0	yellow brown, smoked
1	014	10	LEADCONE	177	343	0.5	1	0	0	50	0	0	yellow brown, smoked
1	015	10	LEADCONE	177	343	0.5	1	0	0	10	0	0	yellow brown, smoked
1	016	10	LEADCONE	177	343	0.5	1	0	0	10	0	0	yellow brown, smoked
1	017	10	LEADCONE	177	343	0.5	1	0	0	20	0	0	yellow brown, smoked
1	018	10	LEADCONE	177	343	0.5	1	0	0	40	0	0	yellow brown, smoked
1	019	10	LEADCONE	177	343	0.5	1	0	0	50	0	0	yellow brown, smoked
1	020	10	LEADCONE	177	343	0.5	1	0	0	40	0	0	blackened, smoked
1	021	10	LEADCONE	177	343	0.5	0	0	0	0	0	0	no apparent change
1	022	10	LEADCONE	177	343	0.5	0	0	0	0	0	0	no apparent change
1	023	10	LEADCONE	177	343	0.5	1	0	0	20	0	0	yellow brown, smoked
1	024	10	LEADCONE	177	343	0.5	1	0	0	50	0	0	blackened, smoked
1	025	10	LEADCONE	177	343	0.5	1	0	0	30	0	0	yellow brown, smoked
1	026	10	LEADCONE	177	343	0.5	0	0	0	0	0	0	no apparent change
1	027	10	LEADCONE	177	343	0.5	1	0	0	60	0	0	blackened, smoked
1	028	10	LEADCONE	177	343	0.5	1	0	0	10	0	0	yellow brown, smoked
1	029	10	LEADCONE	177	343	0.5	1	0	0	20	0	0	yellow brown, smoked
1	030	10	LEADCONE	177	343	0.5	1	1	7	90	0	0	deformed, melted
2	031	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
2	032	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked

Appendix 2. Raw data for materials included in the experimental prescribed burn at
the Oakville Prairie, November 1988, continued.

PL	SAM	MAT		5CM	10CM		COL	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	TYP	RCH	RR	SS	COMMENT
2	033	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	034	10	LEADCONE	399	399	0.5	1	0	0	90	0	0	yellow brown, smoked
2	035	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
2	036	10	LEADCONE	399	399	0.5	1	0	0	20	0	0	yellow brown, smoked
2	037	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	038	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	039	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	040	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
2	041	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	042	10	LEADCONE	399	399	0.5	1	0	0	50	0	0	yellow brown, smoked
2	043	10	LEADCONE	399	399	0.5	1	0	0	40	0	0	yellow brown, smoked
2	044	10	LEADCONE	399	399	0.5	1	0	0	40	0	0	yellow brown, smoked
2	045	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	046	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
2	047	10	LEADCONE	399	399	0.5	0	0	0	0	0	0	no apparent change
2	048	10	LEADCONE	399	399	0.5	1	0	0	40	0	0	yellow brown, smoked
2	049	10	LEADCONE	399	399	0.5	1	0	0	20	0	0	yellow brown, smoked
2	050	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
2	051	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	052	10	LEADCONE	399	399	0.5	1	0	0	10	0	0	yellow brown, smoked
2	053	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
2	054	10	LEADCONE	399	399	0.5	1	0	0	20	0	0	yellow brown, smoked
2	055	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
2	056	10	LEADCONE	399	399	0.5	1	0	0	20	0	0	yellow brown, smoked
2	057	10	LEADCONE	399	399	0.5	1	0	0	20	0	0	yellow brown, smoked
2	058	10	LEADCONE	399	399	0.5	1	0	0	20	0	0	yellow brown, smoked
2	059	10	LEADCONE	399	399	0.5	1	0	0	5	0	0	yellow brown, smoked
2	060	10	LEADCONE	399	399	0.5	1	0	0	30	0	0	yellow brown, smoked
3	061	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	062	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	063	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	064	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	065	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	066	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	067	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	068	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white,
3	069	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	070	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	071	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	072	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	073	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	074	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	075	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	076	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	077	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	078	11	LEADWING	316	288	0.5	0	0	0	0	0	0	no apparent change
3	079	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	080	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white

Appendix 2. Raw data for materials included in the experimental prescribed burn at
the Oakville Prairie, November 1988, continued.

PL	SAM	MAT		5CM	10CM		COL	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	IYP	RCH	RR	SS	COMMENT
3	081	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	082	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	083	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	084	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	085	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	086	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	087	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	088	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	089	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
3	090	11	LEADWING	316	288	0.5	1	0	0	0	0	0	oxidation, white
4	091	11	LEADWING	121	399	1.0	0	0	0	0	0	0	no apparent change
4	092	11	LEADWING	121	399	1.0	0	0	0	0	0	0	no apparent change
4	093	11	LEADWING	121	399	1.0	1	0	0	50	0	0	blackened, smoked
4	094	11	LEADWING	121	399	1.0	1	0	0	50	0	0	blackened, smoked
4	095	11	LEADWING	121	399	1.0						1	likely smoked, lost
4	096	11	LEADWING	121	399	1.0						1	likely smoked, lost
4	097	11	LEADWING	121	399	1.0	0	0	0	0	0	0	no apparent change
4	098	11	LEADWING	121	399	1.0	1	0	0	40	0	0	yellow brown, smoked
4	099	11	LEADWING	121	399	1.0	0	0	0	0	0	0	no apparent change
4	100	11	LEADWING	121	399	1.0	1	0	0	40	0	0	yellow brown, smoked
4	101	11	LEADWING	121	399	1.0	1	0	0	50	0	0	yellow brown, smoked
4	102	11	LEADWING	121	399	1.0	1	1	6	40	0	0	slightly deformed wing
4	103	11	LEADWING	121	399	1.0	1	0	0	40	0	0	yellow brown, smoked
4	104	11	LEADWING	121	399	1.0	1	1	7	100	0	0	deformed
4	105	11	LEADWING	121	399	1.0	1	1	6	50	0	0	slightly deformed wing
4	106	11	LEADWING	121	399	1.0	1	0	0	60	0	0	blackened, smoked
4	107	11	LEADWING	121	399	1.0	1	0	0	50	0	0	blackened, smoked
4	108	11	LEADWING	121	399	1.0	1	1	6	80	0	0	slightly deformed wing
4	109	11	LEADWING	121	399	1.0	1	0	0	40	0	0	blackened, smoked
4	110	11	LEADWING	121	399	1.0	1	1	7	100	0	0	deformed
4	111	11	LEADWING	121	399	1.0	1	0	0	70	0	0	yellow brown, smoked
4	112	11	LEADWING	121	399	1.0						1	likely smoked, lost
4	113	11	LEADWING	121	399	1.0	1	0	0	60	0	0	blackened, smoked
4	114	11	LEADWING	121	399	1.0	1	0	0	50	0	0	yellow brown, smoked
4	115	11	LEADWING	121	399	1.0	0	0	0	0	0	0	no apparent change
4	116	11	LEADWING	121	399	1.0						1	likely smoked, lost
4	117	11	LEADWING	121	399	1.0	0	0	0	0	0	0	no apparent change
4	118	11	LEADWING	121	399	1.0	1	0	0	50	0	0	blackened, smoked
4	119	11	LEADWING	121	399	1.0	1	0	0	30	0	0	yellow brown, smoked
4	120	11	LEADWING	121	399	1.0	1	0	0	20	0	0	yellow brown, smoked
1	001	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	red, no apparent change
1	002	12	GLASSBEAD	177	343	0.5	1	0	0	10	0	0	white, yellow brown smoke
1	003	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	blue, no apparent change
1	004	12	GLASSBEAD	177	343	0.5	1	0	0	20	0	0	red, blackened
1	005	12	GLASSBEAD	177	343	0.5	1	0	0	20	0	0	white, blackened
1	006	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	blue, no apparent change
1	007	12	GLASSBEAD	177	343	0.5	1	0	0	50	0	0	red, blackened
1	008	12	GLASSBEAD	177	343	0.5	1	0	0	30	0	0	white, yellow brown smoke

Appendix 2. Raw data for materials included in the experimental prescribed burn at
the Oakville Prairie, November 1988, continued.

PL	SAM	MAT		5CM	10CM		COL	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	TYP	RCH	RR	SS	COMMENT
1	009	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	blue, no apparent change
1	010	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	red, one small pit?
1	011	12	GLASSBEAD	177	343	0.5	1	0	0	5	0	0	white, 5% yellow smoke
1	012	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	blue, no apparent change
1	013	12	GLASSBEAD	177	343	0.5	1	0	0	10	0	0	red, blackened
1	014	12	GLASSBEAD	177	343	0.5	1	0	0	20	0	0	white, yellow smoke
1	015	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	blue, no apparent change
1	016	12	GLASSBEAD	177	343	0.5	1	0	0	10	0	0	red, blackened
1	017	12	GLASSBEAD	177	343	0.5	1	0	0	30	0	0	white, yellow smoke
1	018	12	GLASSBEAD	177	343	0.5	1	0	0	20	0	0	blue, blackened
1	019	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	red, no apparent change
1	020	12	GLASSBEAD	177	343	0.5	1	0	0	50	0	0	white, blackened
1	021	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	blue, no apparent change
1	022	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	red, no apparent change
1	023	12	GLASSBEAD	177	343	0.5	1	0	0	50	0	0	white, blackened
1	024	12	GLASSBEAD	177	343	0.5	1	0	0	10	0	0	blue, yellow smoke
1	025	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	red, no apparent change
1	026	12	GLASSBEAD	177	343	0.5	1	0	0	10	0	0	white, yellow smoke
1	027	12	GLASSBEAD	177	343	0.5	1	0	0	40	0	0	blue, blackened
1	028	12	GLASSBEAD	177	343	0.5	0	0	0	0	0	0	red, no apparent change
1	029	12	GLASSBEAD	177	343	0.5	1	0	0	10	0	0	white, blackened
1	030	12	GLASSBEAD	177	343	0.5	1	1	6	20	0	0	slightly deformed, smoked
2	031	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	red, no apparent change
2	032	12	GLASSBEAD	399	399	0.5	1	0	0	20	0	0	blue, yellow brown smoke
2	033	12	GLASSBEAD	399	399	0.5	1	0	0	10	0	0	white, yellowish smoke
2	034	12	GLASSBEAD	399	399	0.5	1	0	0	30	0	0	red, brown smoked
2	035	12	GLASSBEAD	399	399	0.5	1	0	0	40	0	0	white, yellowish smoke
2	036	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	blue, no apparent change
2	037	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	red, no apparent change
2	038	12	GLASSBEAD	399	399	0.5	1	0	0	30	0	0	white, yellowish smoke
2	039	12	GLASSBEAD	399	399	0.5	1	0	0	20	0	0	blue, yellowish smoke
2	040	12	GLASSBEAD	399	399	0.5	1	0	0	30	0	0	red, blackened
2	041	12	GLASSBEAD	399	399	0.5	1	0	0	40	0	0	white, yellow brown smoke
2	042	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	blue, no apparent change
2	043	12	GLASSBEAD	399	399	0.5	1	0	0	90	0	0	red, blackened
2	044	12	GLASSBEAD	399	399	0.5	1	0	0	80	0	0	white, blackened
2	045	12	GLASSBEAD	399	399	0.5	1	0	0	30	0	0	blue, yellow brown smoke
2	046	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	red, no apparent change
2	047	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	white, v. lt. smoke?
2	048	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	blue, v. lt. smoke?
2	049	12	GLASSBEAD	399	399	0.5	1	0	0	5	0	0	red, blackened
2	050	12	GLASSBEAD	399	399	0.5	1	0	0	10	0	0	white, faint yellow smoke
2	051	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	blue, no apparent change
2	052	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	red, yellowish smoke?
2	053	12	GLASSBEAD	399	399	0.5	1	0	0	50	0	0	white, smoked, blackened
2	054	12	GLASSBEAD	399	399	0.5	1	0	0	80	0	0	blue, blackened
2	055	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	red, faint yellow smoke?
2	056	12	GLASSBEAD	399	399	0.5	1	0	0	20	0	0	white, yellowish smoke

Appendix 2. Raw data for materials included in the experimental prescribed burn at
the Oakville Prairie, November 1988, concluded.

PL	SAM	MAT		5CM	10CM		COL	FR	FR	SCO	CHA	LO	
OT	PLE	CODE	MATNAME	TEMP	TEMP	DURA	CHA	ACT	TYP	RCH	RR	SS	COMMENT
2	057	12	GLASSBEAD	399	399	0.5	1	0	0	40	0	0	blue, yellowish smoke
2	058	12	GLASSBEAD	399	399	0.5	0	0	0	0	0	0	red, faint yellow smoke?
2	059	12	GLASSBEAD	399	399	0.5	1	0	0	20	0	0	white, yellow brown smoke
2	060	12	GLASSBEAD	399	399	0.5	1	0	0	60	0	0	blue, brown smoke
4	091	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	red, v. lt. smoke?
4	092	12	GLASSBEAD	121	399	1.0	1	0	0	30	0	0	white, blackened
4	093	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	blue, lt. yellow smoke?
4	094	12	GLASSBEAD	121	399	1.0	1	0	0	30	0	0	red, blackened
4	095	12	GLASSBEAD	121	399	1.0	1	0	0	30	0	0	white, 10YR7/3 smoke
4	096	12	GLASSBEAD	121	399	1.0	1	0	0	50	0	0	blue, yellowish smoke
4	097	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	red, no apparent change
4	098	12	GLASSBEAD	121	399	1.0	1	0	0	20	0	0	white, yellow smoke
4	099	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	blue, v. lt. smoke?
4	100	12	GLASSBEAD	121	399	1.0	1	0	0	30	0	0	red, blackened
4	101	12	GLASSBEAD	121	399	1.0	1	0	0	20	0	0	white, yellow brown smoke
4	102	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	blue, v. lt. smoke?
4	103	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	red, v. lt. smoke?
4	104	12	GLASSBEAD	121	399	1.0	1	0	0	90	0	0	white, blackened
4	105	12	GLASSBEAD	121	399	1.0	1	0	0	90	0	0	blue, blackened
4	106	12	GLASSBEAD	121	399	1.0	1	0	0	20	0	0	red, blackened
4	107	12	GLASSBEAD	121	399	1.0	1	1	6	80	0	0	white, blackened, melted
4	108	12	GLASSBEAD	121	399	1.0	1	0	0	20	0	0	blue, blackened
4	109	12	GLASSBEAD	121	399	1.0	1	0	0	10	0	0	red, brown smoke
4	110	12	GLASSBEAD	121	399	1.0	1	0	0	80	0	0	white, blackened
4	111	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	blue, v. lt. smoke?
4	112	12	GLASSBEAD	121	399	1.0	1	0	0	80	0	0	red, blackened
4	113	12	GLASSBEAD	121	399	1.0	1	0	0	10	0	0	white, yellow brown smoke
4	114	12	GLASSBEAD	121	399	1.0	1	0	0	50	0	0	blue, blackened
4	115	12	GLASSBEAD	121	399	1.0	0	0	0	0	0	0	red, no apparent change
4	116	12	GLASSBEAD	121	399	1.0	1	0	0	80	0	0	blue, blackened
4	117	12	GLASSBEAD	121	399	1.0	1	0	0	100	0	0	white, blackened
4	118	12	GLASSBEAD	121	399	1.0	1	0	0	30	0	0	red, blackened
4	119	12	GLASSBEAD	121	399	1.0	1	0	0	30	0	0	white, blackened, smoked
4	120	12	GLASSBEAD	121	399	1.0	1	0	0	30	0	0	blue, brown smoked

APPENDIX 3

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APPENDIX 4

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APPENDIX 5

SAMPLE APPLICATION FOR OPEN BURN VARIANCE AND
BURN PLAN/REPORT FORM



NORTH DAKOTA
STATE DEPARTMENT OF HEALTH

State Capitol
Bismarck, North Dakota 58505

M. A. K. Lommen, M.D., R.P.E.
State Health Officer

Environmental Health Section
Missouri Office Building
1200 Missouri Avenue
Bismarck, North Dakota 58505

AP (Form) 2-72

APPLICATION FOR OPEN BURNING VARIANCE

Name and Address Institute for Ecological Studies
University of North Dakota
Grand Forks, ND 58202

Title R. W. Seabloom, Professor Phone 701-777-4676

Description of Material to be burned (e.g., dry leaves, trees,
old buildings, etc.) Grassland

Location of burning site: Portion of Oakville Prairie Field Station

Section 16 Township 151N

Range 52W County Grand Forks

Nearest towns: (within 5 miles)

Name <u>Emerado</u>	Direction <u>NW</u>	Distance <u>2.5 mi.</u>
<u>Grand Forks</u>		
<u>Air Force Base</u>	<u>NW</u>	<u>3.5 mi.</u>

Nearest occupied residence within 1 mile:

Name <u>W. C. Koenig</u>	Direction <u>W</u>	Distance <u>1.5 mi</u>
<u>Earl Ieddige</u>	<u>NW</u>	<u>2.0 mi</u>

(over)

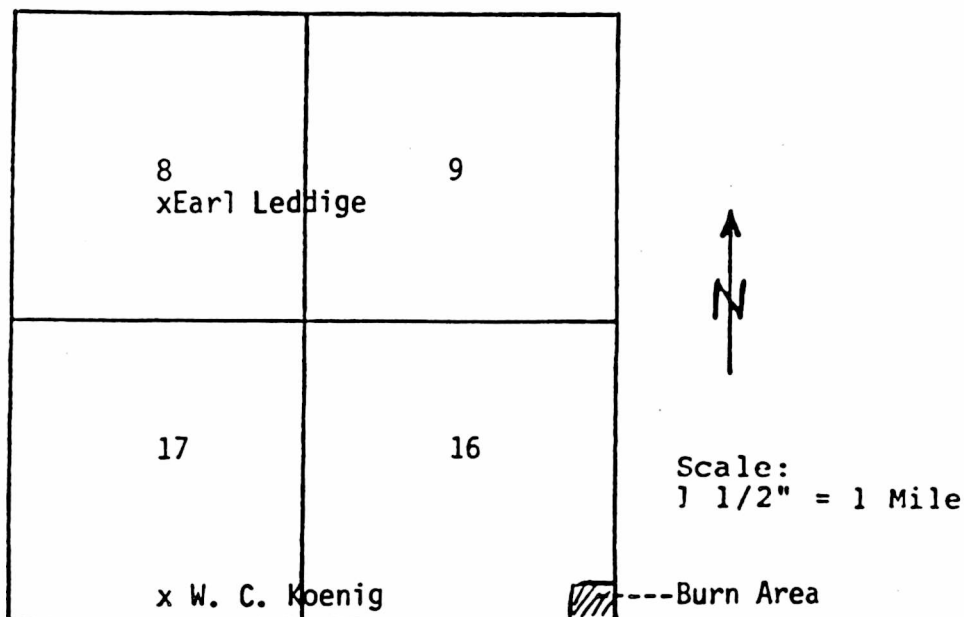
Reason for burning: Test burn of small plots (10m²) to determine the
impact of fire on archaeological resources. Study is in cooperation with
Knife River Indian Villages National Historic Site.

Amount of time required to complete burn: ½ day

Burning will be supervised by: R. W. Seabloom

Approximate date burning will be completed subject to atmos-
pheric conditions: Oct. 8, 1988

Sketch
Location of Homes and Towns



I, the undersigned, understand this authority to conduct open burning as stated above, if approved, does not exempt or excuse a person from the consequences, damages, or injuries which may result therefrom. I also agree to comply with the conditions of Sub-section(s) 6 and/or 7 of Section 33-15-04-02 of the North Dakota Air Pollution Control Regulations.

Comments

Date 23 Sept., 1988

Signature *R. W. Seabloom*

Approval No. _____

(For Official Use)



NORTH DAKOTA
STATE DEPARTMENT OF HEALTH
AND CONSOLIDATED LABORATORIES

State Capitol
Bismarck, North Dakota 58505

ENVIRONMENTAL HEALTH SECTION

1200 Missouri Avenue
P.O. Box 5520
Bismarck, North Dakota 58502-5520

VARIANCE APPROVAL TO OPEN BURN

This Department hereby grants R. W. seabloom, University of ND
(Name of Applicant)

a Variance to Open Burn 10m² plots of grassland
(Type of Material)

at the following location: Portion of Oakville Prairie Field Station

SECTION 16 TOWNSHIP 151N

RANGE 52W COUNTY Grand Forks

Subject to the following conditions and/or restrictions:

1. Prevailing winds at the time of burning must be away from any nearby residence(s) or city.
2. Care must be used to minimize the amount of dirt on the material being burned.
3. Oil, rubber, and other material which produce unreasonable amounts of air contaminants may not be burned.
4. The initial burning may begin only between three hours after sunrise and three hours before sunset and additional fuel may not be intentionally added to the fire at times outside the limits stated above.
5. The burning must not be conducted adjacent to any highway or public road so as to create a traffic hazard.
6. The material must be dry enough to burn cleanly.
7. This variance must be utilized within 60 days of receipt of this notice.
8. The local fire department must be notified prior to burning.



NORTH DAKOTA
STATE DEPARTMENT OF HEALTH
AND CONSOLIDATED LABORATORIES

State Capitol
Bismarck, North Dakota 58505

ENVIRONMENTAL HEALTH SECTION

September 27, 1988

1200 Missouri Avenue
P.O. Box 5520
Bismarck, North Dakota 58502-5520

R. W. Seabloom, Professor
Institute for Ecological Studies
University of North Dakota
Grand Forks, ND 58202

Re: Open Burning Variance

Dear Professor Seabloom:

Attached is a Variance Approval to Open Burn small plots of grassland to determine the impact of fire on archeological resources. The Variance Approval to Open Burn is issued by the Department in response to your application dated September 23, 1988, and in accordance with the North Dakota Air Pollution Control Rules (Article 33-15, North Dakota Administrative Code).

The Governor of the State of North Dakota issued Executive Order 1988-10, effective September 21, 1988, which prohibits all outdoor fires throughout the state when the National Weather Service fire danger index is "very high" or "extreme," unless accompanied by fire fighting equipment as approved by the State Fire Marshal. Therefore, while the Executive Order is in effect Condition 10 of the Variance Approval to Open Burn is modified accordingly.

If you have any questions, please do not hesitate to contact this office.

Sincerely,

Gary L. Kline
Environmental Engineer
Air Quality Management Branch
Div. of Environmental Engineering

GLK:aks

Encl:

cc: Grand Forks Public Health Dept.

9. The burning must be conducted in such a manner to ensure that the refuse that is covered or is about to be covered cannot start on fire.
10. Burning is prohibited if the fire index is in the "extreme" category as issued by the National Weather Service. Notification to this Department is required prior to starting the burn if the fire index is in the "very high" category.
11. If State or local fire officials determine conditions to be unsafe for open burning, such burning must cease until conditions are deemed to be safe.

Be advised that granting you a variance does not exempt or excuse you from the consequences, damages or injuries which may result therefrom.

DATE:

8/27/88

APPROVED BY:


Dana K. Mount, Directorfor
TITLE: Division of Env. Engr.

PRESCRIBED BURN PLAN REPORT

AREA ONLY

Burn Number

Assigned Burn Boss

Expiration Date

LOCATION:

County	Section	Township	Range	Forty(ies)	Administrator	Land Status	Expiration Date
--------	---------	----------	-------	------------	---------------	-------------	-----------------

BURN DATE FRAMES:

Preferred	Acceptable	Actual
-----------	------------	--------

CHARACTERISTICS:

Fuel Model	Loading	Arrangement	Soil Type(s)	Other:
------------	---------	-------------	--------------	--------

PURPOSE OF BURN. (mark the correct box and provide explanation)

☐ Forest Management ☐ Wildlife Habitat ☐ Fuels Management ☐ Prairie Management ☐ Other

EXPLANATION:

WEATHER & FUEL CONDITIONS.

NFDRS INDEXES

FIRE BEHAVIOR

	Acres	Wind/Speed	Temp.(°F)	Rel. Hum.	10 hr. Fuel Moist	BI	SC	Spread Rate	Flame Ht.
DESIRED									
FORECAST									
ACTUAL									

FIRING PATTERN:

- (1) STRIP BACKFIRE (2) STRIP HEADFIRE (3) CHECKERBOARD
4) SPOTTING (5) CENTER FIRE

IGNITION TECHNIQUES.

☐ GROUND ☐ AERIAL

MANPOWER NEEDS.

MAP LEGEND SCALE () = 1 mile

EQUIPMENT NEEDS:

PRE-BURN CHECKLIST:

- ☐ Checked Today's Weather & Forecast
- ☐ Indexes are within Prescriptions
- ☐ Sufficient Manpower Present
- ☐ Sufficient Equipment Present
- ☐ Briefed Crews on Burn Plan/Map
- ☐ Reviewed Firing Techniques
- ☐ Reviewed Contingency Plan
- ☐ Media/Cooperators Contacted
- ☐ Arranged For Data Collection
- ☐ CPR Trained Person Present

Burn Boss's Signature

Time & Date

PLAN APPROVAL SIGNATURES

Dis. Forester or DNR Unit Supv's Signature	Date
Area Forest Supervisor's Signature	Date

POST BURN EVALUATION:**DEGREE OF SUCCESS** (measureable): _____**REMARKS ON CONTROL/FIRE BEHAVIOR:** _____**GENERAL REMARKS/SUGGESTIONS:** _____

Burn Boss's Signature

Date

PROJECT FUNDING:

AD or Other Number
Discipline Project No...
AD
Y.
Cost Estimate

PROJECT COST:**ACTUAL BURN****TRAINING**

1. DNR Personnel \$
2. Hired Labor
3. Hired Equipment ..
4. DNR Equipment
5. Other

TOTALS \$**COST/ACRE** \$**FOLLOW-UP EVALUATION:** (within one (1) year after burn)

Evaluator's Signature

Date

