

FOSSILS AND FIRE: A STUDY ON THE EFFECTS OF FIRE ON PALEONTOLOGICAL RESOURCES AT BADLANDS NATIONAL PARK

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Abstract—National Park Service policies stipulate that each park with vegetation capable of burning will prepare a fire management plan. Badlands National Park completed its fire management plan in 2004. Fossils are a principle resource of the park and the fire sensitivity of fossils is the focus of this study. The surface temperatures of fossil specimens and fire behavior characteristics were monitored in prescribed fires on the landscape and in laboratory burns to develop an understanding of the relationship between burning conditions and changes in fossil specimen properties. Under laboratory conditions, low intensity and low to intermediate rates of spread, the surface temperatures of fossil specimens showed limited temperature increases and no surface discoloration. The fossils included invertebrates from the Cretaceous Pierre Shale and fossil mammal remains from the Eocene/Oligocene White River Group. All specimens had been confiscated during law enforcement activities within the park. The results from burns under these conditions showed that only fossil specimens that were in contact with burning fuel showed increased surface temperatures and discoloration. The laboratory results from burns conducted under high intensity and high rates of spread conditions showed increased surface temperatures and surface discoloration and that the changes in fossil specimen properties were not dependent upon contact with fuel. In field trials during the spring of 2001, prescribed burn treatments were limited by environmental conditions to low rate of spread and low intensity burns. Under these conditions high surface temperatures and surface discoloration were observed on samples that were in direct contact with fuel. Samples that were not in contact with fuel did not show surface discoloration or significant surface heating. Both laboratory and field burns suggest that low to moderate fire conditions have minimal impact on fossil resources except in areas where the fossils are in contact with fuel. The laboratory portion of this study suggests that significant fire effects would be found under high spread rate and high intensity conditions even though there is no fuel contact.

INTRODUCTION

Staff at Badlands National Park (BADL), the Black Hills Fire Use Module and the Midwest Regional Office worked in partnership with researchers from the U.S. Forest Service (USFS) Fire Sciences Laboratory in Missoula, Montana to determine the effects of fire in a prescribed setting on fossil resources within Badlands National Park.

Badlands National Park is world renown for its fossil resources. Paleontological research began in western South Dakota in 1846 with the discovery of a brontothere jaw by fur traders while traveling along the Ft. Pierre to Laramie trail (Prout, 1846). Following this discovery, museums and research institutions sent out surveys to the Dakota Territories from the 1850s through the 1880s. Paleontological research has continued on into the present. Every major museum in North America and Europe has White River Group Collections from western South Dakota.

Paleontological resources were a major reason for originally establishing Badlands National Monument in 1939, for adding the 133,000-acre Stronghold District in 1976 and for obtaining national park status in 1978 (Presidential Proclamation Number 2320 [53 Stat. 2521] and 16 USC 441; National Parks and Recreation Act of November 10, 1978). The congressional report accompanying the 1929 Organic Act for Badlands National Park described the reasons for setting aside the area as the preservation of a unique geological and eroded landscape and because, “vast beds of vertebrate fossil remains are a vast storehouse of the biological past” (Report Number 2607 of the Committee on the Public Lands, 70th Congress – 2nd Session – March 4, 1929).

National Park Service (NPS) Management Policies (National Park Service, 2001) mandate that each park with vegetation capable of burning must prepare a fire management plan, designed to guide a program that responds to the park’s natural and cultural resource objectives. Within

Director’s Order 18 (National Park Service, 2002), wild land fuel complexes are managed to achieve resource benefits and management goals such as hazard fuel reduction, ecosystem restoration and maintaining ecosystem health. One form of hazard fuel reduction is the use of prescribed burns.

Fire effects on paleontological resources has not been well studied. Studies of fire effects on native rock such as obsidian and chert have shown a wide range of responses (Buenger, 2003) due to key fire behavior characteristics such as intensity and duration (Traylor et al., 1983). Small temperature changes have great impacts on fossil specimens and several papers outlining proper storage conditions for fossil specimens have echoed this conclusion (Ashley-Smith, 1987; Brunton, et al., 1985; Fitzgerald, 1995; Howie, 1978; Howie, 1979; Johnson and Horgan, 1979; Stolow, 1966; Thomson, 1986).

The Badlands National Park Fire Management Plan, mandates that the park implement a prescribed burn cycle spanning 15 years, burning over 60,000 acres. As a result of fire management planning, badlands geologic formations have been routinely designated as fire breaks. This study was conducted to address concerns about the potential effects of increased burn activity on the fossil resources at BADL.

METHODS AND RESULTS

This study included prescribed burns conducted in BADL during the spring of 2000 and 2001 and laboratory burning at the USFS Fire Sciences Laboratory in Missoula, Montana in 2001.

2000 FIELD STUDY METHODS

In the spring of 2000, a pilot study was conducted to evaluate fire effects on paleontological resources within a prescribed burn setting.

The prescribed burning was conducted on the Pinnacles Burn Area, which is located on the northeastern boundary of the Badlands Wilderness Area (Fig. 1). The selected study areas within the prescribed burn unit were composed of different fuel types and loadings.

The ground cover in the burn unit ranged from bare soil to areas of mostly continuous grass or grass/shrub cover. Representative study sites were selected in a woody draw (small natural drainage areas covered by trees and shrubs), an area of sparse grass and forb cover, a bare outcrop and a grass covered site.

Six study plots, each consisting of a single fossil specimen from the Eocene/Oligocene White River Group (Fig. 2; Appendix 1) and one tile coated with heat sensitive paint were arranged for the study. The tiles were placed within the burn unit in conjunction with fossil specimens that were either brought in or in situ.

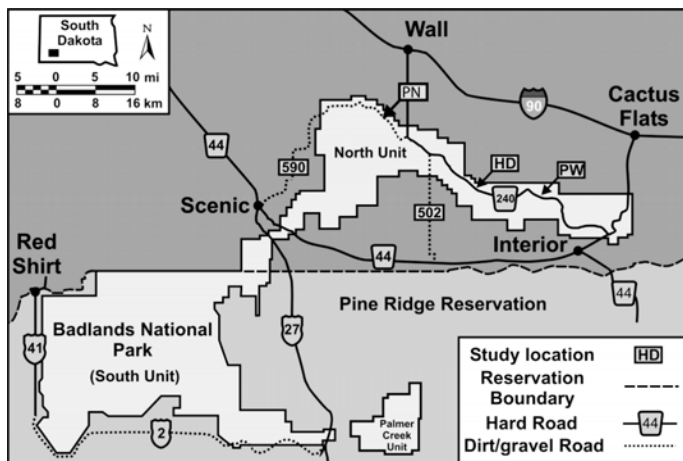


FIGURE 1. Map of Badlands National Park showing study locations. (HD = Hamms Draw; PW = Prairie Winds; PN = Pinnacles; Adapted from Benton et al., 2001).

2000 FIELD STUDY RESULTS

The burn was a low intensity backing fire that primarily burned down hill through the study area. Three of six specimens were damaged during this prescribed burn. The damaged samples were present in the grass and woody draw sites. Post-burn analysis of the specimens from these sites showed surfaces with a brown tar build-up and some smoke staining. Specimens naturally occurring in areas between two and ten meters away from flames were not affected. No change in color of the tiles was observed.

2001 FIELD STUDY METHODS

The 2001 field study was conducted to develop an understanding of the fire environment associated with fossil specimen changes observed during prescribed fires. The fire characteristics that were measured during prescribed burning served as the basis for the development of experimental treatments for the laboratory portion of this study.

The field component of this study included four study sites that were established in the Roadside Burn unit. The burn unit was located on the south side of Rt. 240 between Big Foot Road and Quinn Road intersections (Fig. 1). Data collected from these study sites were representative of the grassland/shrub fuel type found at BADL. The Prairie Wind #1 and Hamms Draw #1 sites were located on flat areas dominated by grassland fuels at an estimated loading of approximately 1000 lbs/acre. Prairie Wind #2 was located in sparse shrub land directly adjacent to badlands. The Hamms Draw #2 site was located in a small draw with a 5-10% slope and was dominated by grass and shrub fuels (Table 1).

The ground cover at Prairie Wind #1 and Hamms Draw #1 was continuous. These sites were considered unnatural settings because fos-

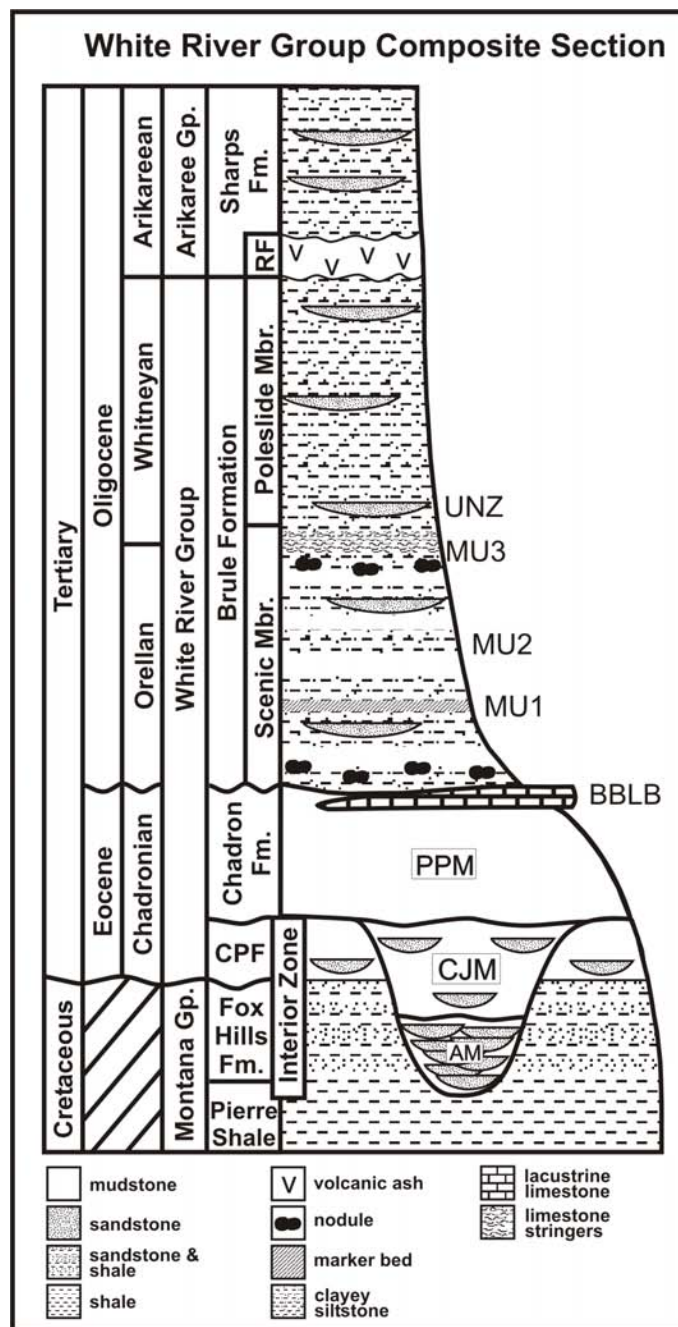


FIGURE 2. Stratigraphic column showing rock formations exposed at Badlands National Park. (AM, CJM and PPM = the Ahearn, Crazy Johnson and Peanut Peak Members of the Chadron Formation, respectively; BBLB = Bloom Basin Limestone Beds; CPF = Chamberlain Pass Formation; LNZ = Lower Nodular Zone; MU = Marker Unit; RF = Rockyford Ash; UNZ = Upper Nodular Zone; Adapted from Benton et al., 2001).

sils are normally found in areas with exposed soil and bedrock and not in areas with continuous grass cover (Table 1).

Fossil specimens from the Cretaceous Pierre Shale and Eocene/Oligocene White River Group were placed on the ground surface at each site (Fig. 2; Appendix 1). Temperatures were measured on the surface of each specimen by small gauge thermocouples attached to the samples. Thermocouples were also used to make temperature measurements on the soil surface and at depths below the soil surface (Figs. 3 and 4).

Radiant heat flux is a measure of the amount of energy transferred from the flaming combustion zone to the surface of the specimens and the soil surface. Radiant heat flux was measured at the soil surface adja-

TABLE 1. Study Site Characteristics – 2001 Field Study. (Radiant flux is measured in kw/m^2 ; na = measurements not available).

STUDY SITE	FUEL	SLOPE (%)	FIRE TYPE	RADIANT FLUX	SETTING TYPE
Hamms Draw #1	Grass	None	Head fire	15.8	Unnatural
Hamms Draw #2	Grass/woody shrubs	5-10	Head fire burning uphill	8.1	Natural
Prairie Wind #1	Dense grass	None	Backing fire	10.7	Unnatural
Prairie Wind #2	Sparse grass/shrubs	None	Head fire	na	Natural

cent to the specimens at each site. Sampling was conducted at two-second intervals for both the temperature and flux. Measurements at each site were recorded with data-logging equipment.

A line of fire was ignited adjacent to each study area and the fire spread through each study site. The fires on the Hamms Draw #1 and Prairie Wind #2 were primarily wind driven head fires while the fire on Prairie Wind #1 was a backing fire. The Hamms Draw #2 site was ignited at the base of the draw and the fire moved up slope through the shrub and grass fuels. All of the 2000 and 2001 prescribed burns followed the Northern Great Plains Prescription for Management of Ignited Prescribed Fires utilizing following ranges: an air temperature of $1.7\text{--}32^\circ\text{C}$ ($35\text{--}90^\circ\text{F}$), a relative humidity of 20-60% and a mid-flame wind speed of $3.2\text{--}16.1\text{ km/h}$ ($2\text{--}10\text{ mph}$) (Rothermel, 1983; Andrews, 1986).

2001 FIELD STUDY RESULTS

The study plots were burned mid-morning to early afternoon under conditions of low wind speed, moderate temperature and relative humidity. Although study site differences were noted in flame front characteristics, fires on these study sites were all characterized by relatively low rates of spread and low intensities. All temperature, humidity and wind speed parameters fell within the Northern Great Plains Prescription for Management of Ignited Prescribed Fires

The peak radiant flux (amount of radiant heat that a fossil surface would receive from flames during burning) measured at the surface of the sites range from 8 to 15.8 kw/m^2 (kilowatts per square meter). Observations at the time of burning showed that the radiant flux was greatest on the Prairie Wind #1 site and lowest on the Hamms Draw #2 site (Table 1). The flame front on the Prairie Wind #2 site failed to reach the radiant flux and soil temperature sensors. Rates of spread and flame angle for two of the four sites were estimated from video imagery taken at the time of the burn. Prairie Wind #1 had a rate of spread of $0.7\text{--}0.8\text{ m/min}$ (meters per minute) and a vertical to one-degree flame angle. Hamms Draw #2

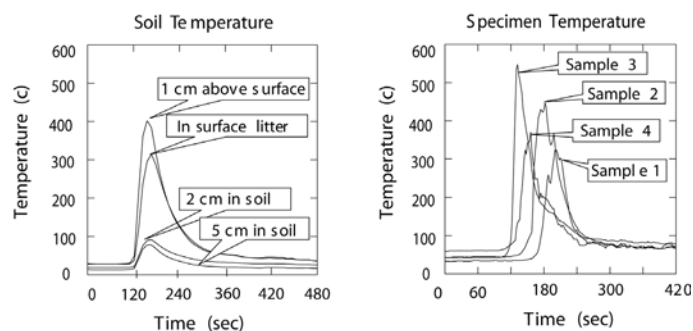


FIGURE 3. Prairie Wind #1; Soil Temperature (left) and Specimen Surface Temperature (right).

TABLE 2. Maximum Specimen Surface Temperatures – 2001 Field Study. (Average maximum temperature increases are calculated from pre-burn ambient temperatures).

STUDY SITE	AVERAGE MAXIMUM SURFACE TEMPERATURE ($^\circ\text{C}$)	TEMPERATURE INCREASE ($^\circ\text{C}$)
Hamms Draw #1	139	129.6
Hamms Draw #2	61	44.3
Prairie Wind #1	439.3	416.3
Prairie Wind #2	45.3	23.03

had a rate of spread of $0.5\text{--}0.6\text{ m/min}$ and a flame angle of 1-2 degrees. Higher rates of spread and longer flame lengths were observed on areas similar to our study sites in the late afternoon when wind speed and temperature increased and relative humidity decreased.

Above ground temperatures associated with soil temperature measurement were greatest at the Prairie Wind #1 site (Fig 3). The maximum above ground surface temperature was 418°C and the soil temperature at 5 cm depth was 82°C . Above ground and soil temperature changes were lowest on the Hamms Draw #2 (Fig 4). Maximum soil surface temperature on this site was 31°C and the temperature at the 5 cm depth was 21°C .

The greatest specimen surface temperature changes occurred at Prairie Wind #1. Maximum temperatures ranged from $324\text{ to }439.3^\circ\text{C}$ (Fig. 3). Specimens at Hamms Draw #2 showed limited changes in specimen surface temperatures. Maximum temperatures on this site ranged from $55\text{ to }67^\circ\text{C}$ (Fig. 3). The lowest increases in specimen surface temperature were measured on the Prairie Wind #2 site (Table 2). However, the results at the Prairie Wind #2 were inconsistent. Three specimens showed surface temperature increases to 45°C and no damage, while the remaining specimen showed an increase to 250°C for a 24 sec interval and sustained damage (Appendix 1).

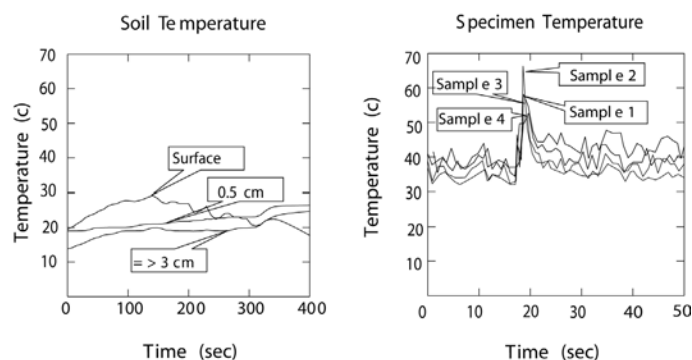


FIGURE 4. Hamms Draw #2; Soil Temperature (left) and Specimen Surface Temperature (right).

Pre- and post-burn comparison of the fossil specimens showed some surface color changes from light color to chocolate brown. The effects were sporadic in sparse fuel settings on Hamms Draw #2 and Prairie Wind #2 sites with partial discoloration in some specimens (Fig 5a). Fossils that were placed in contact with fuel showed consistent discoloration (Fig 5b).

LABORATORY STUDY METHODS

Predicting the fire effects on fossil specimens requires an understanding of the factors affecting the heat transfer from a flaming fire front to the surface of the specimens. As a consequence, the level of fire effects is a function of interrelated factors such as fire intensity, rate of spread

TABLE 3. Maximum Specimen Surface Temperatures – 2001 Laboratory Study. (Average Maximum temperature increases are calculated from pre-burn ambient temperatures).

TREATMENT	AVERAGE MAXIMUM SURFACE TEMPERATURE (°C)	TEMPERATURE INCREASE (°C)
1	31.86	13.74
2	31.64	14.11
3	59.22	40.95
4	44.61	28.59
5 WT	328.77	304.49
6 WT	492.33	467.51
7	493.75	471.5

and flame angle. The laboratory portion of this study concentrated on the relationship between the fire effects on fossil specimens and fire behavior characteristics in a controlled setting.

Laboratory burns were designed to simulate commonly occurring prescribed burning conditions which range from slowly spreading, low intensity fires to quickly spreading, high intensity fires. A range of potential fire effects was created by the seven burn treatments. For burns #1-#7 increases in fire intensity levels were achieved by increased rates of fire spread. Increased spread rates were obtained by increased fuel bed slope or by burning in a wind tunnel (Albini and Baughman, 1979; Rothmel, 1983). Burn treatment #7 was conducted at an intensity similar to burns #3 and #4 but designed to simulate a non-typical or unnatural fossil sites where the fossils were in contact with the fuel.

Burning was done in a controlled environment at the USFS Rocky Mountain Research Station, Fire Sciences Laboratory. We used standard laboratory procedures developed for the measurement of fire behavior



FIGURE 6. Photo of laboratory setup for burn studies.

model parameters (Catchpole et al., 1998).

Grass and grass-shrub fuels are common in BADL. Fire behavior in these grassland communities is dominated by herbaceous fuels (Anderson, 1982). Typical fuel loadings were simulated with grass and grass/shrub treatments. Fuel beds (4.5 x 1 m, L x W) were created using excelsior and multi-flora rose. Excelsior, which is composed of fine aspen wood shavings, was used as a grass fuel surrogate at 1000 lbs/acre. Partially dried multi-flora rose shrubs were added to simulate shrub fuel loadings associated with grassland/shrub fuel complex. The addition of this material increased the fuel loading to approximately 1200-1400 lbs/acre. A total of seven burns were completed.

A rock bed (0.5 x 1.0 m, L x W) was placed at the end of each fuel bed to simulate bare ground adjacent to burning fuel. The rock bed was divided into two parts with a rock matrix composed of either Pierre Shale or mudstones from the White River Group (Fig. 6).

The burns were conducted using fossil samples from two geologic time periods: specimens of marine invertebrates from the Cretaceous Pierre Shale and vertebrates from the Eocene/Oligocene White River Group. For each burn treatment fossil specimens were placed on the rock surface between 2.5 and 7.6 cm from the end of the fuel beds. A total of 28 fossil specimens from the Cretaceous Pierre Shale and Eocene/Oligocene White River Group were used in this study (Fig. 2; Appendix 1).

Thermocouples were attached to the surface of each fossil sample to measure temperature at 0.05 second intervals. Video camera imagery taken during each burn was analyzed to determine the rate of spread and



FIGURE 5. A, Photo showing sparse burn coverage at Hamms Draw Site #2 (BADL 39764). B, Pre-burn and post-burn photos of field specimens from Prairie Wind #1 (BADL 39766).

TABLE 4. Burn Treatment Characteristics – 2001 Laboratory Study. (Effective wind speed was calculated for burns 3, 4 and 7 based on slope of the fuel bed. Radiant and total surface flux is reported in kw/m². WT = wind tunnel, G = grass fuel loading treatment, GS = grass/shrub fuel loading treatment, na = measurements not available).

Burn	Rate of Spread(degrees)	Flame Angle	Fuel Type	Slope (%)	Wind Speed (mph)	Maximum Radiant Surface Flux	Maximum Total Surface Flux
1	10.6	1.6	G	0	0	13.0	25.6
2	0.6	1.2	G/S	0	0	13.0	45.6
3	2.1	37.3	G	39	4-6	21.5	32.3
4	2.3	29.5	G/S	39	4-6	22.2	63.4
5 WT	8.8	47.7	G	0	10-15	NA	NA
6 WT	10.4	42.9	G/S	0	10-15	47.4	60.0
7	2.5	35.5	G/S	39	4-6	18.4	36.7

flame angle. Radiant and total heat flux was measured at the rock surface.

LABORATORY STUDY RESULTS

There were no observable differences between the measured surface temperatures of the marine invertebrates and vertebrate fossil samples.

Burns #1 and #2 had the lowest rates of spread, flame angles and intensity of all of the laboratory studies (Table 4). The spread rates of the grass and grass/shrub fuel treatments were similar. Flames were nearly vertical for both treatments but flame angles were slightly greater for the grass fuel treatment. No difference was present in the surface temperature produced by the grass and grass/shrub fuel treatments. Although radiant intensities were similar, the total intensity was greater for the grass/shrub treatment.

Under these conditions, limited increases in sample surface temperatures were recorded (Fig. 7). The average maximum temperature increase of the specimens was 13-14°C (Table 3). There was no change in the fossil specimen condition in the eight fossil specimens used for burns #1 and #2 (Appendix 1).

Burns #3 and #4 showed rates of spread, intensities and flame angles greater than burns #1 and #2 (Table 4). The spread rate of grass and grass/shrub fuel treatment were similar and the flame angles were greater for the grass treatment. Radiant intensities were similar but total intensity was greater for the grass/shrub treatment.

Change in fossil specimen condition was limited to one of eight fossil specimens used in burns #3 and #4 (Appendix 1). The average maximum temperature increase for this treatment was greater than burns #1 and #2 (Table 3).

Burns #5 and #6 represented a high rate of spread/high intensity conditions. The fire intensity and flame angle were consistent with fire behavior model predictions for these conditions. The spread rates, intensity and flame angles were greater than both the low and intermediate burns. Spread rate was greater for the grass/shrub fuel treatment and flame angles were slightly greater for the grass fuel treatment (Table 4).

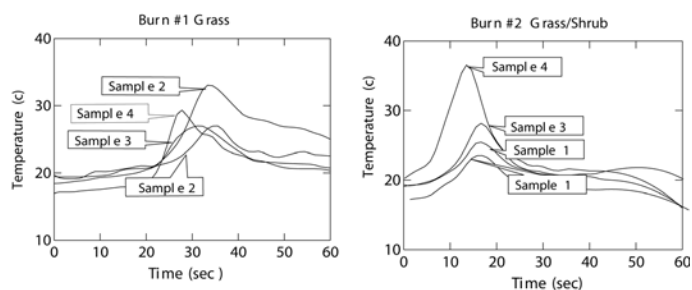


FIGURE 7. Low intensity laboratory burns #1 and #2, Specimen Surface Temperatures.

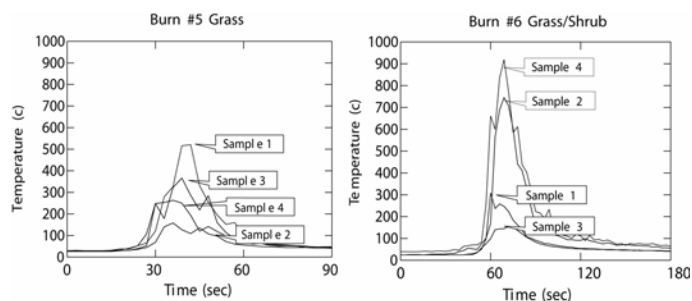


FIGURE 8. High intensity laboratory burns #5 and #6, Specimen Surface Temperatures.

Fire effects were observed in seven of the eight fossils used in burns #5 and #6 (Appendix 1). The average maximum surface temperature increase of the samples was greater than lower intensity burns (Table 4). Maximum surface temperatures were greater for the grass/shrub treatment (Fig. 8).

Burn #7 represented an intermediate grass/shrub fuel treatment where specimens were in direct contact with fuel. The measured spread rate and flame angle was similar to the previous intermediate spread rate burns (Table 4). The average maximum surface temperature for this burn treatment was 493.7°C (Table 3). All fossils specimens in this treatment were covered with tar build up and had significant discoloration but no cracking or splitting was observed. (Fig. 9; Appendix 1).

DISCUSSION

The prescribed burn conducted in 2000 was a low intensity backing fire that primarily burned down hill. Post burn observations noted that burn patterns were extremely variable. Fires often died out before they reached a grassland/bedrock interface and in areas with greater fuel loading, (woody draws and grass cover) the burn was more extensive and complete in coverage. Although the heat sensitive tiles showed no change, damage was observed in three of the six specimens used in this burn. The results show that the tiles coated with heat sensitive paint are not good



FIGURE 9. Pre-burn and post-burn photos of study specimens used in burn #7 (BADL 39758 and BADL 39759).

indicators of damage under a range of low intensity burning conditions.

The fire behavior of the field burns conducted during the spring of 2001 can be characterized as slow rate of spread and low intensity burns. There were differences present in the soil temperature measurements across the study sites. The soil profiles measured at the Prairie Wind #2 and Hamms Draw #2 had both bare soil and a thin layer of surface litter, while the soil surface of the Prairie Wind #1 and Hamms Draw #1 site was dominated by a layer of litter and sod produced by smooth brome (*Bromus inermis*). The limited increase in soil temperatures suggests that on typical fossil sites with sparse cover there would be minimal effect from soil heating of fossil material buried in the soil. The disparity between maximum soil temperatures and specimens on the Prairie Wind #1 site was primarily the result of fuel differences.

The maximum fossil surface temperatures were linked with maximum soil surface temperatures. The most extensive specimen surface changes occurred on the flat grassy expanses of uniform fuel distribution. Discoloration occurred on all specimens that had contact with fuel. Based on field observations, specimens exposed on bare bedrock that were at a distance from fuel or were not in contact with fuel were not affected.

The results of the laboratory burning, show levels of damage increasing with faster rates of spread, higher intensities and greater flame angles. Increases in intensity and rate of spread lead to increased heat transfer from the flame front to the specimen surfaces. No damage was observed in burns of low intensity where there was no contact with fuel or flames. Surface temperatures for the grass/shrub fuel treatment were greater than the grass fuel. In high intensity fires with quickly spreading flame fronts there was an effect on all exposed fossils. Significant fire effects were also observed under intermediate intensity when the specimens were in direct contact with the fuel. These results suggest that the size of the buffer zone needed to protect the samples was dependent on fire behavior and fuel distribution.

The comparison of laboratory fire behavior and field burn observations suggests that the 2001 field burns were similar to the low intensity laboratory burns. No fire effects were found on fossil specimens resulting from laboratory burning under low spread rates, low intensities and without physical contact with fuel. However, damage was observed on samples in the field burns of 2001.

The most significant sample damage was observed on Hamms Draw #1 and Prairie Wind #1. Sites were not considered typical or unnatural fossil sites due to continuous fuel cover. Maximum specimen surface temperatures on the Prairie Wind #1 site were comparable with surface temperatures measured during high intensity laboratory burns. Surface temperatures on the Hamms Draw #1 site were between the intermediate and high intensity laboratory burns. Similarities in radiant flux measurements in conjunction with differences in surface temperatures suggest that the fuel and specimen distribution played an important role in higher specimen surface temperatures on these sites.

Less damage was observed on Hamms Draw #2 and Prairie Wind #2 and the effects were greater than those measured in similar low intensity laboratory burns. These sites were more representative of typical

fossils sites, with sparse vegetation and bare ground. Although the radiant intensities of the laboratory and field burns were similar, specimen surface temperatures of the field burns were greater than the surface temperatures on the low intensity laboratory burns.

The results show that the maximum radiant energy was greater from the field burns, than the low intensity and lower than the intermediate intensity laboratory burn #7, but the maximum total flux measured during the field burns was comparable with higher intensity laboratory burns. Under laboratory conditions of moderate spread rate and flame angle, significant energy was contributed to the specimen surface by conductive and convective processes. The results demonstrate that in complex fuel and fossil distributions radiant flux alone is not a good predictor of fossil damage.

While there was no physical damage (cracking or fracturing) to the specimens observed in the laboratory studies, the field studies did show fracturing on one specimen from Hamms Draw #2. Physical damage to native rocks has been observed in fires of grassland/shrub land fuels in a number of studies (Buenger, 2003).

The most consistent fire effect found in both the field and lab studies was chemical discoloration or "sooting" of the specimens. The interaction of combustion, smoke and surface temperature appeared to create these effects. These features did not vary with the size or type of fossil. The data suggest that the interaction between fossil surface temperature and the distance from fuel are important predictors of fire effects on exposed specimens. Flame angle and flame height play a key role in these surface temperatures.

As with any research project, many new questions are often generated. The results of this study have shown the significance of the relationship of fire effects with flame and fuel contact. An improved understanding of the dynamics of a fossil protective "buffer zone" size for a range of prescribed and wild fire conditions is needed to develop a predictive relationship between burning and levels of resource damage. The data from these studies is essential to the development of burning prescriptions that minimize expected resource damage. The results of this future study might be applicable to a wide range of resource questions.

CONCLUSION

There are paleontological resource management concerns over the use of prescribed fire at BADL. A number of these concerns can be addressed during fire prescription development. Through the integration of paleontological resource distributions with practical burning constraints, operational burning plans can be developed that will incorporate firing techniques to minimize expected resource damage. The implementation of burning strategies includes black lining, burning away from important resource areas and burning sensitive areas with low rates of spread and low intensities. In addition to the above listed techniques, the control of foot and vehicle traffic in fragile fossil rich areas would also minimize paleontological resource damage.

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APPENDIX 1. FOSSIL SPECIMENS USED FOR 2000 AND 2001 FIELD AND LABORATORY BURN STUDIES.

<i>Study Number</i>	<i>Site/Burn Number</i>	<i>Specimen Number</i>	<i>Taxa</i>	<i>Element</i>	<i>Formation/Group</i>	<i>Comments</i>
2000 Field Study	Site #1	Specimen #1	Oreodont	Skull	White River	No change
	Site #2	Specimen #2	Oreodont	Molar Fragment	White River	No change
	Site #3	Specimen #3	Oreodont	Skull	White River	No change
	Site #4	Specimen #4	Oreodont	Skull	White River	Discoloration
	Site #5	Specimen #5	Oreodont	Premaxilla Fragment	White River	Discoloration
2001 Field Study	Site #6	Specimen #6	Oreodont	Molars	White River	Discoloration
	Hamms Draw #1	Specimen #1	Oreodont	Jaw Fragment	White River	Discoloration
		Specimen #2	Oreodont	Maxillary Fragment	White River	Discoloration
	Hamms Draw #2	Specimen #3	Baculite	Fragment	Pierre Shale	No change
		Specimen #4	Baculite	Fragment	Pierre Shale	No change
		Specimen #5	Oreodont	Jaw Fragment	White River	Discoloration
		Specimen #1	Oreodont	Skull Fragment	White River	No change
		Specimen #2	Rhinoceros	Maxillary Fragment	White River	Discoloration
	Prairie Wind #1	Specimen #3	Baculite	Fragment	Pierre Shale	No change
		Specimen #4	Inoceramus	Cluster	Pierre Shale	No change
		Specimen #1	Rhinoceros	Partial Jaw	White River	Discoloration
		Specimen #2	Oreodont	Jaw fragment	White River	Discoloration
		Specimen #3	Baculite	Fragment	Pierre Shale	Discoloration
	Prairie Wind #2	Specimen #4	Baculite	Cluster	Pierre Shale	Discoloration
		Specimen #1	Oreodont	Maxillary Fragment	White River	Discoloration
		Specimen #2	Oreodont	Vertebral Column	White River	No change
		Specimen #3	Scaphite	Parital Shell	Pierre Shale	No change
		Specimen #4	Baculite	Fragment	Pierre Shale	No change
2001 Lab Study	Burn #1	Specimen #1	Oreodont	Femur, head	White River	No change
		Specimen #2	Oreodont	Mandible	White River	No change
		Specimen #3	Baculite	Fragment	Pierre Shale	No change
		Specimen #4	Baculite	Fragment	Pierre Shale	No change
	Burn #2	Specimen #1	Mammalia	Acetabulum	White River	No change
		Specimen #2	Mammalia	Limb Element	White River	No change
		Specimen #3	Baculite	Fragment	Pierre Shale	No change
		Specimen #4	Oreodont	Molar	White River	No change
	Burn #3	Specimen #1	Mammalia	Podial, distal end	White River	No Change
		Specimen #2	Mammalia	Vertebral Fragment	White River	No Change
		Specimen #3	Baculite	Fragment	Pierre Shale	No Change
		Specimen #4	Mammalia	Astragalus	White River	No Change
	Burn #4	Specimen #1	Mammalia	Phalanx, distal end	White River	No Change
		Specimen #2	Mammalia	Tibia, distal end	White River	No Change
		Specimen #3	Baculite	Fragment	Pierre Shale	No Change
		Specimen #4	Mammalia	Tibia, distal end	White River	Discoloration
	Burn #5	Specimen #1	Mammalia	Astragalus	White River	Discoloration
		Specimen #2	Mammalia	Femur, head	White River	No Change
		Specimen #3	Mammalia	Molar Fragment	White River	Discoloration

<i>Study Number</i>	<i>Site/Burn Number</i>	<i>Specimen Number</i>	<i>Taxa</i>	<i>Element</i>	<i>Formation/Group</i>	<i>Comments</i>
		Specimen #4	Mammalia	Phalange, distal end	White River	Discoloration
	Burn #6	Specimen #1	Oreodont	Femur, head	White River	Discoloration
		Specimen #2	Oreodont	Mandible	White River	Discoloration
		Specimen #3	Baculite	Fragment	Pierre Shale	Discoloration
		Specimen #4	Baculite	Fragment	Pierre Shale	Discoloration
	Burn #7	Specimen #1	Mammalia	Tibia, distal end	White River	Discoloration
		Specimen #2	Mammalia	Tibia, distal end	White River	Discoloration
		Specimen #3	Baculite	Fragment	Pierre Shale	Discoloration
		Specimen #4	Mammalia	Tibia, distal end	White River	Discoloration