United States
Department of
Agriculture

Forest
Service

**Southwestern
Region**

April 2007

Warm Fire Assessment

Post-Fire Conditions and Management Considerations

North Kaibab Ranger District, Kaibab National Forest

Coconino County, Arizona

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Chapter 1 – Introduction

Many of the forested stands on the North Kaibab Ranger District have had unnaturally high live and dead fuel loading for some time, particularly in the ponderosa pine and mixed conifer vegetation types. Thousands of acres are in need of treatment. Methods to achieve desired conditions include mechanical thinning, prescribed burning, and wildland fire use. The high costs associated with planning and implementation of prescribed burns and thinning projects have made wildland fire use a desirable option.

In order to implement wildland fire use, fires must be naturally ignited (lightning) and a "relative risk assessment" must be conducted. This assessment considers fire hazards, such as fire behavior, potential fire size, and forest conditions; probability factors such as time of season, barriers to fire spread, and seasonal severity; and values at risk; and (USDI and USDA 2005).

The Warm Fire was started by lightning on June 8, 2006. The fire met the criteria for wildland fire use, and was consistent with the Kaibab National Forest Plan, Kaibab Fire Management Plan, and the Federal Wildland Fire Management Policy. The Warm Fire was managed as a wildland fire use fire for approximately 2 ½ weeks, during which time, approximately 19,000 acres were treated. However, on June 25, winds pushed the fire south, outside the Maximum Manageable Area (MMA). Approximately 39,000 acres burned between June 25 and July 4 while the fire was managed under a wildfire suppression strategy, much of which burned at high intensity and resulted in severe fire effects.

On July 1, 2006, a Burned Area Emergency Response (BAER) team was assembled to conduct a soil and hydrologic assessment and to initiate rehabilitation activities to minimize threats to human life and property, the loss of soil productivity, and effects to downstream water quality. This assessment identified post-fire threats, critical values at risk, and emergency stabilization measures.

On August 1, an Interdisciplinary Post-Fire Assessment Team was assembled to assess the status of the resources, identify recovery needs, and recommend a program of recovery work beyond BAER in the wildfire suppression area. Field observations, combined with systematic sampling and survey were used to assess the effects of the Warm Fire.

Effects to vegetation were measured by assessing specific factors at 5 levels of vegetation strata, from the ground through the overstory canopy. These data were then correlated to the Burned Area Reflectance Classification (BARC) map which displayed the change in reflectance of the Landsat satellite image before and after the fire. An estimated 12,000 acres of ponderosa pine; 4,300 acres of mixed conifer; and 3,100 acres of pinyon-juniper woodlands experienced stand-replacing fire with nearly 100% tree mortality.

This stand-replacing fire negatively affected wildlife habitat structure and composition, soil stability, hydrological function, and caused damage to heritage resources, infrastructure, and recreational opportunities. The interdisciplinary team identified resource management needs and a menu of possible actions to address those needs. The priorities were to protect public safety, vulnerable resources, and restore desired resource conditions.

Chapter 2 – Resource Assessments

Soil and Watershed

The objective of this section is to disclose the fire effects to the soil and watershed resources in the Warm Fire suppression area. To meet this objective, field trips were conducted to observe and discuss the fire effects to soil and watershed conditions. Published information about the soil and watershed resources of the area were collected and reviewed. Information sources included the Terrestrial Ecosystem Survey Report of the Kaibab National Forest (TES), The Status of Water Quality in Arizona (ADEQ 2004), and the Burned-Area Emergency Response Report (USDA Forest Service 2006) along with its supporting information assisted in determining the status of current soil and watershed conditions. Research publications were also reviewed to assist in the explanation of fire effects on soil and watershed resources.

The Warm Fire suppression area is located within the Marble Canyon portion of the Colorado River (15010001) and Kanab Creek (15010003) 4th code watersheds. The Kanab Creek Watershed occurs in Arizona and Utah. The acreage presented in Table 1 for the Kanab Creek Watershed is for that portion of the watershed which occurs in Arizona.

Table 1. Watersheds burned in the Warm Fire suppression area.

Watershed Area	Marble Canyon (15010001)	Kanab Creek (15010003)
Total Watershed Acres	939,084	1,094,111
Watershed Acres Burned	18,505	20,596
Percent Watershed Burned	2.0%	1.9%

Soil Conditions

Burn Severity

Burn severity is a term that describes the effects of heat on soil and watershed conditions that are important for their influence on soil productivity and the potential for destructive flooding. Site indicators used to assess burn severity include the degree of water-repellent soils, degree of litter and duff consumed, the amount and kind of live vegetation consumed, degree of downed woody material consumed and charred, and post-fire vegetative ground cover. Using these indicators, burn severity was described and summarized in three burn severity classes: high, moderate, and low (DeBano et al. 1998).

High Burn Severity: These areas experienced a high degree of soil heating that killed the live vegetation. A large majority of the trees were killed, with entire tree canopies totally consumed by intense heat and fire. Foliage, litter, and duff were completely consumed. Coarse downed woody debris was deeply charred or totally consumed. Water-repellent (hydrophobic) soils were present near the soil surface and in some cases two to three inches below the soil surface (USDA 2006). Infiltration was significantly reduced resulting in increased runoff and soil erosion. Sheet and rill erosion was active during the intense rainfall events that followed the Warm Fire. Soil nutrients in

the litter and duff layer were consumed or turned to ash during combustion. Ash (black to white in color) was highly mobile and easily transported by wind and water. Rainfall and runoff events during the 2006 monsoon season have already washed away most of the ash, especially on the steeper slopes.

Moderate Burn Severity: These areas experienced moderate soil heating. The surface litter layer was consumed and the duff layer was deeply charred by the fire. Some water repellency existed below the soil surface with strong water repellency in isolated areas. Water infiltration was reduced, increasing soil erosion and runoff. Active signs of sheet and rill erosion were present. Ash (mostly gray in color) was present as a result of the litter layer being burned (USDA 2006). Much of this ash has moved off site due to wind and water. Small woody debris was mostly consumed; larger logs remained, but were charred. Vegetative ground cover was patchy and not continuous. Much of the tree canopy remained; however, it was scorched, turning the needles brown. These needles will eventually fall to the soil's surface, providing immediate mulch and initiating the slow recovery process of reestablishing vegetative ground cover.

Low Burn Severity: In low burn severity areas, there was light ground char where the litter was scorched, charred, or partially consumed. The duff was largely intact, although it was charred on the surface in places. Woody debris accumulations were partially scorched or charred. Mineral soil properties were not changed. Vegetative ground cover remained intact and was adequate to protect soils from accelerated soil erosion (USDA Forest Service 2006). Evidence of sheet and rill erosion as a result of the fire was minor. In forested areas, much of the tree overstory was green with some scorch at the base of the trees and in the lower branches. Most of the trees survived; however, there were pockets of seedlings and saplings that were killed or consumed. Many of the shrubs, forbs and grasses were burned under conditions that could be described as a "cool" burn. In these cases, much of this vegetation survived. The area mapped as "low burn severity" also contains large unburned areas.

Methods

To map areas within each burn severity class, a Landsat Burned Area Reflectance Classification (BARC) image was obtained from the Forest Service Remote Sensing Applications Center (RSAC). The area was viewed from a fixed winged aircraft to assess the extent of the burn severity and calibrate the Landsat image. Soil conditions were assessed for presence or absence of vegetative ground cover and coarse woody debris, evidence of surface sheet and rill erosion, water repellency, fire effects to vegetation and vegetative recovery.

Polygons of homogeneous high and low severity classes were identified. The areas of moderate severity were not contiguous or homogenous, but occurred in a matrix of high and moderate burn severity. For this reason the "moderate" class was redefined as "moderate/high." ArcGIS was used to calculate the area in each severity class. Within the 39,000 acres of the Warm Fires suppression area, approximately 41% (16,026 acres) of the area was classified as low burn severity, 19% (7, 290 acres) was moderate/high burn severity, and 40% (15,780 acres) was classified as high burn severity (Figure1).

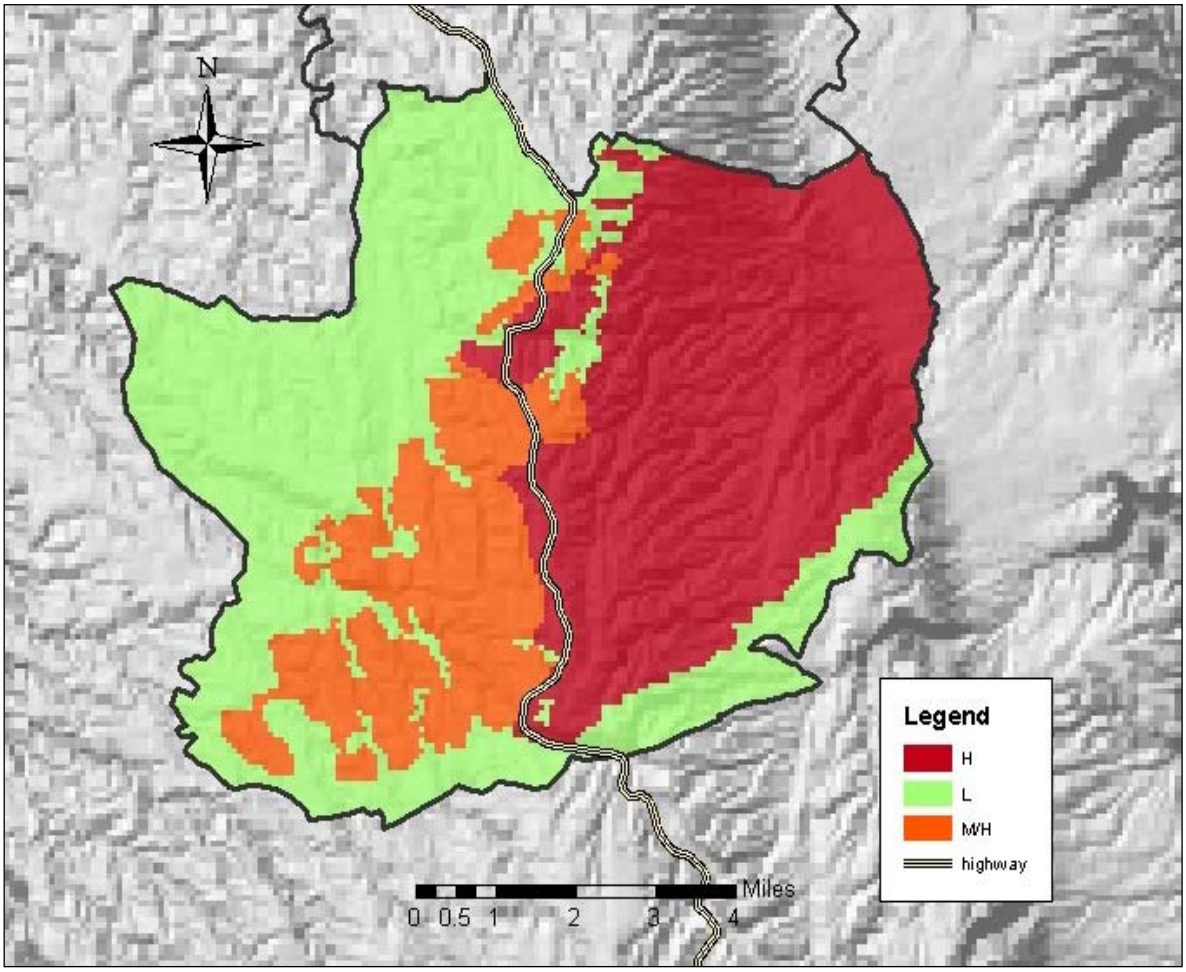


Figure 1. Burn Severity map of the Warm Fire suppression area.

Coarse Woody Debris

Forest ecosystems have evolved with a continual flux of small and large woody material. Woody material is an important component in maintaining long-term soil productivity and is critical in the development and function of forest ecosystems. Soil wood, humus, and the upper layers of mineral soil that are rich in organic matter are the primary substrates for the development of ectomycorrhizae, a type of fungus associated with tree roots. Ectomycorrhizae absorb moisture and nutrients from the soil and translocates them to their host plants, making ectomycorrhizae essential for the development of forest ecosystems. Therefore, their presence and abundance is assumed to be a good indicator of a healthy functioning forest soil (Graham et al. 1994). Other important soil fungi are associated with herbaceous plants, litter and duff, and soil organic matter. Both above-and below-ground nutrients are lessened by the removal of vegetation, organic matter and coarse woody debris. This loss of vegetation and reduction in coarse woody debris, which resulted in a loss of site productivity, characterizes the moderate and high burn severity areas.

Soil Organic Matter

Fire affects organic matter in two ways. First, moderate and high severity fires kill the biological organisms that decompose organic matter (Neary et al. 2005). A variety of microbiota and invertebrates play an active role in the conversion of litter, leaves, and other organic debris into humus. Microorganisms including bacteria and fungi, which are the primary decomposers of organic matter the soil (DeBano et al. 1998), were affected by the fire.

Secondly, fire dramatically increases the rate of organic matter decomposition during the combustion process. Most of the organic matter in the soil was concentrated near the surface in the upper soil layers and was exposed to intense radiant heat during the fire. Different chemical components found in organic matter are lost when soil temperatures increase during heating. The loss of soil organic matter is closely linked to volatilization of nitrogen (DeBano et al. 1998), which contributes to a loss of site productivity.

Erosion Hazard

Erosion is a natural, continual process. However, in the moderate and high severity burn areas, erosive forces at the soil surface were intensified when fire consumed the protective vegetation cover and litter accumulations, and other decomposed organic matter on the soil surface, exposing bare mineral soil. Additionally, soil erodibility was exacerbated due to the volatilization of the soil organic material and the destruction of soil aggregates (DeBano et al. 1998).

Post-fire soil loss rates were higher on hydrophobic soils than on nonhydrophobic soils. The reduced infiltration on hydrophobic soils and consequent accelerated overland flows combined to create conditions that contributed to the dislodgement and transport of soil particles. Water repellency is usually confined to severely burned areas that had high levels of litter and plant cover. Generally, widespread strong water repellency was found on sites where dense vegetative cover burned intensely, while weakened, discontinuous layers formed where sparse vegetative cover was only partially consumed (DeBano et al. 1998).

The Forest Service, Region 3 defines erosion hazard as the probability of soil loss resulting from complete removal of vegetation and litter (USDA Forest Service 1986). A soil erosion hazard class (slight, moderate, or severe) was assigned to each ecological soil type within the Warm Fire suppression area (USDA Forest Service 1991). Tables 2 and 3 display acres of each erosion hazard class for each burn severity class identified in each watershed.

Table 2. Acres of erosion hazard by burn severity class in the Marble Canyon Watershed.

Erosion Hazard Class	Burn Severity Class		
	Low	Moderate/High	High
Slight	717	1	2,734
Moderate	991	294	5,411
Severe	1,273	225	6,859
Total Acres Burned	2,981	520	15,004

Table 3. Acres of erosion hazard by burn severity class in the Kanab Creek Watershed.

Erosion Hazard Class	Burn Severity Class		
	Low	Moderate/High	High
Slight	2,973	78	0
Moderate	5,638	3,732	449
Severe	4,436	2,960	330
Total Acres Burned	13,047	6,770	779

Watershed Conditions

Surface water from the Warm Fire suppression area potentially flows into the Marble Canyon portion of the Colorado River and Kanab Creek. However, stream courses within the wildfire area are primarily ephemeral and stream flows generally occur only after large, high intensity, rainstorm events or runoff from spring snow melt. The sporadic nature of these stream flows may result in sediment and ash being potentially stored within in these ephemeral stream channels and then transported during surface runoff events to both the Marble Canyon portion of the Colorado River and Kanab Creek.

During the summer monsoon season that followed the Warm Fire, the area received a lot of precipitation in the form of rain. The combined effects of a loss of vegetative ground cover, a decrease in litter accumulations and other decomposed organic matter on the soil surface, and the formation of strongly water repellent soils have become the source areas of accelerated runoff and erosion resulting in increased stream flow discharges. Ephemeral stream channels within the high burn severity areas have experienced a loss in their ability to buffer runoff from heavy rainfall events. Ephemeral tributaries are experiencing increased channel scour and incision caused by accelerated runoff and erosion from severely burned watershed areas. It is anticipated that adjustments to channel width and depth of ephemeral channels will occur over time to achieve equilibrium.

Due to the heavy rainfall events that followed the fire, there were considerable overland flows and ash movement. Sediment and ash has collected in ephemeral stream channels, stock tanks and meadows. In many cases, these meadows did not burn nor did the immediate, adjacent forest. Increased overland flows have damaged some low lying roads, culverts, and low water crossings. Also, in the lower elevation areas, on the eastern portion of the wildfire area, archaeological sites are being negatively affected by the increased erosion and sedimentation (see Heritage Resources section later in this assessment).

The Arizona Department of Environmental Quality (ADEQ) biennial report provides information on the status of water quality within the two 4th code watersheds that were affected by the Warm Wildfire. This report meets the reporting requirements under the Clean Water Act sections 305 (b) (assessments), 303 (d) (impaired waters list), 106 (monitoring), 204 (grants), 319 (nonpoint source), and 314 (lakes program) (Diroll and Marsh 2004). The State of Arizona has identified and assigned

narrative numeric surface water quality standards to the Marble Canyon portion of the Colorado River and Kanab Creek. The standards are based on the designated uses of the water (Diroll and Marsh 2004).

In the most recent ADEQ biennial (2004) report, the State did not report any violations of water quality for designated uses within the Kanab Creek and Marble Canyon portion of the Colorado River, and the status of the water quality was not reported. ADEQ has not yet reported the effects on downstream water quality for these two streams as a result of the Warm Fire.

Post-Fire Recovery

Due to the precipitation that the wildfire area received during the summer monsoon, natural recovery of the watersheds has begun to occur. Within a month after the fire, isolated patches of "green" began appearing across the landscape. Mutton bluegrass and other perennial grasses are already well established, especially in the low and moderate burn severity areas. Aspen, and other root sprouting species have begun to emerge, and many forbs including lupine have become established. In areas identified as high burn severity, vegetation recovery has occurred, but is not as pronounced. Gambel oak, New Mexican locust, lupine and other forbs have begun to appear, but for the most part, grasses are absent.

Some germination of the seeded annual rye grass has occurred, but it was mostly limited to areas where sediment and water have collected. Much of the annual rye grass seed that was seeded on steep slopes has been washed downstream as a result of accelerated overland flows and erosion. Germination from the BAER seeding was sparse and generally not effective in controlling erosion.

Desired Conditions

It is Forest Service policy to apply management practices that meet the requirements for protecting, maintaining, restoring or improving watershed conditions (USDA Forest Service 2004). Forest Service objectives call for degraded watershed conditions to be restored by stabilizing soil, controlling surface runoff and erosion, reducing flood potential, improving long-term soil productivity and stabilizing the drainage network (USDA Forest Service 2004).

A primary objective for the wildfire area is to restore the loss of soil and hydrologic function and restore site productivity in the moderate and high burn severity areas. In order to meet this objective, it will be necessary to restore organic matter to the soil and reduce accelerated soil erosion by increasing effective vegetative ground cover and managing for coarse woody debris using the following guidelines:

- Increase effective vegetative ground cover (total litter + vegetation basal area, which is expressed as percent cover) to desirable levels for each ecological type. Desirable and natural vegetative ground covers are assigned to each ecological type (Appendix 2). Natural vegetative ground covers are obtained from the Forest's Terrestrial Ecosystem Survey (TES). Natural vegetative ground cover is defined as the amount of vegetative ground cover that is predicted to occur under climax vegetative conditions (USDA Forest Service 1991). See Appendix 3 for acres of TES map units by burn severity class.

- In forested ecosystems, a minimum of 10 to 15 tons per acre of downed coarse woody debris should be managed for in the moderate to high burn severity areas, and 5 to 10 tons per acre in the low burn severity areas. In woodland ecosystems (pinyon-juniper), manage towards a

minimum of 5 tons per acre. Coarse woody debris (material larger than 3 inches in diameter) should occur in all size classes and should be distributed evenly across the soil surface.

Soil and Watershed Conclusions

The moderate and high burn severity areas lost critical soil and hydrologic function. In some areas, natural soil recovery has already begun to occur. Vegetative ground cover and coarse woody debris are necessary for the recovery of forest and grassland ecosystems. Because severely burned soils are particularly vulnerable to soil erosion and compaction, mitigations are needed to minimize the impacts associated with ground disturbing post-fire management. Ground disturbing activities can impede natural vegetation establishment, soil recovery, and hydrologic function can contribute to a decline in site productivity and delay the ecosystem recovery. As a result, management activities should be designed and implemented in a manner that minimizes soil erosion and compaction. Recommended Best Management Practices (BMPs) can be found in the Region 3 Soil & Water Conservation Practices Handbook (1990).

Forested Vegetation

The Warm Fire mostly burned in the ponderosa pine cover type with fewer acres burned in the mixed conifer, pinyon-juniper and aspen cover types. Within the fire suppression perimeter, seven dominant vegetation cover-types occur.

Table 4. Prefire vegetation cover-type composition within the Warm Fire perimeter.

Cover Type	Acres	Percent of Total Acres
Ponderosa Pine	25,421	65%
Mixed Conifer*	5,619	14%
Pinyon-Juniper	3,863	10%
Aspen	2,531	6%
Meadow	1,311	4%
Spruce	243	1%
Other Hardwoods	120	<1%
Total Acres:	39,115	100%

* “Mixed Conifer” is composed of the Douglas fir and white fir cover types combined.

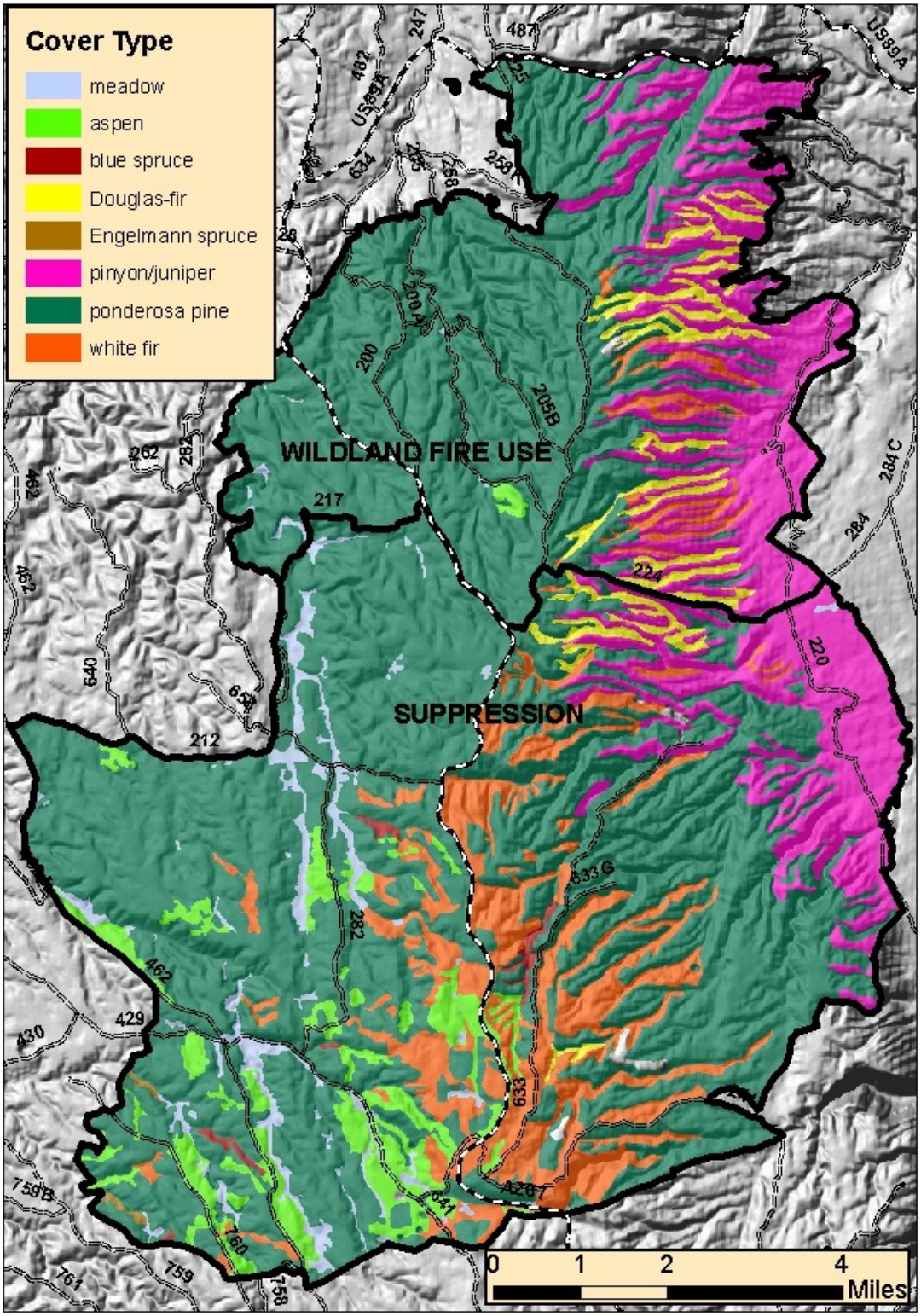


Figure 2. Vegetation cover types in the Warm Fire area.

Ponderosa Pine

Before the fire, ponderosa pine occurred throughout the plateau uplands on flat to moderately steep slopes. Ponderosa pine was also found at lower elevations on the steep slopes and alluvial deposits in the eastern portion of fire area where the vegetation type transitions to pinyon-juniper.

Ponderosa pine dominated the overstory with aspen present in moist areas, along drainages, and vegetative transition zones around meadows. Douglas fir and white fir seedling regeneration frequently occurs in drainages associated with aspen and at higher elevations where ponderosa pine transitions to mixed conifer cover types.

Mixed Conifer

The mixed conifer cover type occurred on flat plateau uplands to moderately steep north-facing slopes and drainage bottoms at higher elevations in the south and central portions of the fire area. "Mixed conifer" is primarily composed of ponderosa pine, white fir, Douglas fir and quaking aspen. Small amounts of blue spruce can be found in some of the cooler microsites (Stuever, pers. comm. 2006). The mixed conifer cover type is found at elevations above 8,000 feet on the Kaibab Plateau between the ponderosa pine and spruce-fir cover types.

Pinyon-Juniper

Pinyon and juniper woodlands occurred along the eastern edge of the fire at elevations less than 7,200 feet generally on steep south facing slopes in the higher elevations and on alluvial bottoms in lower elevations. Pinyon pine and Utah juniper are the dominant tree species with lesser amounts of Rocky Mountain juniper and one seed juniper. Shrub form Gambel oak is regenerating as ground cover on upland landforms, canyon drainages and on alluvial fans. New Mexico locust is also present. The pinyon-juniper areas are the driest vegetation cover type in the Warm Fire area. This lack of moisture results in slower growth rates and slower response following disturbance.

Aspen

Aspen occurs at higher elevations in the central and southwestern portions of the fire area. Where aspen occurs as the overstory species it exists as dense clonal stands, interspersed with young and mature ponderosa pine and minor amounts of blue spruce, Douglas fir and white fir. Dense aspen stands occupied transition zones between upland conifer forests and meadows.

Fire Effects to Vegetation

Methods

The vegetation mortality map was created by modifying a Landsat Burned Area Reflectance Classification (BARC) image provided by the Forest Service Remote Sensing Applications Center (RSAC). The BARC image uses the Normalized Burn Ratio (NBR) as a quantitative measure of burn severity (Key and Benson 2006). NBR is a function of reflectance values for Landsat Bands 4 and 7. NBR, or delta NBR (dNBR), is calculated by subtracting post-fire NBR values from pre-fire NBR values and is thus a measure of the change in Landsat reflectance data from pre-fire to post-fire. The pre-fire Landsat image used for this analysis was taken on July 21, 2004, and the post-fire image was taken on July 9, 2006. The BARC images have dNBR values that range from 0 to 255 (hereafter referred to as dNBR values).

To calibrate and validate the BARC image, Composite Burn Index (CBI) field sampling was conducted using methods described in Key and Benson (2006). Locations of CBI plots were selected using a stratified systematic sampling design. Random sampling of CBI plots is not considered necessary because the BARC image provides a complete "census" of 30-meter pixels throughout the burn area (Key and Benson 2006), and CBI plot sampling is done to describe the relationship between severity on the ground and the dNBR satellite reflectance data.

The Warm Fire area was stratified using a 4-class BARC image provided by RSAC. Approximately 20 potential CBI sample points were identified for each of the 4 classes designated by RSAC. These original classes were designated based on past experience between burn severity and dNBR value. In this 4-class BARC image, the unburned/very low severity class was defined by dNBR values less than 75; the low severity class was defined by dNBR values from 76 to 109; the moderate severity class was defined by dNBR values from 110 to 187; and the high severity class was defined by dNBR values greater than 187.

Within each of these 4 classes, potential CBI plots were systematically selected in ArcMap by locating plots well distributed throughout the entire fire area in areas that could be easily accessed from roads. Points representing plot centers were designated in ArcMap, and the UTM coordinates for these points were downloaded into handheld GPS units. Plot centers were located in the field by using the GPS units as closely as possible to these points.

CBI plots are designed to sample an area similar to the spatial scale of the Landsat reflectance data (30 X 30 meter pixels). CBI plots are 15-meter radius circles. A list of the factors used in the analysis and a brief description of each is provided below. Each of the factors listed below was calculated at the plot level; except frequency of plot with greater than or equal to 80 percent upper canopy scorch and percent tree mortality, which were calculated from plot data pooled across each mortality class.

- % plot burned: percent area of plot showing any sign of burning;
- litter/fuel <3" consumed: percent litter, duff (humus), and fuels less than 3 inches in diameter consumed were assigned to a numerical value ranging from 0.0 to 3.0;
- fuel 3-8" consumed: same as above for fuels 3 to 8 inches in diameter;
- fuel >8" consumed: same as above for fuels greater than 8 inches in diameter;
- vegetation <3' altered: percent of vegetation less than 3 feet tall altered by fire (scorched or consumed) were assigned to a numerical value ranging from 0.0 to 3.0.
- vegetation 3-16' altered: same as above for vegetation 3 to 16 feet tall;
- % subcanopy green: percent of subcanopy (intermediate) volume unaltered by fire;
- % subcanopy black: percent of subcanopy volume consumed (torched) by flames;
- % subcanopy brown: percent of subcanopy volume killed by fire, but not consumed (scorched);
- % subcanopy scorch: percent subcanopy black plus percent subcanopy brown (see Sieg et al. 2006);
- % upper canopy green: percent of upper canopy (dominant and codominant trees) volume unaltered by fire;
- % upper canopy black: percent of upper canopy volume consumed by flames;

- % upper canopy brown: percent of upper canopy volume killed by fire but not consumed;
- % upper canopy scorch: percent upper canopy black plus percent upper canopy brown;
- frequency of plots with >80% upper canopy scorch: percent of plots with upper canopy scorch greater than 80 percent (see Sieg et al. 2006);
- % tree mortality: percent of upper canopy trees killed by fire; includes trees with $\geq$ 80% scorch.

The thirty-meter diameter CBI plots were not centered on 30-meter Landsat pixels, so CBI plots typically overlapped multiple pixels and thus multiple dNBR values. To assign a representative dNBR value to each CBI field plot, UTM coordinates from CBI plot centers were plotted in ArcMap. A 15-meter radius circular area was identified, corresponding to the 15-meter radius or 30-meter diameter area in which CBI field sampling occurred. The dNBR value assigned to each CBI plot was equal to the average of dNBR values from 5 systematically located points from within the circular buffer: the plot center and one point from the center of each of the 4 quadrants of the circle.

There were 85 total CBI plots in the final sample (CBI plot data can be found in Appendix 4). Substrate and vegetation factors calculated from the 85 CBI plots were highly correlated with dNBR values. Pearson correlation coefficients (*r*) for the key substrate and vegetation factors used in this analysis are presented below. Each of these correlations except two were statistically significant at a probability (P value) of less than 0.01.

Table 5. Composite Burn Index factor correlation and statistical significance.

Factor	Correlation coefficient (*r*)	P-value
% plot burned	0.64	P < 0.01
litter/fuel <3" consumed	0.83	P < 0.01
Fuel 3-8" consumed	0.75	P < 0.01
Fuel >8" consumed	0.54	P < 0.01
Vegetation <3' altered	0.67	P < 0.01
Vegetation 3-16' altered	0.69	P < 0.01
% subcanopy green	-0.71	P < 0.01
% subcanopy black	0.85	P < 0.01
% subcanopy brown	-0.22	P = 0.05
% subcanopy scorch	0.71	P < 0.01
% upper canopy green	-0.81	P < 0.01
% upper canopy black	0.84	P < 0.01
% upper canopy brown	0.12	P = 0.2
% upper canopy scorch	0.81	P < 0.01

The two factors with the lowest correlation coefficients were percent subcanopy brown and percent upper canopy brown. The weaker correlations between these two factors and dNBR reflected the opposing patterns observed. Values for percent canopy brown were low in lower mortality areas (high percent canopy green) and in high-severity areas (high percent canopy black). Frequency of plots with ≥80% upper canopy scorch and percent tree mortality are not included below because these factors were calculated at the severity class level, not the plot level.

Vegetation mortality classes were determined by evaluating association between subcanopy and upper canopy scorch values and values of dNBR. Data from the 85 CBI plots were sorted by dNBR value, and the data were qualitatively evaluated to determine natural breaks in dNBR value associated with different levels of subcanopy and upper canopy scorch. Four vegetation mortality classes were chosen and described as low (dNBR≤ 60), mixed-low (dNBR 61-91), mixed-high (dNBR 92-124), and high (dNBR ≥ 125). Although field data from CBI plots were used to determine vegetation mortality classes based upon association between dNBR and vegetation mortality, severity classes were then defined solely based on dNBR value.

The raster Landsat image was converted to a polygon shapefile in ArcGIS. Pixels were classified into one of the 4 classes described above, and the dissolve tool was used to aggregate features based on this 4-value grouping field. For subsequent analyses, other GIS layers were overlaid with the vegetation mortality shapefile to determine acreages and percentages within the 4 vegetation mortality classes.

Cloud cover at the time of the post-fire Landsat image resulted in distorted reflectance values in some areas along the western and southwestern edge of the Warm Fire. The Landsat image was used to create a cloud cover polygon shapefile. Using the “Update” tool in ArcGIS, we incorporated cloud cover into the vegetation mortality shapefile, which allowed us to exclude areas where cloud cover may have led to an inaccurate assignment of vegetation mortality class.

The accuracy of the vegetation mortality map was qualitatively evaluated from the ground and in a fixed-wing flight over the entire Warm Fire area on September 1, 2006. A GPS unit connected to ArcMap on a laptop was used to show real time location in relation to the severity map. From this perspective (flown at an altitude of approximately 10,000 feet), the vegetation mortality map appeared to be accurate in depiction of effects of the fire on upper canopy vegetation. For example, even small patches (e.g. patches less than an acre) of high tree mortality surrounded by areas of lower mortality were accurately depicted on the map as patches of high vegetation mortality surrounded by area mapped as mixed-high to mixed-low vegetation mortality. Some discrepancies between Landsat mapped vegetation mortality and actual fire effects were detected. One example was that some of the narrow meadows in the burn area were classified as mixed-low mortality based on dNBR values even though these meadows had no apparent fire effects.

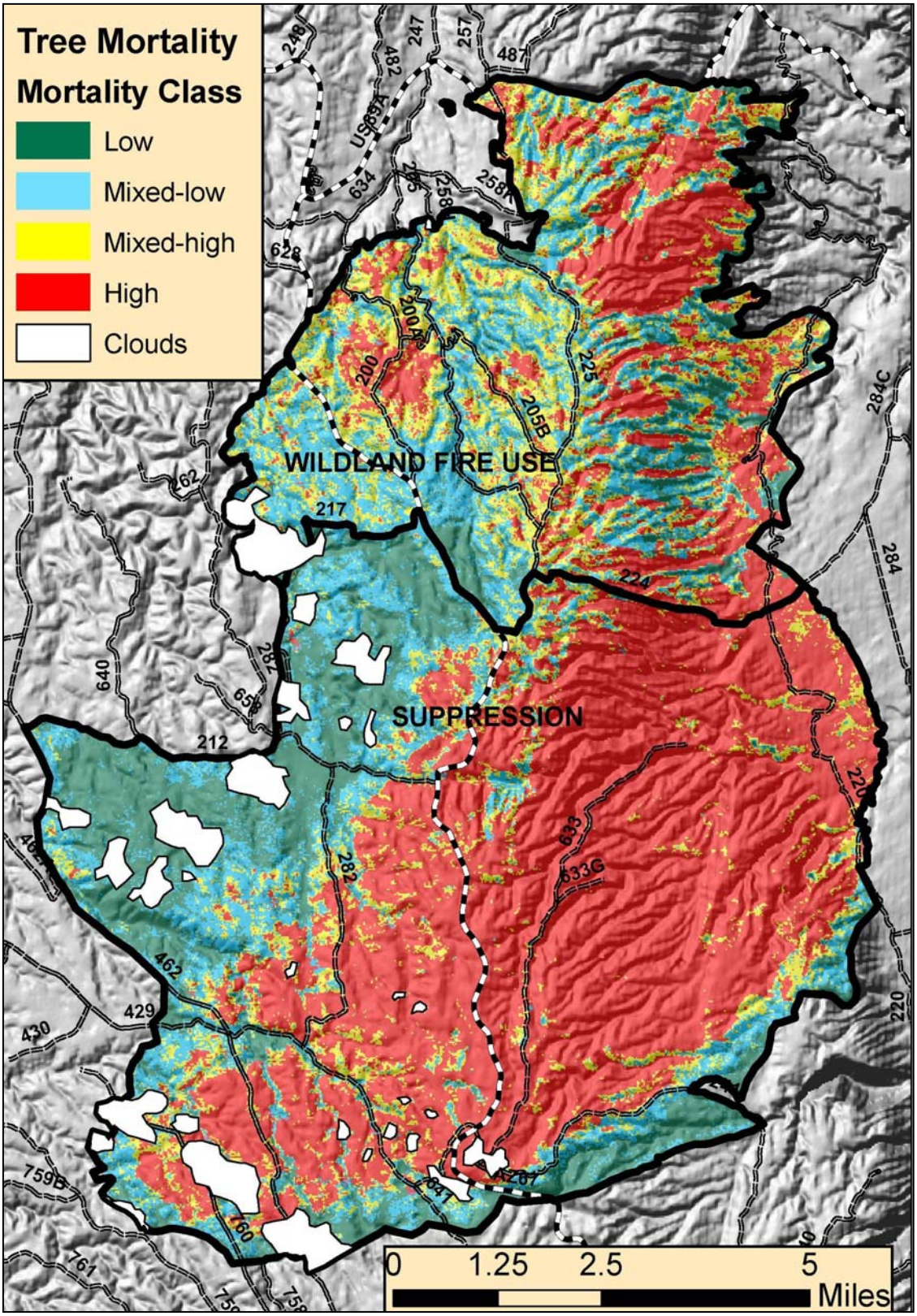


Figure 3. Vegetation mortality classes in the Warm Fire area based on BARC image.

Table 6. Median values of Composite Burn Index factors for each mortality class.

CBI Factor	Low	Mixed-Low	Mixed-High	High
Substrate Factors				
Percent Plot Burned	6	80	100	100
Litter and Light Fuel Consumed*	0.1	0.5	1.0	3.0
Fuels 3”-8” diameter Consumed*	0.3	1.0	2.5	3.0
Fuels > 8” Consumed*	1.5	2.4	3.0	3.0
Understory Vegetation Factors				
Vegetation Altered, < 3 feet in Height*	0.2	2.3	2.9	3.0
Vegetation Altered 3 to 16 feet in Height*	0.2	2.0	2.5	3.0
Subcanopy Factors				
Percent Green	98	50	0	0
Percent Brown	3	40	60	1
Percent Black	0	0	10	99
Percent Scorch (Black+ Brown)	3	50	100	100
Upper Canopy Factors				
Percent Green	100	90	60	0
Percent Brown	0	10	40	25
Percent Black	0	0	0	75
Percent Scorch (Black+ Brown)	0	10	40	100
Percent of Plot with ≥ 80% Upper Canopy Scorch	0	7	36	100
Percent Overstory Mortality	3	12	71	100

* substrate and understory values were measured on a continuous scale from 0.0 (unaltered) to 3.0 (severe).

Low Vegetation Mortality: The low vegetation mortality class was characterized by areas that were either unburned or burned in small patches. CBI plot data indicated that low vegetation mortality areas were characterized by plots in which less than 25% of litter/duff and light fuels (fuels < 3 inches in diameter) was consumed, plots with less than 10% loss or deep charring of medium-diameter fuels (fuels 3 to 8 inches in diameter), plots with less than 25% loss or deep charring of large-diameter fuels (fuels >8 inches in diameter), plots with less than 15% alteration (mortality) of vegetation in the less than 3 foot and 3 to16 foot strata classes, and plots with little to no scorching of subcanopy and upper canopy trees (Table 6). None of the 16 “low mortality” CBI plots had greater than 81% percent upper canopy scorch, or more than 5% of the upper canopy trees killed by the Warm Fire (Table 6).

High Vegetation Mortality: This class was characterized by CBI plots where burning resulted in near complete consumption of litter and duff (humus), at least 60% loss or deep charring of medium diameter fuels, at least 40% loss or deep charring of large diameter fuels, complete alteration of vegetation in the less than 3 foot and 3 to 16 foot height classes, 100% scorching of the subcanopy and upper canopy trees, and 100% mortality of upper canopy trees (Table 6).

Mixed-low and Mixed-High Vegetation Mortality: These classes were characterized by fire effects intermediate between the low and high mortality classes (Table 6). The mixed-low class was characterized by approximately 10% mortality of upper canopy trees and 50% subcanopy scorch. Two of 27 (7%) CBI plots in the mixed-low mortality class had an upper canopy scorch value greater than 80%. The mixed-high mortality class was characterized by approximately 70% mortality of upper canopy trees sampled and median values of 100% subcanopy scorch and 40% upper canopy scorch. Four of 11 (36%) CBI plots had greater than 80% upper canopy scorch.

The post-fire Landsat image from which the vegetation mortality map was created was taken on July 9, 2006, only 5 days after the fire was declared fully contained. Because of delayed vegetation mortality, a certain proportion of areas classified as mixed-high severity in this initial fire assessment would likely be classified as high severity by the 2007 growing season. The southern two-thirds of the Warm Fire (suppression area) was dominated by area classified as high vegetation mortality (20,940 acres or 57% of suppression area), with lesser areas classified as low, mixed-low, and mixed-high mortality (Figure 3 and Table 6). The northern third of the Warm Fire (Wildland Fire use area) was characterized by relatively similar amounts of mixed-low, mixed-high, and high vegetation mortality areas (Figure 3).

Table 7. Percent mortality class within the primary cover types.

	Low	Mixed-Low	Mixed-High	High
Ponderosa Pine	23%	18%	12%	47%
Mixed Conifer	8%	7%	7%	78%
Pinyon-Juniper	3%	4%	12%	81%
Aspen	15%	18%	15%	52%

Fire Ecology and Vegetation

The three major cover types within the Warm Wildland Fire area— ponderosa pine, mixed conifer, and pinyon-juniper, historically supported varying fire regimes based on their geographic location, edaphic factors and climatic factors such as lightning and precipitation amounts. Several fire history and forest composition studies have been completed in the North Rim area of the Grand Canyon National Park within similar elevational limits as the Warm Fire. These studies have described historic fire regimes based on these general cover types. A fire regime is a description of the role fire plays in an ecosystem, based on characteristics of the disturbance, the dominant or potential vegetation being described, or the fire severity as it effects dominant vegetation (Agee 1993). Fire regimes are based on fire occurrence and behavior prior to European settlers' influence, and described with characteristics of frequency, seasonality, intensity, duration and size. For the purposes of this post-fire assessment, fire regimes, vegetation response, fuel modeling and

predicted fire behavior will focus on these three major cover types contained within the fire perimeter.

Fire Regimes

Fire regimes in the fire area range from high frequency, low intensity in ponderosa pine, to mixed severity in the mixed conifer and pinyon-juniper. Generally, in low severity fire regimes, most trees survive a disturbance, while in high severity fire regimes, most trees are killed. These fire regimes are found in adjacent stands in the southwest on steep elevational gradients. A wildland fire disturbance that produces both low and high severity effects on adjacent forest patches is called a mixed severity fire regime (Fulé et al. 2003).

Forest Types and Fire Regimes of the Kaibab Plateau

Due to moisture limitations, the three major forest types in the southwest are readily demarcated by elevation. On the Kaibab Plateau, ponderosa pine occurs from 7,220 to 8,040 feet (2,200 to 2,450 m), with white fir as an associate. Mixed conifer can be found between 8,040 and 8,700 feet (2,450 to 2,650m) with white fir, ponderosa pine, and Douglas-fir dominants. In elevations above 8,700 feet (2,650), the forests are a mix of Engelmann spruce, ponderosa pine, white fir and blue spruce. Aspen occurs in all of these types as an early seral species (White and VanKat 1993).

White and VanKat (1993) found five major forest types in the high elevation coniferous forests of the North Rim of the Grand Canyon National Park. There are four mixed conifer types: ponderosa pine/Douglas fir (PIPO/PSME), ponderosa pine/white fir (PIPO/ABCO), blue spruce/ponderosa pine (PIPU/PIPO), white fir/ponderosa pine/Douglas fir (ABCO/PIPO/PSME) and one spruce type: Engelmann spruce/subalpine fir (PIEN/ABLA). All four of the mixed conifer types has a high frequency/low severity fire regime, with the frequency decreasing as site moisture conditions increased. The spruce type demonstrated the longest fire return interval, meaning that fuel build-up between subsequent fires would have been enough to support a more intense, high severity fire when they did occur.

A study of fire regimes in high elevation forests at the Grand Canyon (Fulé et al. 2003) found similar fire regimes based on elevation and cover type. The authors compared an upper elevation, more mesic mixed conifer site (ponderosa pine, white fir, aspen, Engelmann spruce) to a lower elevation drier ponderosa pine site. The more mesic, mixed conifer site had a longer mean fire return interval, while the drier ponderosa pine site experienced more frequent fires.

Changes to Fire Regimes after European Settlement

Prior to 1880, Grand Canyon forests were characterized by large fires and high fire frequencies, with fire sizes prior to European settlement reaching at least hundreds of hectares (Fulé et al. 2003, 2003a). An abrupt disruption of the historic fire regime began with the arrival of Mormon settlers in the 1850's. Extensive livestock grazing commenced by the 1880's and in 1887 there were 200,000 sheep and 20,000 cows documented on the Kaibab Plateau. Large deer herds were blamed for overgrazing in the 1920's, 30's and 50's. Fire suppression started in the early 20th century (White and VanKat 1993). Most of the Rim country experienced fire exclusion after 1879 with modern fire-free intervals about 5.5 times longer than presettlement at the two sites that Fulé and others studied (2003).

Fire Regime by Vegetation Type

Pinyon-Juniper

Fire regime information for the pinyon-juniper type is derived from the upper limit of its extent where it transitions with the ponderosa pine type. Species in the pinyon-juniper woodlands include Utah and Rocky Mountain juniper as well as true pinyon. Fire was the most important natural disturbance before introduction of livestock grazing. Large areas of woodland savannas would have burned, especially during dry years following wet years when herbaceous growth would have been plentiful. A study in Walnut Canyon, AZ found a 20 to 30 year return interval for surface fires. Pre-settlement fire behavior in dense stands was a mixture of surface and ground fire. Frequency and intensity depended on site productivity. Where grass cover was higher and more continuous during pre-settlement, fire frequency would have been higher, a 10-year return interval or less, and the frequency would have maintained these areas as savannas or grasslands (Brown et al. 2000).

Current Pinyon-Juniper Composition and Structure

Woodland cover and stand densities have increased throughout the west over the last century. The increasing range of the pinyon-juniper woodlands has been attributed to a variety of factors, including grazing, lack of fire, and favorable climatic conditions. Currently, pinyon-juniper stands are dense and are known to experience crown fires when high winds and low relative humidities occur (Brown et al. 2000).

Ponderosa pine

For 300 to 500 years prior to the 19th century, Southwest ponderosa pine (*Pinus ponderosa*) forests experienced high frequency, low intensity fires with return intervals of 2-20 years, while low frequency, high intensity crown fires were rare or non-existent (Savage and Mast 2005). Ponderosa pine developed adaptive traits to survive these frequent disturbances, including thick bark, rapid seedling growth, and flammable litter that burned off easily with little soil damage. These frequent low intensity fires maintained relatively open forests dominated by large trees with a diverse, productive understory. Lang and Stewart's 1910 survey of the Kaibab Plateau found a mean stand density of 52 trees per acre (28 trees/ha) for ponderosa pine trees with diameters greater than 6 inches (15.2 cm) (Savage and Mast 2005).

There have been several fire history studies in the drier ponderosa pine forests on the North Rim of the Grand Canyon adjacent to the Warm Fire area (Fulé et al. 2003, Fulé et al. 2003a, Gildar and Fulé 2004). While frequencies varied, all studies found frequent, low intensity fire occurrence in the ponderosa pine type. Assessing fire regimes for forests on both the North Rim and South Rim, Fulé et al. (2003a) found a mean fire return interval (MFI) of 3.2 to 5.5 years for all scars for the North Rim sites, while 25% of the trees sampled had a MFI of 6.4 to 9.5 years. At all sites, fires tended to occur in dry years following wet years. Gildar and Fulé (2004) found fire frequencies of 6.1 to 7.5 MFI for greater than 25% of all fire-scarred trees sampled, and 3.4 to 3.9 MFI for all fires recorded. Another study, in the ponderosa pine vegetation type, found a mean fire interval for all fire scars of 4.0 years, while more than 25% of all the sampled fire-scarred trees had a frequency of 6.8 years, and a range of 2 to 18 years (Fulé et al. 2003).

Fire exclusion since the late 1800's has resulted in the loss of the key ecosystem disturbance process from ponderosa pine forests. The rapid onset of fire suppression and domestic livestock

grazing brought an abrupt cessation to this surface fire regime (Savage and Mast 2005). The results may be seen in denser forests, reduced understory species composition and plant cover, and higher accumulation of litter and duff on the forest floor (Gildar and Fulé 2004). Gildar and Fulé (2004) found, when measuring burned and unburned sites in ponderosa pine forests in the Grand Canyon National Park, that tree density, forest floor, and coarse woody debris were significantly higher at the site that had not burned for at least 120 years.

Current Ponderosa Pine Composition and Structure

Savage and Mast (2005) studied multiple ponderosa pine sites that had experienced stand-replacing crown fires in the late 20th century and identified three general pathways of vegetation response following fire. These pathways are:

- Ponderosa pine—crown fire to dense ponderosa pine regeneration.
- Ponderosa pine—crown fire to shrub fields, Gambel oak, manzanita
- Ponderosa pine—crown fire to grass

They suggest that these alternative states after crown fire could be perpetuated by a fire regime favoring these compositions and structures, self-perpetuating themselves through stand-replacement disturbances. They also state post-crown fire forests of high density ponderosa pine seedlings may be just as vulnerable to stand-replacing fires as those already considered at high risk (Savage and Mast 2005).

Mixed Conifer

While more mesic than the ponderosa pine type adjacent to it, the mixed conifer type on the Kaibab Plateau is still considered a dry form of mixed conifer. The drier mixed conifer type on the Kaibab Plateau contains a variety of dominant overstory species, including ponderosa pine, Douglas-fir, white fir, aspen and blue spruce. The increase in moisture on these sites allows for a slightly longer fire frequency than the ponderosa pine type. White and VanKat (1993) found fire frequencies ranging from 6 to 27 years in an ABCO dominated type. The more mesic site conditions on the ABCO/PIPO/PSME forest type they delineated allowed for longer fire return intervals, and more intense fires, sometimes creating openings in the canopy where the more shade intolerant species of ponderosa pine and aspen could regenerate.

A study of fire regimes in high elevation forests of the Grand Canyon (Fulé et al. 2003), found similar fire regimes based on elevation and cover type. The more mesic, mixed conifer site had a mean fire return interval of 31 years for fires scarring more than 25% of sampled trees, and a mean fire interval of 2.6 years for all scars.

Mixed conifer communities with similar site characteristics in south central Utah on the Paunsaugunt Plateau were found to have a fire frequency of 7.5 years from 1500-1900 (Jenkins et al. 1998). They state that the altered stand composition in favor of white fir and Douglas-fir observed since European influence could not have occurred with frequent, low-intensity fire. The reduction in surface fire is noted as altering community type structure and reducing area occupied by aspen and ponderosa pine. They note the change in vegetation composition and structure has brought about a change in fuel loading and subsequently changed the fuel model 2 (timber-grass and understory) to a fuel model 8 (closed timber litter) or 10 (timber-litter and understory).

Current Mixed Conifer Composition and Structure

The frequent nature of fire disturbances in the forest types of the North Rim pre-European settlement favored regeneration of ponderosa pine, aspen and Douglas-fir. These species have adapted ecologically to these frequent disturbances and have become fire tolerant in a variety of ways. The increase in young, fire intolerant trees such as spruce and fir (White and VanKat 1993, Fulé et al 2003, Fulé et al. 2004) since Euro-American settlement means greater vertical and horizontal fuel continuity when combined with dead fuel loading. This change in the fuel profile to an increase in ladder and crown fuels suggests a change in the fire regime from high frequency/low severity to infrequent/high severity.

Vegetation Response to Fire

The post-fire vegetative response and composition depends on several factors including fire severity, prefire vegetation, and species adaptations to fire (Brown et al 2003).

Pinyon-Juniper

Pinyon pine and juniper trees are easily killed by fire. Both species have low fire resistance from seedling to maturity based on bark thickness and inability to regenerate easily after disturbance (Brown et al 2000). A possible pathway of re-establishment from a post crown-fire pinyon-juniper stand to pinyon-juniper woodland may take up to 300 years and would potentially progress through the following successional stages (Brown et al. 2000):

⇒ Skeleton forest/bare ground
⇒ Annual stage
⇒ Perennial grass/forb stage
⇒ Shrub stage
⇒ Shrub open tree
⇒ Climax woodland

Pinyon-juniper stands in the Warm Fire area experienced mostly high intensity fire behavior and subsequent high severity effects, resulting in high levels of overstory mortality. Much of this pre-fire cover type of pinyon-juniper is now at the skeleton forest/bare ground stage, and will progress to the next stage based on the available seed source and presence of sprouting shrub species such as Gambel oak. In pinyon-juniper areas experiencing less than high severity effects, the climax woodland stage still exists or the stands have been moved back a stage to the shrub open tree sere.

Ponderosa Pine

As stated previously, Savage and Mast (2005) investigated trajectories of ponderosa pine stands following crown fire. At most sites they studied, ponderosa pine (PIPO) was the most abundant of any tree species following fire. They found a higher proportion of mixed conifer forest species, such as white fir and aspen occurring at higher elevation sites that regenerated to forest, while more Douglas-fir occurred at mid-elevation burn sites. The recruitment and establishment of PIPO trees appeared to initiate soon after the fire occurred, even during drought years. Two general pathways of recovery emerged at their study sites in the decades after crown fire occurrence: 1—recovery to a PIPO forest, with densities exceeding the historic range of variation or 2—a “deflection” of forest recovery toward another vegetative state. The density of trees measured at these post-crown fire sites was higher than the range of natural variation for the ponderosa pine type. They conclude that

the high density of mature and sapling sized trees at these reforested sites make them more vulnerable to crown fire.

In the low and mixed-low fire severity sites on the Warm Fire in ponderosa pine sites, ponderosa pine seedlings were evident on the forest floor by August and September. The ability of ponderosa pine to regenerate these sites and more severely burned sites will depend on surviving seed trees, competition from sprouting species, such as oak and aspen, as well as moisture conditions necessary to the seedlings survival.

Aspen

Quaking aspen (*Populus tremuloides*) is very competitive on burned sites. It often dominates a site after fire even where it was barely noticeable as a component of the pre-fire vegetation. Aspen has adapted to fire in many ways, including easy top-kill by fire so root systems can send up a profusion of sprouts, and rapidly growing sprouts that extract the needed water, nutrients and photosynthate from the post-fire extant root system (FEIS 2006).

Aspen root suckering is affected by depth and diameter of parent roots. A study in Utah by Schier and Campbell found that over 90% of aspen sprouts following fire came from within 4.7 inches of the soil surface. On a Utah burn site, high-severity fires appeared to increase the depth at which sprouts originated (FEIS 2006). Moderate severity fire does not damage aspen roots. Severe fire may damage or kill shallow aspen roots, but deep roots are not damaged by fire and maintain the capacity to sprout (FEIS 2006). Severe fire may result in fewer sprouts than moderate severity fires; however, since aspen is self-thinning, post-fire sprouting densities between moderate and severe fires achieve similar numbers several years after the fire (FEIS 2006). Aspen are clearly evident and even abundant in the mixed-low, mixed-high, and high fire severity sites on the Warm fire.

Douglas-Fir

From seedling to pole-sized, Douglas-fir (*Pseudotsuga menziesii*) has a low-branching habit and thin bark make it very susceptible to fire damage. Crown scorch can kill Douglas-fir. The low branching habit encourages damage to the crown, which can outweigh the insulative nature of the bark. However, as they mature, the bark thickens, and survival of moderately severe fires is possible (FEIS 2006).

The ability of Douglas-fir to reestablish following the Warm Fire will depend on a viable seed source and desirable growing conditions. Douglas-fir seed germinates and establishes best on bare mineral soils, conditions provided by fire disturbance. Douglas-fir seedlings need partial shade while they are very young, but once established, require full sunlight (FEIS 2006). Regeneration success of Douglas-fir on the Warm Fire will depend on available and surviving seed trees, good seed crops and accessible bare mineral seedbeds.

White Fir

White fir (*Abies concolor var. concolor*) is highly susceptible to fire damage as a young tree due to its thin bark, resin blisters on the bole and drooping lower branches. As a result, young trees are easily killed by even low intensity surface fires. As trees mature, the bark thickens and the older trees develop some degree of fire tolerance. Following fire, white fir reestablishes via wind-

dispersed seed (FEIS 2006). White fir is an aggressive shade-tolerant tree that is able to reproduce successfully in the understory of ponderosa pine, Douglas-fir, and aspen stands.

Fuel Models

The assessment of changes in fuels in the Warm Fire suppression area will focus on the three major cover types (pinyon-juniper, ponderosa pine, and mixed conifer) and the fuel models used to describe the fire behavior within each type. Pre-fire fuel models were determined based on expert knowledge (Russ Truman, pers. comm. 2006) and described using Anderson's (1982) 13 Fire Behavior Fuel Models while predicted post-fire fuel models are a combination of Anderson's 13 and Scott and Burgan's (2005) 40 standard fire behavior fuel models. Wildfires create a variety of effects across the landscape, therefore fuel models pre and post-fire are expressed according to three broad categories of low, moderate, and severe fire effects. A fuel model is defined as a specific set of fuelbed parameters needed by a particular fire behavior model (Scott and Burgan 2005) to estimate fire behavior such as rate of spread in chains per hour or flame length in feet. Pre and post-fire fuel models are estimated (Table 8) for the Warm Fire suppression area, and fire behavior of each fuel model listed is described (Figure 6) by estimating rate of spread for the 50th and 97th percentile weather and fuel conditions (Table 9) on the North Kaibab Ranger District.

Changes in the Presettlement Fuel Profile

Fuels, including ladder and crown fuels, have increased in the Warm Fire area since pre-settlement conditions, particularly in the mixed conifer sites. The contribution of this change in fuel structure to changing fire behavior from historical conditions can be assessed by looking at two parameters that contribute to crown fire initiation and spread: average stand crown bulk density and crowning index.

As stated earlier, Lang and Stewart's 1910 surveys found a mean of 52 stems/acre (128 stems/ha) for ponderosa pine. This increase in stand density and shade intolerant species as they affect fire behavior has been reported in other studies. Fulé and others (2004) estimated changes in canopy fuels over time on the North Rim of the Grand Canyon, in sites ranging from 7,545 feet (2,300 m) feet to 9,166 feet (2,894 m) in elevation, from ponderosa pine dominated sites to mixed conifer and spruce-fir. They found canopy biomass increased at all sites since 1880, especially in higher elevations. There was an increase in shade intolerant species such as white fir, subalpine fir and spruce, which are all fire susceptible species. Fuels managers are concerned with canopy biomass because it is a factor in crown bulk density, which in turn is related to the ability of fire to travel between crowns and sustains itself as a crown fire. Prior to 1880, at all sites canopy bulk density was below 0.05 kg/m^3, a threshold value associated with crown fire/passive fire behavior (Fulé et al. 2004). In 1960, all study sites had crown bulk densities exceeding 0.05 kg/m^3 except the lowest ponderosa pine sites. Crowning index (CI) is the windspeed required to sustain crown fire movement through the stand. CI is related to canopy bulk density; if a stand has a denser crown structure, a lower windspeed is required to sustain a crown fire. In 1880, high winds were needed for crown fire in the stands examined by Fulé and others (2004). The study's modeling predicted that by 2040, only a windspeed of 28 miles per hour (a very low CI) would be needed. This windspeed is common as gusts or sustained winds in Northern Arizona during severe fires.

Fuel Model Changes Resulting from the Warm Fire

Fuel models did not change appreciably in the areas experiencing low severity fires. In the Ponderosa pine FM2—timber grass understory, the primary carrier of the fire is still timber grass

understory (Table 8). However, in the moderate to high severity areas, fuel conditions are now better described using fuel models that include large dead wood such as the TL7 in the mixed conifer. Additionally, some sites experienced a reduction in the fuels that would easily ignite and carry the fire such as in the ponderosa pine, mixed conifer high severity areas, where timber litter and understory was reduced, while large dead fuels increased.

Table 8. Pre and post-fire fuel models based on dominant overstory vegetation severity class based on Anderson's 13 and Scott and Burgan's (2005) 40 standard fire behavior fuel models.

Fuel Type	Severity	Pre-Fire	Post-Fire
Ponderosa Pine - Timber Grass Understory	Low	2	2 GR2-Low load, dry climate grass
	Med	2	2 TL1-Low load, compact conifer litter, (needlecast)
	High	2	TL7-Large downed logs
Pinyon Juniper - Brush	Low	5	5 SH1-Low load, dry climate shrub
	Med	5	5 SH1-Low load, dry climate shrub
	High	5	2 GR2-Low load, dry climate grass
Pinyon-Juniper - Compact Timber Litter	Low	8	8 TL1- Low load, compact conifer litter (needlecast)
	Med	8	8 TL1-Low load, compact conifer litter, (needlecast)
	High	8	TL7-Large downed logs
Ponderosa Pine, Mixed Conifer - Hardwood Litter	Low	9	9 TL1-Low load, compact conifer litter (needlecast)
	Med	9	10 TU1-Low load dry climate timber-grass-shrub (used for aspen stands with grass/shrub understory)
	High	9	TL7-Large downed logs
Mixed Conifer - Timber Understory	Low	10	10 TU1—Low load dry climate timber-grass-shrub (used for aspen stands with grass/shrub understory)
	Med	10	10 TU1—Low load dry climate timber-grass-shrub (used for aspen stands with grass/shrub understory)
	High	10	TL7-Large downed logs

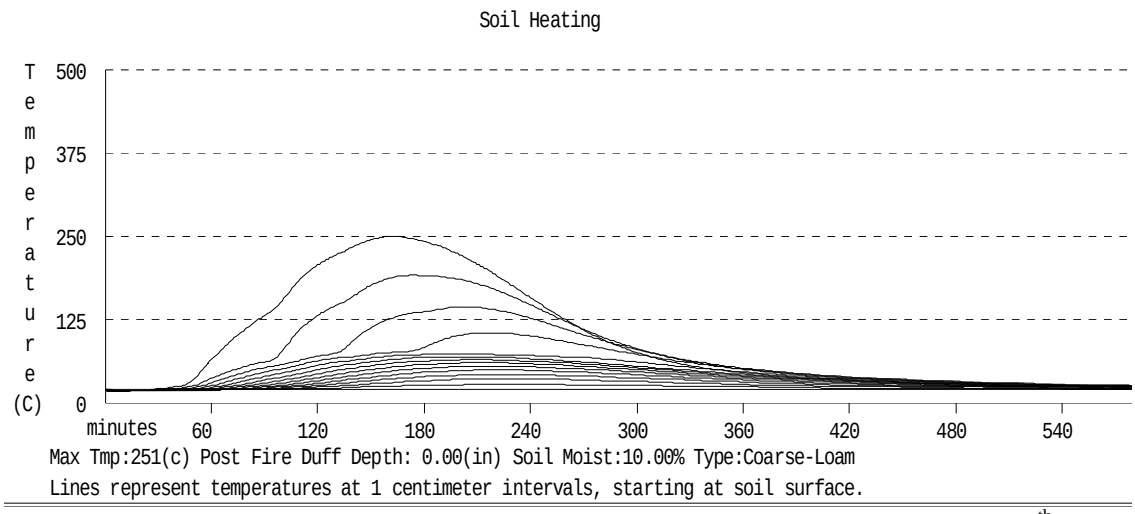
* Pre-fire fuels models are based on Anderson's (1982) 13 fire behavior prediction fuel models. Post-fire fuels models are a combination of Anderson's 13 and Scott and Burgan's (2005) 40 standard fire behavior fuel models.

Post-Disturbance Fire Behavior

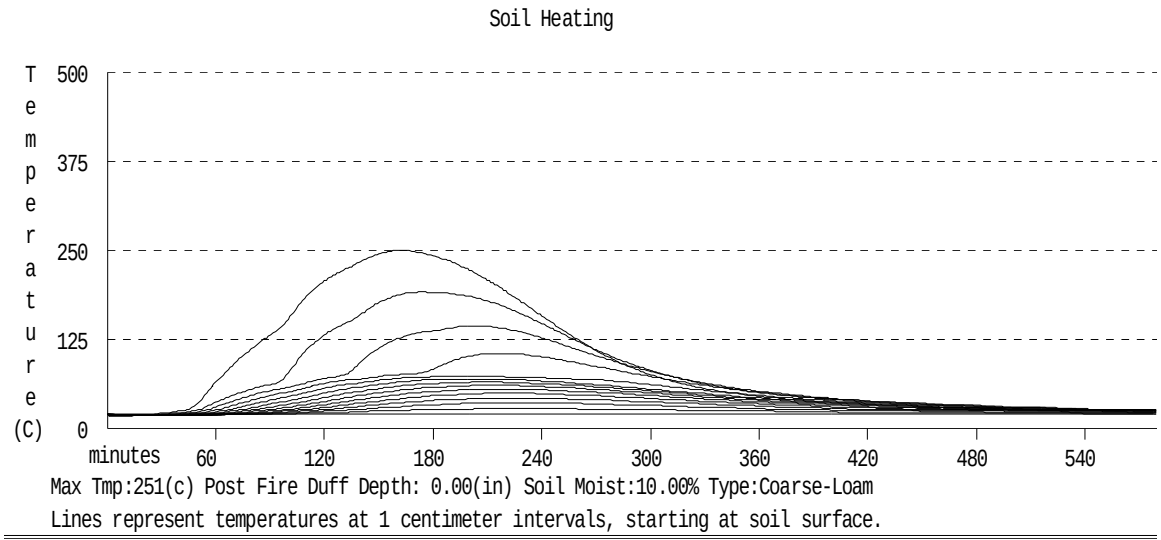
Fire Intensity and Fire Severity

Fire intensity is defined as the amount of heat generated by an active fire, and is usually expressed as heat per unit area of flaming front or just as flame length. Debano et al. (1998) describes fire severity as the ecosystems response to fire such as changes in dominant vegetation and soil conditions, while fire intensity expresses the amount and rate of surface fuel consumption. Fire severity is the result of a combination of fire intensity and duration or residence time of heat from the fire. Potential future fire intensity and severity have changed in all vegetation types as a result of the Warm Fire. Future fire behavior is predicted in Figure 4 for all post-fire fuel models by rate of spread in chains per hr. In areas that experienced low fire intensity and severity during the Warm Fire, such as the underburn areas in the ponderosa pine type, where surface fuel loading of needles was reduced and the lower branches on the overstory were killed and removed, future fire behavior will be mitigated by the reduction of fuels. Both surface fuel loading and crown fuels contribute to the risk of a crown fire. Surface fuels have been reduced and the average crown base height in the stand has been raised, so it will be less likely for these areas to experience a crown fire. When a fire does occur in the area, it will be less intense, produce less heat, and consequently less severe, translating to less overstory mortality and changed soil conditions.

In areas that experienced high severity fire effects, such as the mixed conifer sites on the Warm Fire, most of the surface fuels and much of the fine fuels in the overstory have been consumed. Future fire intensity (Table 8, FM TL7) and severity will not be a concern in these areas until the stand regenerates and the overstory snags fall down and come in contact with the soil surface. When large logs ignite, they produce more heat for a longer time than smaller fuels. Thus with higher fire intensities, fire severity is higher because soil damage increases with more heat for a longer period of time. Future fire intensity in the mixed conifer sites will depend on the type and arrangement of the vegetation that becomes established. Future fire intensity will be lower in areas where aspen becomes established and is the dominant understory. Because aspen does not readily ignite and burn, potential fire intensity and severity would be lower in the future. With lower fire intensities, it is less likely that downed logs will ignite. Figure 4 shows the soil heating profile for an aspen stand (b) without a coarse woody debris component and an aspen stand post-fire (a) that is regenerating to aspen with 100 tons per acre of coarse woody debris on the ground. Predicted soil heating temperatures and duration of heating does not change between the two stands because the overstory stand of aspen does not readily ignite and carry a fire, making it more difficult for the large downed logs to burn.



a. Soil heating in a post-fire aspen stand with 100 tons of coarse woody debris at the 97th percentile weather and fuel conditions.

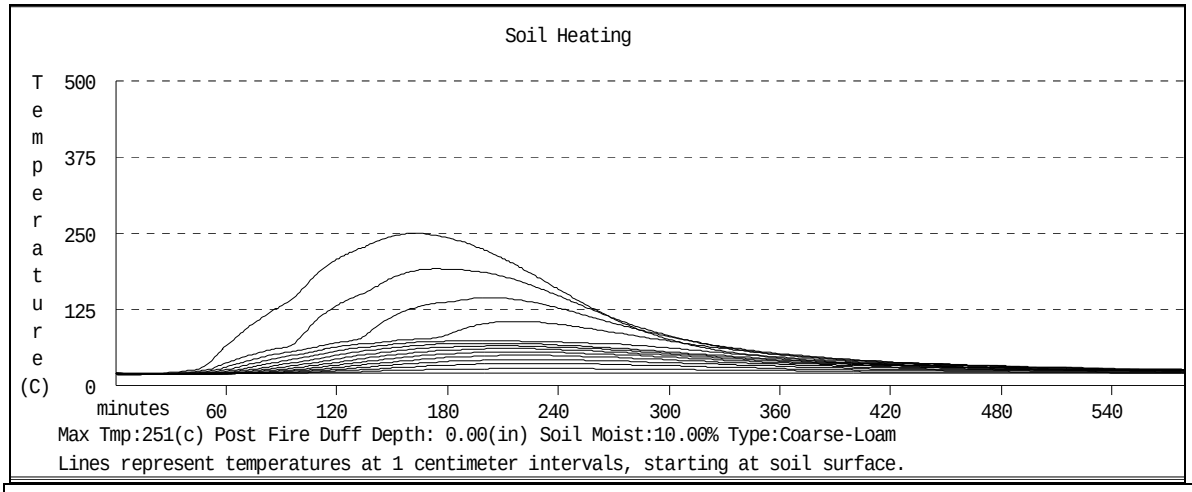


b. *S*oil heating in aspen for a fire with 97th percentile weather and fuel condition

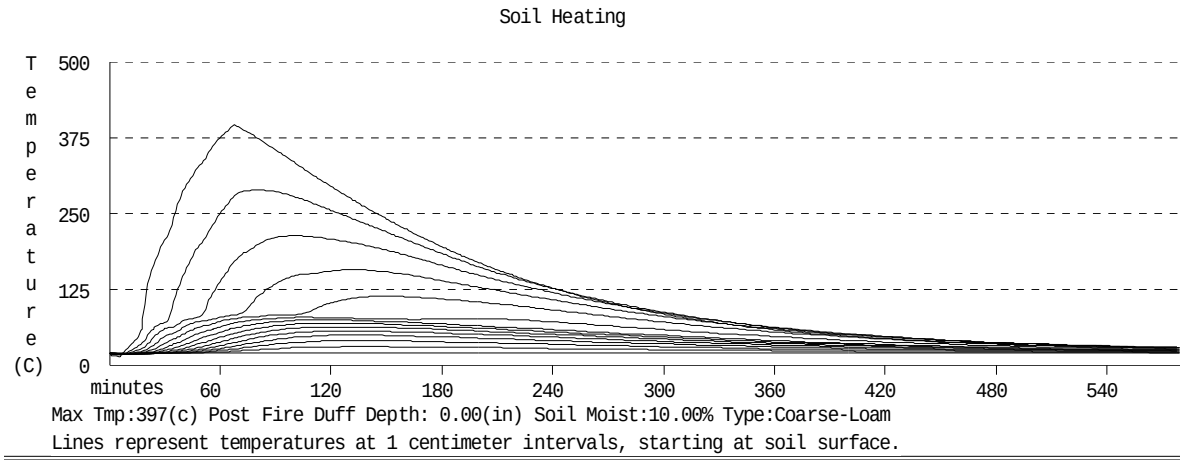
Figure 4. Soil heating estimates for aspen based on predicted coarse woody debris.

For mixed conifer areas that regenerate to ponderosa pine, future fire intensity is potentially higher because once the pine seedlings grow and reach crown closure, fires can easily ignite and spread through the crowns, meaning the downed snags will also ignite more readily and potentially cause soil damage.

Predicted soil temperatures for a ponderosa pine site with 40 tons per acre of coarse woody debris (CWD) (Figure 5 *b*) show a spike in temperatures and an increase in depth of lethal temperatures (60 degrees C). The lethal temperatures start earlier and last longer than without the 40 tons per acre of CWD (Figure 5 *a*).



a. Soil heating for a pre-burn ponderosa pine stand burning under 97th percentile weather and fuel conditions



b. soil heating for a ponderosa pine stand with 40 tons/acre of coarse woody debris burning under 97th percentile weather and fuel conditions

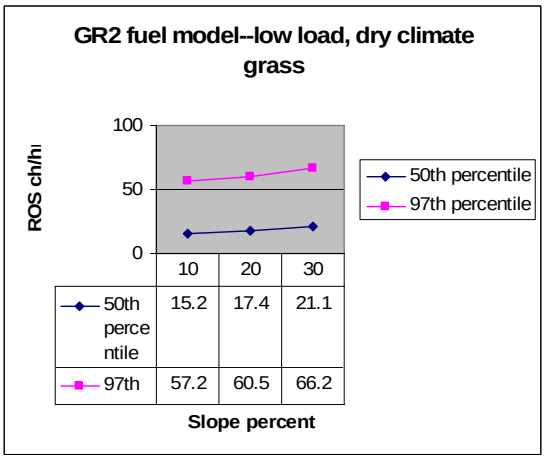
Figure 5. Soil heating estimates for ponderosa pine based on predicted coarse woody debris.

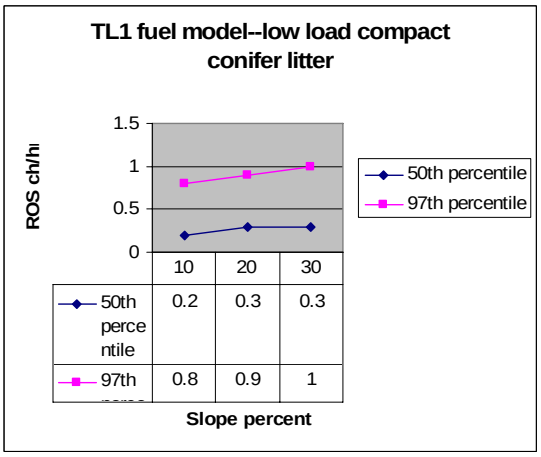
The fire behavior displayed in Figure 5 is based on local weather and fuel conditions (Table 9) while fuel amounts are default conditions provided for the fuel models in the BEHAVEPlus Version 3.0.1 program.

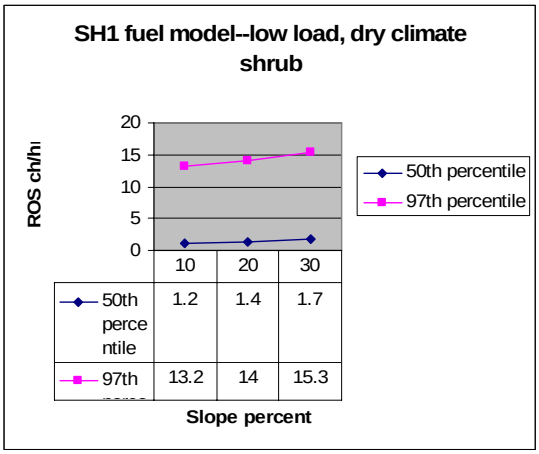
Table 9. Weather and fuel moisture parameters from the Warm Springs Canyon RAWS Data 1984-2005 for the 50th and 97th percentile.

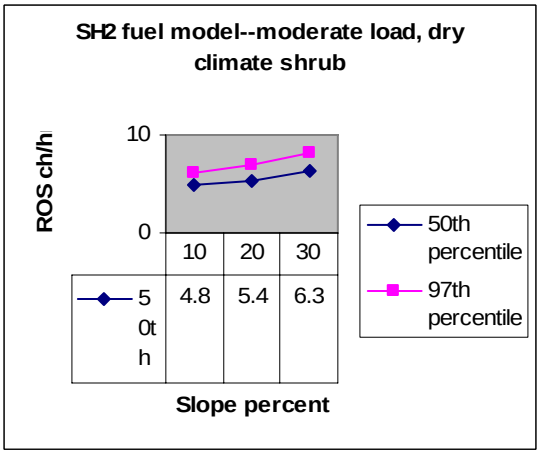
Weather/Fuel variable	50th percentile	97th percentile
20-ft. windspeed	4	10
1-Hr. FM	6	2
10-Hr. FM	8	2
100-Hr. FM	10	4
1000-Hr. FM	12	5
Herbaceous FM	30	30
Woody FM	61	59

Actual fuel loads and fire behavior would be reduced post-fire because of the removal of fine fuels that play an important role in the initiation and spread of fire. Many of the pre-fire fuel models did not change in the post-fire environment because the site experienced a low or mixed-low intensity fire. For example, in the ponderosa pine fuel model 2, a low to mixed-low severity fire would have the effect of reducing surface fuel loading while raising the crown base height, making it more difficult for this type to experience a crown fire. Other cover types that experienced high severity, stand-replacing effects have transitioned from a high load of fine fuels to a potential high load of large fuels. This is illustrated in the shift from a TU1 fuel model to a TL7. TU1 represents a fire environment of low load, dry climate timber, grass and shrub, while TL7 represents large downed logs. Based on weather and fuel conditions on the North Kaibab, TL7 will experience a slower rate of spread, and a reduced flame length.



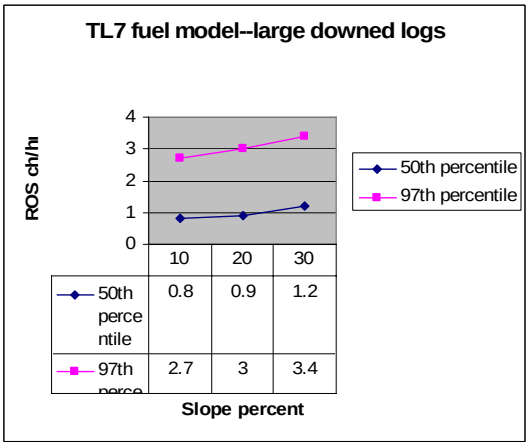


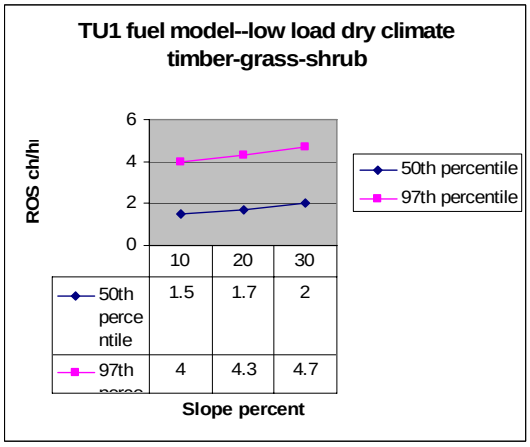




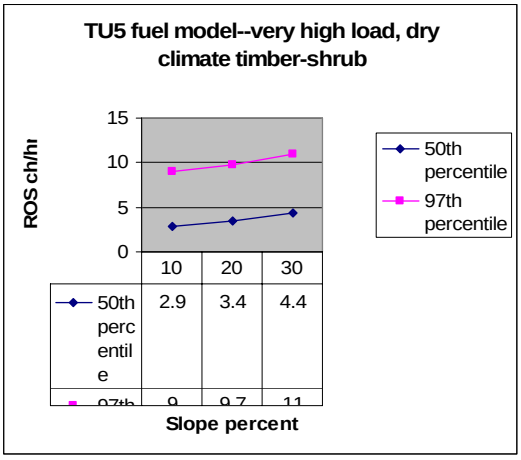
Primary carrier—woody shrubs, shrub litter **-woody shrub, shrub litter**

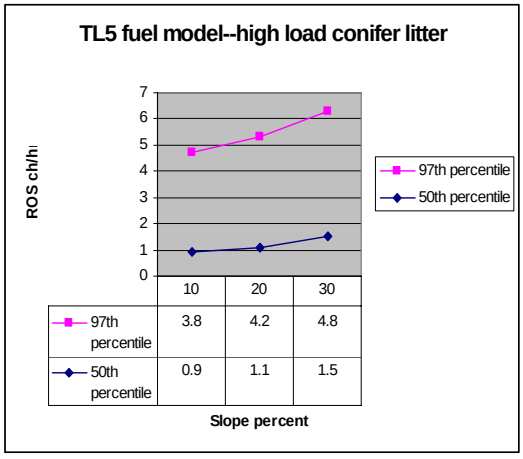
(Figure 6 Continued next page)





Primary carrier—heavy load forest litter **-grass and/or shrub/litter (aspen)**





Primary carrier - heavy forest litter w/shrub **high load conifer litter, mortality fuel**

Figure 6. Rate of spread for each post-fire fuel model for the 50th and 97th percentile weather and fuel moisture conditions as predicted by BEHAVE PLUS Version 3.0.

Fuel Model Progression and Coarse Woody Debris

As the post-fire stands re-establish and vegetation matures, the new vegetation will influence fire behavior as will the remaining vegetation and burned or scorched structures. The influence of small woody fuels (less than inch diameter) on spread rate and intensity of surface fire and torching and crowning is substantial. The standing large dead fuels that have been created have little influence on initiation and spread or intensity, but can contribute to development of large fires and high fire severity (Brown et al. 2003).

Fire persistence, resistance to control, and residence time (soil heating) are all influenced by large woody fuel loading, size, and state of decay. Torching, crowning, and spotting are greater where large woody fuels have accumulated under a forest canopy and can contribute to surface fire heat release (Brown et al. 2003).

The large standing dead trees in the mixed-low, mixed-high, and high severity areas will contribute to fire severity once they fall and come in contact with the soil surface. Several factors play a roll in how long snags stay standing including: species, size, decay stage, crown scorch, and stand

density. Based on a study of fire-killed ponderosa pine from two fires near Flagstaff, most trees were standing 3 years post-fire, but after 7 years, 41 percent had fallen (Chambers and Mast 2005). Similarly, a study on fall rate of mountain pine beetle-killed ponderosa pine trees in Colorado found the average fall rate was about 3 to 5 percent per year beginning in year 3, unless winds exceeded 75 mph. Trees generally broke off within 2 feet of ground level (Schmid et al. 1985). A study by Russell and others (2006) between logged and unlogged burned sites on ponderosa pine sites in Idaho found that overall a larger percent of Douglas-fir remained standing than ponderosa pine at the end of the study. Trends by species still standing were similar between logged and unlogged sites.

The study concluded that small-scale variables at the level of individual trees have the greatest effect on estimated persistence. Half-lives were longer for both ponderosa pine and Douglas-fir in unlogged areas. Larger diameter snags survived longer in both burns studied. Ten percent of ponderosa pine snags fell within 5 years post-fire. A study in Arizona found 6 to 14 percent of burned ponderosa pine snags had fallen within 3 to 5 years after a high severity fire. Larger snags and snags surrounded by higher snag densities survived longer on both sites (Russell et al. 2006). Standing dead trees with little to no fine fuels (less than 3” diameter) will contribute minimally to fire spread and intensity, and will not contribute to fire severity until they fall and come in contact with the soil surface.

Fuel Development Timeline

Brown and others (2003) developed a potential timeline for post-fire fuel structures and their contribution to possible fire behavior:

- 0-10 years—High severity fire is unlikely, duff and litter layer has recently been consumed and is absent. Salvage logging may produce small accumulations of fuel that would encourage severe burns in small areas. Surviving and sprouting herbs and shrubs dominate.

- 10-30 years—Downed coarse woody debris is experiencing some decay which equates to a longer burning and smoldering time. Small amount of duff accumulation does not contribute to fire severity. Consequently, high severity would occur where downed material lies on soil surface. Conifer regeneration may become established.

- 30-60 years—Considerable decay is occurring in coarse woody debris. Duff and litter is increasing. Higher severity burning is possible based on amount of coarse woody debris. If conifer overstory has become established, possibility of a crown fire coupled with burnout of coarse woody debris could increase burn severity.

Following Brown’s (2003) timeline, a fuel model progression was developed for the post-fire Warm Fire cover types (Table 10).

Table 10. Fuel model progression by pre-fire cover type for three time periods (after Brown et al. 2003).

Pre Fire Cover Type	Low	Moderate*	High
0 - 10 years			
Pinyon-Juniper	SH2**	SH2	GR2
	TU1	TL1	
Ponderosa Pine	TL1	TL1	TL1 (w/ pine seedlings)
	GR2	TL5	TU1 (with aspen)
Mixed conifer	TU5	TU5	TU1 (with aspen)
10 - 30 years			
Pinyon-Juniper	SH2	SH2	GS2
	TU1		
Ponderosa Pine	TL1	TL1	TL1 (w/ pine seedlings)
	GR2	TL5	TU1 + TL7
Mixed conifer	TU5	TU5	TU1 + TL7
30 to 60 years			
Pinyon-Juniper	SH2	TU1	SH1
	TU1	SH2	
Ponderosa Pine	TL1	TL1	TL1
	GR2	TL5	TU1 + TL7
Mixed conifer	TU5	TU5	TU1 + TL7
			TU5

* combines mixed low and mixed high vegetation severity into one class for purposes of fuel modeling only.

- GR2—Low load, dry climate grass
- SH1—Low load, dry climate shrub
- SH2—Moderate load, dry climate shrub
- TL1—Low load, compact conifer litter (needlecast)
- TL5—High load conifer litter (light slash or mortality fuel)
- TL7—Large downed logs
- TU1—Low load dry climate timber-grass-shrub (used for aspen stands with grass/shrub understory)
- TU5—Very high load, dry climate timber-shrub (heavy forest litter)

The pre-fire vegetation, severity experienced by the site, and ability to respond to disturbance all influence the post-burn vegetation and fuel model description. For example, a low severity fire in ponderosa pine did not substantially change vegetation composition but it did change fuel structure by reducing surface fuel load and raising the live crown base height of the stand. This fuel structure means that the next fire event will likely be one of low intensity and severity, due to the reduced surface fuel loading and higher crown base height. However, a high severity fire in mixed conifer not only changes stand structure, but also vegetation composition because of individual species response to fire. The species best able to respond to a high severity disturbance is aspen, and is reflected by the number of aspen sprouts already observed. Ponderosa pine, Douglas-fir and true firs respond more slowly or take decades to return to the site from off-site seed. These vegetative responses are reflected in the estimated fuel model progression shown in Table 10.

Coarse Woody Debris

The Bechsta Report (Bechsta et al. 2002) states that fire plays an important ecosystem function, creating disturbance and recovery patterns that endemic species have adapted to. The Report states the patterns and processes that result from fires are critical to ecosystems over the long term, and there is no immediate ecological need for intervention. However, due to the changes in crown fuels as observed by Fulé and others (2004) in the mixed conifer stands at the North Rim of the Grand Canyon (south of and similar to those in the Warm Fire), the disturbance pattern exhibited by the Warm Fire in the mixed conifer stands is different than those that occurred pre-settlement. Pre-settlement fires in the mixed conifer were large, but of mixed severity, combining surface fire with pockets of overstory mortality. Warm Fire area fuel conditions were more dense and homogenous than historic conditions, and as a result, large areas of mixed conifer experienced high severity, stand-replacing fire. In the low and mixed-low severity ponderosa pine areas of the Warm Fire, fuels and fire effects were not very different than those reported for pre-settlement fires on the North Rim.

Following Brown and other's (2003) methods for measuring standing snag contributions to coarse woody debris in tons/acre, number of snags by species and 2 inch size class were measured on each burn severity plot in forested types. Data from 29 plots were used to estimate coarse woody debris in tons/acre for plots with predominant pre-fire ponderosa pine vegetation. Coarse woody debris calculated on the Warm Fire CBI plots ranged from 0.28 to 143.7 tons per acre (Appendix 5), equaling the total loading of standing dead ponderosa pine coarse woody debris as calculated by Brown (2003). Seventeen percent of the 29 plots used to determine CWD amounts had over 58 tons/acre of coarse woody debris (74.5 to 143.7 tons/acre), which is higher than the slash fuel model's upper limit, while 83% of plots calculated had less than 58 tons per acre, ranging from 0.28 to 54.5 tons per acre. The slash fuel model (Anderson 1982) tons per acre amounts presented here are for the fine fuels less than 3 inches in diameter, as these are the fuels that easily ignite and spread. In the high severity areas of the Warm Fire, fine fuels are now largely absent, particularly in the 0-.25" inch size-class, while in the low-moderate to high-moderate severity, more dead fine fuels have been created.

Coarse woody debris in tons per acre were input into the First Order Fire Effects Model (FOFEM) soil heating module to determine depth of damaging and lethal soil temperatures in centimeters (Figures 4 and 5). Predicted temperatures can be assumed to be higher under large pieces of wood, but lower farther away. Excessive soil heating is concentrated under large woody pieces and generally occurs with loadings greater than 40 tons per acre. Soil damage occurs at 60 degrees C, and plant tissue dies at 275 degrees C. However, even at high fuel loads, only a small portion of an area is actually covered by woody fuel (Brown et al. 2003).

Passovoy and Fulé (2006) compared post-wildfire CWD on seven wildfires in Northern Arizona that occurred 3 to 27 years prior to 2004, when the study was conducted. They delineated between fine fuels less than 3 inches and CWD greater than 3 inches in their calculations. They compared the amount of fine fuel loading to the amount reported for slash fuel models 11, 12, and 13 (Anderson 1982). These models are designed to predict fire behavior in areas where the fire would spread through downed woody debris. All of the fine woody fuel loads measured at the seven fire sites, 1.2 tons per acre to 4.46 tons per acre, were below the range of 11.6 to 58 tons per acre for the slash fuel models, meaning surface fire behavior would be less at these sites than predicted for the slash fuel models. Passovoy and Fulé (2006) did find that the rotten wood component of the coarse woody debris had increased from the mid-range fires, 8 to 9 years old, to the oldest fire, 27 years.

They suggest the change of status from sound to rotten indicates an increase in fire hazard because rotten wood ignites more easily and smolders longer.

Brown et al. (2003) established optimum levels of coarse woody debris, balancing benefits for wildlife habitat and productivity against soil heating and fire hazard, between approximately 5 and 20 tons per acre. Accumulated coarse woody debris amounts in Passovoy and Fulé (2006) study sites were low, rising to within the optimal range, but not exceeding Brown's (2003) suggested values. The values of coarse woody debris calculated for the standing trees in the Warm Fire area ranged from 1 to 148 tons per acre. It remains to be seen what actual on the ground accumulations are; this will be effected by a variety of factors, including pre-fire tree size, tree soundness, climate and decay rate.

Table 11. Soil heating depths based on coarse woody debris tons/acre assuming all duff has been removed by fire. Living organisms begin to die at 60 degrees C and excessive soil heating is possible at 275 degrees C.

Tons/Acre Fuels >3''	Fuel Moisture (%) Fuels >3"	Season	Duff Depth	Max. Soil Depth with 60 Degrees C (cm)	Max. Soil Depth with 275 Degrees C (cm)
10	12	Summer	0	0	0
10	5	Summer	0	0	0
40	12	Summer	0	8	0
40	5	Summer	0	8	1
70	12	Summer	0	9	2
70	5	Summer	0	10	2
120	12	Summer	0	10	3
120	5	Summer	0	10	4

Soil temperatures and depth of soil heating increase with increasing tons per acre of coarse woody debris. Forty tons per acre of coarse woody debris in a ponderosa pine cover type experiences 60 degrees C to an 8 cm depth (Table 11), while 120 tons per acre can heat the soil to 60 degrees Celsius to a depth of 10 cm. These values are calculated based on a cover type of ponderosa pine. If a mixed conifer stand regenerates to aspen, the FOFEM soil heating model predicts that when a fire occurs and a large amount of coarse woody debris has been created because of falling snags, the depth and duration of soil heating would be no different than for an aspen stand without the large amount of coarse woody debris (Figure 4).

Fire and Fuels Conclusions

Future fire behavior, fire intensity, and fire severity are dependent on the amount of fuels consumed by the Warm Fire, the amount of mortality, and the type of vegetation that reestablishes on each site. Because future fire behavior is influenced by the establishing vegetation, planted species will also have an impact. Planting ponderosa pine or any conifer species on some sites will mean that future fire intensity may increase sooner because the conifer seedlings and saplings are more flammable than aspen, and will produce more fire intensity. If aspen makes up a high proportion of the forest, the crown fire hazard would be reduced because of lower crown bulk densities, a higher crown base height, and a reduced rate of surface fire spread and intensity (Fulé et al. 2004).

The difference in fire behavior will be exhibited in fire intensity and fire severity. Since intensity is heat release/unit area, those fuels most available to burn influence fireline intensity, such as the small fuels. Severity is a combination of heat release and duration of heating, therefore both fine and large fuels play a role. Much of the fine fuels have been removed in the mixed-high to high severity areas, so fires will ignite less readily and have difficulty spreading once they do ignite. Fire severity will be reduced due to the lack of fine fuels and the lower ignitability of the larger fuels until they fall down and start to rot. Future fine fuels in these areas will come from the type of vegetation that regenerates.

Predicting Post-Fire Tree Mortality

Pre-fire Mortality Agents

Ponderosa Pine

Historically, mountain pine beetle (*Dendroctonus ponderosae*) has been the most important bark beetle attacking ponderosa pine on the North Kaibab with outbreaks occurring in the 1920's and 1970's (Blackman 1931, Wilson 1996, Dahms and Geils 1997). However, mountain pine beetle populations have been very low between 2000 to the present (USDA-Forest Service, Region 3 Insect & Disease Conditions Reports). Almost all beetle-caused ponderosa pine mortality in the last 5 years can be attributed to a combination of western pine beetle (*D. brevicomis*), roundheaded pine beetle (*D. adjunctus*), and pine engraver beetles (*Ips pini*) (J. McMillin, personal observations); albeit even this mortality has been lower than other areas of the Southwest (USDA Forest Service, Region 3 Insect & Disease Conditions Reports). Defoliator populations have also been low over the past several years, although minor amounts of tiger moth (*Lophocampa ingens*) defoliation were observable in 2005 and 2006. Pandora moth (*Coloradia pandora*) reached outbreak status on the North Kaibab in the early 1980's (reviewed by Schmid and Bennet 1988). This species can have outbreaks every 20 to 25 years in some locations of its range; however, no observable defoliation has occurred since the last outbreak on the North Kaibab. Ponderosa pine is also infected with southwestern dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum*) throughout several areas of the District.

White Fir and Douglas-Fir

Mortality of white fir caused by fir engraver (*Scolytus ventralis*) has been occurring on the North Kaibab since the early 1990's (J. Wilson, unpublished data) and is still occurring (J. McMillin, personal observation). Douglas-fir mortality is limited on the North Kaibab, but has increased throughout the Southwestern Region during the past few years (USDA Forest Service Region 3 Insect & Disease Conditions Reports). The primary cause of Douglas-fir mortality has been by Douglas-fir beetle (*D. pseudotsugae*), with attacks focused on large trees heavily infected with Douglas-fir dwarf mistletoe (*A. douglasii*).

Pinyon Pine

High levels of pinyon mortality were detected by aerial survey between 2001 and 2003 with more than 40,000 acres impacted (USDA Forest Service Region 3 Insect & Disease Conditions Reports). Mortality levels declined dramatically in 2004 and 2005. The cause of mortality was attributed to pinyon ips (*I. confusus*) attacking drought-stressed pinyon.

Aspen

Relatively high levels of defoliation on mature aspen have been observed on the North Kaibab beginning in the late 1990's through 2005 with aerial detection surveys finding more than 3,000 acres being impacted. Defoliation, dieback, and mortality of mature aspen have been caused by a combination of frost damage, drought, and limited western tent caterpillar activity (*Malacosoma californicum*) (USDA-Forest Service, Region 3 Insect & Disease Conditions Reports).

Post-Fire Tree Mortality Factors

Ponderosa Pine

Many factors influence tree mortality following fire, including: 1) the amount of tree crown that is damaged by scorch (heat-caused damage of foliage) and consumption (foliage that is actually consumed in the fire), 2) severity of damage to the bole cambium and root systems, 3) tree size, 4) season in which the fire occurs (active growing season vs. dormant season), and 5) infestation by insects such as bark beetles and wood borers (reviewed by DeNitto et al. 2000, Fowler and Sieg 2004, Parker et al. 2006). Previous studies have consistently ranked crown damage as the best predictor of post-fire mortality of ponderosa pine trees (Dieterich 1979, Wyant et al. 1986, Saveland and Neuenschwander 1990, Stephens and Finney 2002, Wallin et al. 2003, McHugh and Kolb 2003, McHugh et al. 2003).

A recent paper reported that separate measurements of crown scorch and crown consumption resulted in increased accuracy of predictions models compared with total crown damage (scorch plus consumption) (Sieg et al. 2006). However, a model that included both total crown damage and bole char severity best predicted ponderosa pine mortality from the 1996 Bridger-Knoll wildfire on the North Kaibab (McHugh and Kolb 2003). In general, there seems to be a threshold level of 70% total crown damage at which ponderosa pine mortality begins, and mortality rates continue to increase at levels above this (reviewed by McHugh and Kolb 2003).

Tree size also influences the probability of mortality following burning. Larger diameter and taller trees generally survive greater levels of fire damage (Wyant et al. 1986, Harrington 1993, Regelbrugge and Conard 1993, Stephens and Finney 2002, Thies et al. 2006). In most of these studies, decreasing probability of mortality of ponderosa pine trees with increasing diameter was attributed to greater bark thickness with age (Ryan 1982). However, McHugh and Kolb's (2003) study suggests that large diameter trees (>40 cm dbh) may be more susceptible to post-fire mortality during severe droughts.

Although western pine beetle, red turpentine beetle, and pine engraver species may be attracted to fire-damaged pine trees (Miller and Patterson 1927, Miller and Keen 1960, Smith 1971, Bradley and Tueller 2001, Ganz et al. 2003, McHugh et al. 2003), some species, such as mountain pine beetle, do not seem to be to attracted to fire-damaged pine trees (Ryan and Amman 1996, Rasmussen et al. 1996, McHugh et al. 2003). Recent studies have demonstrated the importance of bark beetles in models of post-fire mortality of ponderosa pine trees (McHugh et al. 2003, Wallin et al. 2003, Sieg et al. 2006). In general, bark beetle attacks occurred on trees sustaining greater crown damage, with increased probability of bark beetle attack at total crown damage levels above 50% (McHugh et al. 2003). However, trees must have enough green phloem for successful bark beetle attack and brood production (Parker et al. 2006); thus, trees sustaining severe bole damage may not be a viable host.

Douglas-Fir and White Fir

Crown scorch and either bark char, basal scorch, or direct measures of cambium death appear to be the best predictors of Douglas-fir post-fire mortality (Ryan et al. 1988, reviewed by Fowler and Sieg 2004). Despite their thick bark, mature Douglas-fir often suffer high levels of mortality after fire because Douglas-fir beetles are attracted to trees with moderate amounts of crown scorch (DeNitto et al. 2000, Parker et al. 2006). Apparently, Douglas-fir beetles prefer trees sustaining more than 50% basal girdling, ample green phloem, and less than 75% crown scorch. Populations of Douglas-fir beetle may increase in burned areas and subsequently attack trees in neighboring unburned areas (reviewed by DeNitto et al. 2000, Parker et al. 2006) leading to large-scale outbreaks (McMillin and Allen 2003).

Models predicting post-fire white fir mortality include measures of crown damage cambium kill, tree size, and the presence of ambrosia beetles (Hood et al., internet presentation). Ambrosia beetles are closely related to bark beetles, but do not kill trees, instead feed on fungi that they introduce into the sapwood of dead or dying trees (Furniss and Carolin 1977). Therefore, their presence is an excellent indicator of tree mortality. Based on a walk-through of several areas of the Warm Fire, fire-killed white fir trees were already heavily infested with ambrosia beetles by early September.

Pinyon Pine

Models that predict pinyon pine mortality following fire do not currently exist; however, based on the relatively thin bark of this species and shallow root systems, models similar to other thin-barked species should be applicable. In addition, there are no reports of how pinyon ips responds to fire-damaged trees. Because of their thin bark and apparent susceptibility to severe bole damage, fire damaged pinyon pine probably would not be good host material for attacking beetles (J. McMillin, personal observation).

Bark Beetle Risk vs. Susceptibility

“Hazard” or “susceptibility” is the inherent characteristics of a stand of trees (e.g. high stand density) that affect its likelihood of attack and damage by a bark beetle population. “Risk” is defined as the short-term expectancy of tree mortality in a stand as a result of a bark beetle infestation. Thus, risk is a function of stand susceptibility and beetle pressure. Beetle pressure is determined by the population size of beetles and their proximity to the stand being assessed, and relates to the likelihood of a beetle population entering a given stand. A "high-hazard" stand can exist with little risk when local populations of bark beetles are low. Conversely, a “low-hazard” stand can have moderate risk when beetle populations are high (Shore and Safranyik, 1992).

Although many ponderosa pine stands in the Warm Fire may be highly susceptible to bark beetle attack because of high stand densities and large numbers of fire-weakened trees, because beetle populations in the area are currently low, there is little risk of large-scale outbreaks. Similarly, because Douglas-fir is a relatively minor component of stands on the North Kaibab and Douglas-fir beetle populations are currently low, the risk to widespread Douglas-fir beetle-caused tree mortality both inside and outside the fire is low. Because both white fir and pinyon pine are very susceptible to severe cambium damage, it does not seem that they will provide good host material for bark beetles.

Tree Deterioration

Deterioration of dead trees is caused by fungi, insects (both directly and indirectly by vectoring in decay fungi), and weathering (reviewed in DeNitto et al. 2000). The three most common deteriorations are blue stain, decay and weather checking. Blue stain is discoloration in sapwood of dead trees caused by non-decaying fungi, and does not affect the structural integrity of wood. Decays are caused by fungi that break down wood cells by enzymatic action, thus causing significant loss of wood strength (Panshin and de Zeeuw 1980). Decays can affect sapwood and heartwood of trees. When trees begin to dry out after death they lose moisture, shrink and develop cracks. Weather checking is often most common in upper boles of trees, and on hot, dry, or windy sites. These cracks can be entry points for decay fungi, but once trees slough off their bark, they often become too dry for fungi to be successful. Cracks also reduce the strength of affected wood.

Several factors influence the rate of deterioration of fire-killed trees, including: tree species (white fir deteriorates faster than pine and Douglas-fir), species characteristics (such as bark thickness and the ratio of sapwood to heartwood), tree size, local site conditions, severity of the fire, and time of year the burn occurred (reviewed by Lowell et al. 1992). Different combinations of these factors result in varied rates of deterioration. However, in general, blue stain will appear in susceptible trees within the first year, some sapwood will be decayed in the second year, and sapwood of most conifers will be unusable after three years, especially in smaller trees and the tops of larger trees (Kimmey 1955). Decay of the heartwood can take much longer (>5 - 10 years), especially of large diameter trees.

Management Considerations

Bark beetle populations are currently low on the North Kaibab RD, and for some beetle species their host is a relatively minor component of forests. As a result, there is minimal risk of widespread beetle activity both within the Warm Fire boundaries and in adjacent areas. Undoubtedly, there will be additional tree mortality caused by bark beetles attacking fire-damaged trees, but there is little evidence of bark beetle outbreaks occurring in ponderosa pine forests following fire. The post-fire tree mortality model developed from data collected on the Bridger-Knoll Fire should be applicable to making decisions regarding mortality of ponderosa pine in the Warm Fire.

Douglas-fir beetle risk is relatively low because their host makes up a small percentage of the forested areas within the boundary of the fire, and because most of the Douglas-fir in this area is dominated by small diameter trees. Because true firs are very fire-susceptible to fire damage, they are in general not good hosts for fir engraver beetles. They will harbor large numbers of ambrosia beetles and wood borers. Fir engraver beetles will likely continue to kill white fir outside the burn area. There is a paucity of research on bark beetle response to fire-damaged pinyon pine. However, based on a walk-through of sections of the Warm Fire that contain pinyon-juniper woodlands, most of the pinyon boles were severely burned and therefore would not make good a food resource for bark beetles.

In most areas of its historic range in the western US, aspen has been declining or nearly eliminated from forests over the past few decades. The landscape-level disturbance caused by the Warm Fire will result in a “re-birth” of large aspen stands through new sprouts developing from root systems of mature, fire-damaged aspen.

Wildlife Resources

Historic and Pre-fire Conditions

The concept of Historical Range of Variation or Variability (HRV) is useful for a general discussion of desired conditions for wildlife habitat under the assumption that HRV describes the evolutionary context under which all native wildlife species evolved. Descriptions of HRV identify ecosystem components and processes and their variability (Schussman and Smith 2006). For this report, it is assumed that fire effects that depart from HRV are more likely to negatively affect native wildlife species and their habitats than fire effects considered to be within HRV.

In a description of HRV for national forests in Arizona and New Mexico, Schussman and Smith (2006) list 24 potential natural vegetation types for the region. Of these, six occur within the Warm Fire area: aspen forest, mixed conifer forest, montane grassland, pinyon juniper woodland, ponderosa pine forest, and spruce-fir forest. Ponderosa pine forest is the most extensive of these vegetation types within the Warm Fire area, followed by mixed conifer forest, pinyon-juniper woodland, aspen forest, montane grassland, and spruce-fir forest (Figure 2 and Table 4).

It is beyond the scope and not the objective of this report to discuss HRV for each of the potential natural vegetation types, but it is useful to briefly discuss the effects of the Warm Fire on wildlife habitat in relation to HRV. HRV fire regime for ponderosa pine forests of the Southwest is characterized by frequent, low-severity surface fires (Friederici 2003). HRV forest structure is characterized by a patchy distribution of uneven-aged trees, with widely spaced large-diameter, fire-resistant ponderosa pine trees. Almost 12,000 acres of ponderosa pine cover type in the suppression area was classified as high vegetation mortality, in which there was nearly 100% mortality of dominant and codominant trees (Table 3). Crown fire likely occurred throughout most of this area. For a fire regime characterized by frequent, low-severity surface fires, these effects clearly exceeded HRV fire effects. Despite past silvicultural treatments within the ponderosa pine type in the Warm Fire area, tree densities and canopy volumes in much of this vegetation type in the Warm Fire area exceeded HRV tree densities and canopy volumes as a result of decreased fire since 1880 (White and Vankat 1993, Fulé et al. 2003). Some of the implications of these fire effects for wildlife species associated with ponderosa pine forest are discussed below in the effects to individual species section.

The mixed conifer potential natural vegetation type on the Kaibab Plateau is characterized by an HRV mixed fire regime (Fulé et al. 2003, Schussman and Smith 2006). Fulé et al. (2003) estimated that on approximately 40% of the mixed conifer forest they studied on the North Rim of Grand Canyon south of the Warm Fire, surface fires burned regularly between 1700 and 1879. On approximately 60% of the landscape, severe fires occurred at intervals that averaged 20-30 years in the century preceding 1880. Fulé et al. (2003) acknowledge that the fire regime in these forests that are transitional between lower-elevation ponderosa pine forests and higher-elevation spruce-fir forests are complex and variable. High severity, larger crown fires in mixed conifer forest of this area have been predicted based on the increase in tree densities and canopy volumes that have occurred since the late 1800s (White and VanKat 1993, Fulé et al. 2003). The large areas of crown fire-produced high mortality effects in the mixed conifer forest in the Warm Fire are consistent with these predictions, and these effects exceed mixed conifer HRV fire effects.

HRV conditions and processes for pinyon-juniper woodland, the third most extensive potential natural vegetation type within the Warm Fire area, are more poorly understood than HRV

conditions and processes for ponderosa pine and mixed conifer potential natural vegetation types (Baker and Shinneman 2004). Baker and Shinneman (2004) concluded after an extensive literature review that there is little support for pinyon-juniper fire regimes typically described in the literature. They concluded that, while uncertain, low-severity surface fire was most likely not a common type of fire in pinyon-juniper woodlands in the western U.S., and that at least in some parts of the West, the natural fire regime was dominated by infrequent high-severity crown fires.

Aspen forests provide habitat for numerous wildlife species. Aspen forests have declined throughout extensive areas of the western United States (Bartos 2001). One of the primary factors contributing to aspen decline has been conifer encroachment resulting from reduced wildfire disturbance since the late 19th century. Fire regimes for aspen are determined by the adjacent or matrix potential natural vegetation type (Schussman and Smith 2006). Aspen can regenerate without disturbance, but if fire is excluded for too long, more shade-tolerant conifer species encroach upon aspen stands, and aspen are out-competed and decline and eventually die out over time. Before the Warm Fire, much of the aspen in the Warm Fire area occurred in mixed stands with conifers (ponderosa pine, Douglas-fir, and white fir). Aspen is a relatively short-lived species that readily sprouts from clonal root systems when disturbed, especially by fire. Extensive aspen suckering was observed in many areas within the Warm Fire while conducting CBI field sampling, only 2 months after the fire was contained. Extensive aspen suckering indicates that large areas that had become or were becoming dominated by ponderosa pines and other conifers will become dominated by aspen for the next several decades. Because aspen forests provide important habitat for many wildlife species and they have been declining across the West, increased aspen cover can be considered a significant ecosystem benefit of the Warm Fire.

Direct effects on montane grasslands or meadows within the Warm Fire were minimal. Indirect effects of the fire caused by mortality of trees and shrubs adjacent to meadows are likely positive and may lead to temporary meadow expansions. Relatively little spruce-fir forest occurs within the Warm Fire area. Spruce-fir occurs at higher elevations at the southern end of the fire area. Fulé et al. (2003) concluded that the diverse forest structure in spruce-fir forest on the North Rim of the Grand Canyon suggests a combination of surface fires and crown fires similar to the mixed conifer forests in that area.

Implications of the Warm Fire for Specific Species and Their Habitats

Mexican Spotted Owls

Mexican spotted owls nest on the Kaibab National Forest on the Williams Ranger District and within the Grand Canyon in Grand Canyon National Park, but there are no confirmed breeding records on the North Kaibab Ranger District. However, the boundary of Critical Habitat Unit CP-10 (Colorado Plateau Unit 10) extends into the Warm Fire area of the North Kaibab Ranger District (Figure 7).

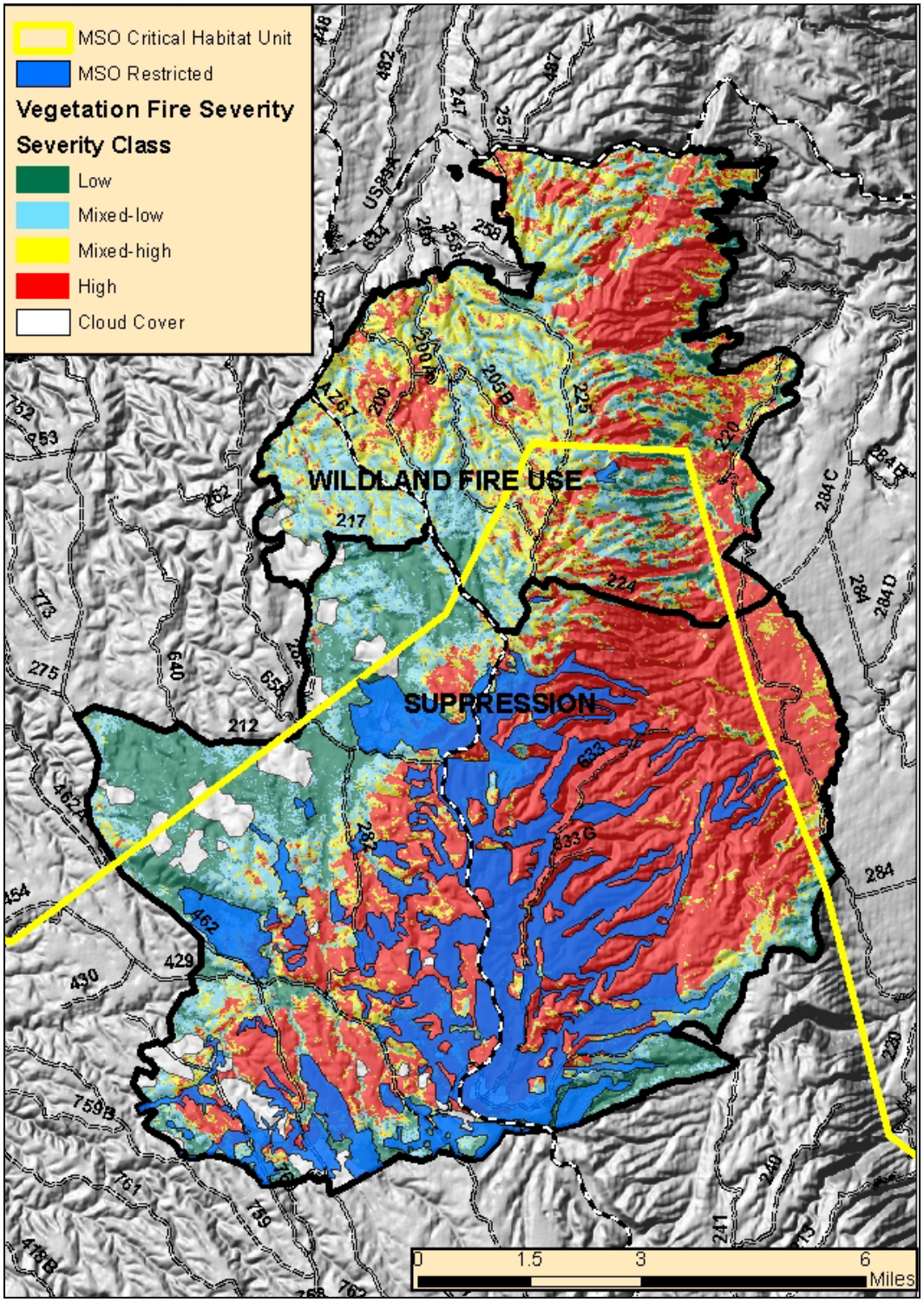


Figure 7. Mexican spotted owl critical habitat boundary and associated restricted habitat in relation to vegetation mortality.

Mixed conifer forest is considered Mexican spotted owl restricted habitat, and protected and restricted habitat within Critical Habitat Unit boundaries is considered designated Critical Habitat. Although there are no confirmed spotted owl nesting records on the Kaibab Plateau and no Protected Activity Centers (PACs), the Warm Fire affected spotted owl restricted habitat and designated Critical Habitat because areas of mixed conifer forest were affected by the Warm Fire.

The Kaibab National Forest developed a model to identify stands that met the definition of mixed conifer forest in the Mexican Spotted Owl Recovery Plan. Initial results of this model characterized 64,100 acres of the Kaibab Plateau as mixed conifer forest. However, a number of these stands are not mixed conifer. Currently, the Kaibab National Forest and the U.S. Fish and Wildlife Service are revising the list of stands that meet the Recovery Plan definition of mixed conifer. Of the 10,556 acres of modeled spotted owl Restricted habitat located within the boundaries of the Warm Fire and Critical Habitat Unit CP-10, 7,123 acres (70%) were classified as high vegetation mortality, 914 acres (9%) were mixed-high mortality, 1,090 acres (11%) were mixed-low mortality, and 1,042 acres (10%) were low mortality (percentages exclude the 387-acre area covered by clouds in post-fire Landsat image).

Although individual spotted owls were not affected by the Warm Fire, all of the mixed conifer forest classified as high vegetation mortality and a proportion of the mixed conifer forest classified as mixed-high mortality will not be considered spotted owl habitat for many years. Key habitat components and Critical Habitat primary constituent elements related to both forest structure (i.e. large trees and snags, canopy cover) and maintenance of prey species (i.e. high volume of logs and woody debris, wide range of tree and plant species, plant cover) were completely altered within the high mortality mixed conifer areas. These habitat components were substantially altered in the mixed-high mortality areas of mixed conifer forest, and lesser amounts of these habitat components, primarily key habitat components and primary constituent elements related to maintenance of prey species, were altered in the mixed-low mortality areas of mixed conifer forest. Alteration of spotted owl habitat components in the low mortality areas of mixed conifer forest was minor (see Table 6 for quantitative information on level of alteration of forest structural attributes in different vegetation mortality classes).

It will take a very long time before the high vegetation mortality areas will recover to the point that they can be considered potential spotted owl habitat. The Kaibab National Forest will consult with U.S. Fish and Wildlife Service on post-fire actions that would potentially affect Mexican spotted owls or designated Critical Habitat.

Northern Goshawks

Dr. Richard Reynolds and others have been studying goshawk ecology on the Kaibab Plateau since 1991 (e.g. Reynolds et al. 1994, 2006, Wiens et al. 2006). The Warm Fire encompassed 18 known goshawk territory centers. Thirteen of the 18 territories were characterized by high severity vegetation effects (Reynolds, personal communication 2006). Of the 18 territories within the fire area, 8 were known to have been active (eggs had been laid) at the time the fire occurred; reproductive status had not been determined by the time of the fire for the other 10 territories. Of the 8 known active nests, 4 were in areas characterized by high vegetation mortality crown fire, and at least 7 nestling/fledgling goshawks were likely killed by the fire (R. Reynolds, personal communication).

An analysis was conducted using the Kaibab National Forest goshawk post-fledging family area (PFA) GIS layer. Fifty-three percent of the total PFA area located in the suppression area of the Warm Fire had high mortality vegetation effects, compared to 23% in the fire use portion of the fire. All of the high and a proportion of the mixed-high mortality forested areas can no longer be considered goshawk nesting habitat, and it will take a long time, over a hundred years, for nesting habitat to develop again in these areas. All of the low and most of the mixed-low mortality forested areas likely remains potential nesting habitat.

Goshawk foraging habitat is much more variable than nesting habitat (Reynolds et al. 1992). This is partly because goshawks hunt a wide variety of prey species, and different prey species are associated with different habitat characteristics. Important prey species on the Kaibab Plateau include American robin, Stellar's jay, hairy woodpecker, northern flicker, red-naped and Williamson's sapsuckers, chipmunks, golden-mantled ground squirrels, cottontail rabbits, black-tailed jackrabbit, Kaibab squirrel, and red squirrel (Reynolds et al. 1992, Wiens et al. 2006). The Warm Fire likely had negative effects on most of the goshawk prey species in the high vegetation mortality areas. Prey populations in low and mixed-low mortality areas were probably minimally affected. Some prey species, such as certain woodpecker species, may increase in abundance during the next few years in mixed-high and high severity areas compared to pre-fire abundances.

Goshawks typically select forests with open understories for foraging habitat (Reynolds et al. 1992). Fire-caused understory thinning occurred in parts of low vegetation mortality areas, much of the mixed-low severity areas, and parts of the mixed-high severity areas. Thus, fire likely had positive effects on goshawk foraging habitat outside of the high vegetation mortality areas.

The Kaibab National Forest Land Management Plan directs the Forest to manage for a particular distribution of vegetation structural stages (VSS) for ponderosa pine, mixed conifer, and spruce-fir forests representative of multi-aged forest conditions (USDA Forest Service 1996). Post-fire forests will initially develop as even-aged stands in the high mortality areas of the Warm Fire. Uneven-aged management of these stands will not be possible until trees reach cone-bearing age. At that time, group selection and other silvicultural treatments can be implemented to begin conversion from even-aged to uneven-aged stand structure.

Mule Deer

The mule deer population on the Kaibab Plateau is widely recognized and has been intensively managed since the early 1900s. The Warm Fire area is located within the Grand Canyon National Game Preserve, which was established by President Theodore Roosevelt in 1908 to protect game species and their habitat on the Kaibab Plateau. Peak mule deer fawning on the Kaibab Plateau occurs at the end of May to first part of June (Todd Buck, personal communication 2006). The Warm Fire began on June 8, but for the most part burned at relatively low intensities until June 25, when strong winds caused the fire to make a major run in a short period of time. Mule deer fawns develop rapidly, and it is likely that many of the fawns within the Warm Fire area would have been mobile and able to escape the fire by the time of the June 25 run (Todd Buck, personal communication 2006). Surveys of the fire area by Arizona Game and Fish Department failed to detect any fire related mortalities of deer or other large mammals (Arizona Game and Fish Department 2006). Radio telemetry data on California condors did not show evidence of increased condor feeding activity in the Warm Fire area during the fire and post-fire periods, which may have been expected if there had been a large number of deer that died in the fire (Arizona Game and Fish Department 2006).

Composite burn index vegetation surveys conducted during the last week of August, 2006 indicated that aspen and Gambel oak suckering was extensive in many parts of the fire, and many species of grasses and forbs had already become reestablished. The Warm Fire will have short-term negative effects on mule deer forage on higher elevation, summer range portions of the fire. Recovery of herbaceous forage plants as well as many browse species such as aspen and Gambel oak will likely be extensive by the 2007 growing season. Longer term effects on forage in these higher elevation areas are likely to be positive. Negative effects on thermal and security cover in the mixed-high and high mortality areas will last longer. The most significant negative effects on mule deer habitat may be mortality of cliffrose and other browse species in the lower-elevation pinyon-juniper dominated areas on the east side of the fire (Ron Sieg and Todd Buck, personal communication 2006). The lower elevation areas on the east side of the fire provide important mule deer winter and transitional range, and vegetation mortality was high in these areas. Arizona Game and Fish Department and Kaibab National Forest biologists will evaluate vegetation recovery in this area during the fall 2006 and consider planting browse species (e.g. cliff rose, four-wing salt bush, winterfat, and mountain big sagebrush) to mitigate adverse effects of the fire on mule deer winter range.

Implications of the Warm Fire for the Kaibab Squirrel

The Kaibab squirrel is a subspecies of Abert's squirrel endemic to the Kaibab Plateau. It is closely associated with ponderosa pine forests. In 1965, 200,000 acres of ponderosa pine forest within the Kaibab National Forest and Grand Canyon National Park were designated as the Kaibab Squirrel National Natural Landmark. National Natural Landmarks are designated by the Secretary of Interior and represent unique examples of ecological and geological features that comprise our nation's natural history. The Warm Fire encompasses 43,737 acres of the Kaibab Squirrel National Natural Landmark. Of those acres, 13,686 acres were characterized as high vegetation mortality within the suppression area, and 3,602 acres were characterized as high mortality in the wildland fire use portion of the fire. Kaibab squirrel mortality from the fire was likely high in these areas because crown fire moved rapidly through most of the high vegetation mortality areas. Ponderosa pine forests characterized as high mortality can no longer be considered Kaibab squirrel habitat, and it will take decades for these areas to recover sufficiently to become Kaibab squirrel habitat again. A certain proportion of mixed-high mortality ponderosa pine forests also can no longer be considered Kaibab squirrel habitat. Individuals and habitat were likely little affected in low vegetation mortality areas, and effects were likely minor in mixed-low mortality areas. Planting ponderosa pine seedlings in large areas of ponderosa pine forest characterized by high vegetation mortality would likely shorten the recovery time for ponderosa pine forest and thus benefit Kaibab squirrels and other wildlife species associated with ponderosa pine forest.

Species Associated with Snags or Logs

Snags and logs are wildlife habitat components significantly affected by the Warm Fire. The fire altered many existing pre-fire snags and created many thousands of snags. Many of the snags altered or created by the fire will fall to the ground in the coming years to become logs. Numerous wildlife species use snags in ponderosa pine, mixed conifer, aspen, and spruce-fir forests and pinyon-juniper woodlands of northern Arizona. Some of the many species known to use snags in southwestern ponderosa pine forests for nesting, roosting, or foraging include (Chambers and Germaine 2003): American kestrel, great horned owl, American three-toed woodpecker, flammulated owl, northern pygmy owl, northern saw-whet owl, western screech-owl, downy woodpecker, hairy woodpecker, Lewis's woodpecker, northern flicker, violet-green swallow, brown

creeper, mountain chickadee, mountain bluebird, western bluebird, pygmy nuthatch, white-breasted nuthatch, house wren, Allen's lappet-browed bat, big brown bat, fringed myotis, long-legged myotis, occult little brown bat, pallid bat, silver-haired bat, long-eared myotis, southwestern myotis, Townsend's big-eared bat. Logs provide important habitat for numerous species of lizards, snakes, and small mammals in southwestern ponderosa pine forests (Chambers and Germaine 2003).

Hutto (1995) found that bird communities in northern Rocky Mountain conifer forests following high severity crown fires are unique because of greater abundances of woodpeckers, flycatchers, and seed eaters. He also argued that stand-replacement fires may be necessary for long-term maintenance of populations of bird species closely associated with burned forests (e.g. black-backed woodpecker). The fire regimes of ponderosa pine and mixed conifer forests of northern Arizona are different than the fire regimes of forests studied by Hutto (1995), but burned forests in northern Arizona also provide habitat for numerous bird species. The American three-toed woodpecker, which is closely related to the black-back woodpecker, is commonly found in recently burned forests in northern Arizona. Research indicates that larger-diameter snags are more widely used by cavity-nesting birds than smaller-diameter snags, that broken-top snags are more widely used than snags with intact tops, and that live trees with dead portions resulting from injury (e.g. lightening scars, fire scars) are also widely used by cavity-nesting birds (Cunningham et al. 1980, Bull 1983, Saab and Dudley 1998, Chambers and Mast 2005). Research also indicates that certain primary cavity nesting bird species select nest sites in clumps of snags (Saab and Dudley 1998, Chambers and Mast 2005), and that snags protected from the wind by clumps of live or dead trees stay standing longer (Chambers and Mast 2005).

Several studies have examined fall rates of ponderosa pine snags following wildfire. Fall rates are typically relatively high in the first 4-7 post-fire years after which the fall rate decreases (Chambers and Mast 2005). Keen (1929) reported 42% of ponderosa pine snags 10-18 inches dbh remained standing 7 years post-fire, whereas Chambers and Mast (2005) reported 60% of snags in this diameter class standing 7 years post-fire. Both studies found about 60% of snags in the 20-28 inch dbh class standing 7 years post-fire (Keen 1929, Chambers and Mast 2005). Larger snags stay standing longer. Chambers and Mast (2005) found 100% of snags 30-42 inches in dbh standing 7 years post-fire.

Because of high pre-fire tree densities and the preponderance of high severity crown fire, post-fire forest structure in ponderosa pine forest throughout the Warm Fire cannot be considered to be typical of HRV post-fire forest structure. Numbers of snags and logs that will be added to the forest floor during the next 5 to 10 years are likely orders of magnitude greater than post-fire snag and log levels typical of HRV conditions in ponderosa pine forests.

Management Activities

Objectives of potential post-fire management activities related to wildlife resources are 1) to more rapidly move wildlife habitat conditions toward desired conditions, and 2) to mitigate adverse effects the fire had on wildlife habitat. As described in the section above, desired conditions for wildlife habitat are primarily the habitat conditions thought to be typical of HRV because these are the conditions under which all wildlife species native to the area evolved and to which they are presumed to be adapted. HRV is not the sole determinant of desired conditions for wildlife resources, but provides the context for identifying desired conditions. For example, because of the significant recreational value of the Kaibab Plateau mule deer population, habitat that supports a

productive mule deer herd is an important desired condition and actions that mitigate adverse effects to key mule deer habitats may be desired.

As a result of many factors, but especially the reduced wildfire frequency beginning about 1880, pre-fire conditions and processes within the Warm Fire area and elsewhere on the Kaibab Plateau departed from HRV for the ponderosa pine, mixed conifer, and aspen potential natural vegetation types. As a result, the fire and its effects within large areas of these vegetation types were outside of HRV. Natural vegetative recovery has begun and will likely proceed rapidly in many parts of the fire area where burn severity effects to the soil were low to moderate. However, vegetation recovery is likely to be much slower in areas where the fire resulted in high-severity soil effects and high vegetation mortality over extensive areas. In these large areas, seed sources are likely to be limited because soil seed banks were reduced by fire effects and the relatively great distances to post-fire seed sources. Post-fire management considerations for wildlife habitat and other natural resources are discussed in Chapter 3.

Threatened, Endangered, and Sensitive Plants

There are no known or suspected species, listed by the US Fish & Wildlife Service (USFWS) as Threatened or Endangered inside the Warm Fire perimeter or in other areas impacted by fire suppression activities. There are four species on the USFS Region 3 Sensitive Species List that are known or suspected to occur within the fire perimeter. These are Kaibab paintbrush (*Castilleja kaibabensis*), Kaibab bladderpod (*Lesquerella kaibabensis*), Kaibab beardtongue (*Penstemon pseudoputus*), and Paradine plains cactus (*Pediocactus paradinei*). The paintbrush, bladderpod, and beardtongue are meadow species, found in DeMotte Park, Little Pleasant Valley, and other, smaller meadows on that part of the Kaibab Plateau (Kane Ranch EA 2000).

Air attack operations for the Warm Fire were staged in DeMotte Park. Sensitive plant surveys were not done immediately prior to bringing in helicopters and support equipment; however, all activity was contained to a site that has been used before in order to minimize impacts to any potentially existing populations. Several small areas of unsurveyed suitable habitat for these species occur in the northwest portion of the wildfire (TES 1991). This general area burned at low intensity; and little, if any, burn occurred within the meadows. Thus, minimal impacts are believed to have occurred to the three sensitive meadow species from the fire or suppression activities. The Warm Fire burned more than 5,000 acres of Paradine plains cactus habitat.

Paradine Plains Cactus

The Paradine plains cactus (which is also known as the Kaibab plains cactus) was previously a Category 1 candidate for listing as Endangered by the USFWS (Phillips 1981). In lieu of formal listing, an interagency Conservation Assessment and Strategy was prepared for the Paradine plains cactus (*Pediocactus paradinei* B.W. Benson) and signed by the Kaibab National Forest and Bureau of Land Management, and U.S. Fish and Wildlife Service (Phillips et al. 1996). The agreement details conservation actions including monitoring known populations and mitigation measures for potential impacts. The Paradine plains cactus remains on the FS Region 3 sensitive list. It is also a State of Arizona protected species, in the “Highly Safeguarded” category. The Warm Fire burned approximately 5,735 acres within the Paradine plains cactus conservation area.

The Paradine plains cactus is known exclusively from the eastern slopes of the Kaibab Plateau (East Kaibab monocline) and small portions of the adjoining House Rock and Coyote Valleys. The

species is found exclusively on the North Kaibab Ranger District and the Arizona Strip District (BLM); the entire range of the species encompasses approximately 90,000 acres. No occurrences of this species have been verified on the west side of the Kaibab Plateau (Phillips 2005). The Paradine plains cactus is a small single, green globose cactus usually no more than 1.5 inches tall above ground, with half of its stem underground. Habitat for Kaibab plains cactus occurs in open, mostly level sites (alluvial fans, valley bottoms, and ridge tops) in the pinyon-juniper woodland and shrub/grassland on soils derived from Kaibab limestone.

During periods of drought, individual plants retract into the soil, and are covered with soil and pebbles (Phillips et al. 1996). Flowering generally occurs in late April. *Pediocactus paradinei* plants are colonized by vesicular-arbuscular endomycorrhizae (VAM) (Milne 1987, Phillips et al. 1996). The majority of plants present in mature pinyon-juniper plant communities, including juniper, are colonized with VAM. Pinyon is not colonized with VAM, but with ectomycorrhizae, as are ponderosa pine trees (Klopatek et al. 1990).

Figure 8. Photo of a Paradine plains cactus (*Pediocactus paradinei*).

Pre-Fire Condition

Detailed monitoring of population trends has been conducted from 1987 to present on 14 permanently marked plots in six study areas on National Forest lands distributed throughout the range of the species (Warren et al. 1992; Frye 1995, 1996, 1998, 2000, 2001, 2002b, 2005). Frye added 5 additional plots in 1998 and 1999 to better represent the range and habitats of the species (Frye 2000). No significant Pediocactus recruitment or population increases have occurred in the last few years and mathematical modeling shows that only one of the 14 plots will consistently demonstrate a high probability of persistence in the future (Frye 1996, 2000, 2005; 2005; personal communication with Barbara Phillips 2006).

Field surveys and monitoring in the spring and summer of 2000 showed an apparent sharp decrease in numbers of the cacti throughout its range (Phillips et al. 2000, Frye 2000). This decline was attributed to drought conditions from 1998 to the summer of 2000 and substantial predation [presumably by wood rats (Neotoma spp.) and black-tailed jackrabbits (Lepus californicus)], observed during droughts (Phillips and Phillips 1996). Observations since 2000 have continued to document declines in the populations (Hughes 2004, Frye 2005, personal communication to Barbara Phillips, Frye and Phillips 2005, personal observations).

During the Houserock Allotment landscape assessment (2005), known sites north of Highway 89A were searched with negative results (Frye 2005, Barbara Phillips, pers. comm. 2006). Plant numbers were also very low in two monitoring plot areas south of Highway 89A. At one monitoring site that was inadvertently burned about 20 years ago, cheatgrass and non-native mustards have become dominant, while cactus plants have completely disappeared from one plot and were in very low numbers in the other two monitoring plots. At a second population area, heavy runoff in 2005 has resulted in overland flow of water through one of the plots, resulting in a deposition of debris. Plant numbers have continued to decline in the three plots in this monitoring area over the years (Frye and Phillips 2005, personal observations).

Phillips and others (1996) noted that Native Americans used fire to maintain openings and encourage browse production in areas occupied by Paradine plains cactus. Changes in management practices, including the use of domestic livestock and fire suppression, affect the fine fuels that carried fire and reduced the spread of non-native invasive, and native pinyon and juniper into occupied areas. These practices also allowed the expansion of pinyon-juniper trees into areas formerly occupied by grasses and sagebrush. It is likely that Paradine plains cactus tolerated infrequent, low-intensity fires during that period, but may be subject to decimation by recent fires due to pinyon-juniper encroachment and non-native invasive species like cheatgrass.

Actions that have been taken on behalf of Pediocactus paradinei and its habitat by the Kaibab National Forest, the Bureau of Land Management, and others between 1976 and 1996 are listed in the Conservation Assessment and Strategy (Phillips et al. 1996). Actions since 1996 include road closures, elimination of grazing within a population area under the Burro Allotment Plan, elimination of fuelwood collection along the East Side Game Road, consultation with the Fish and Wildlife Service on road maintenance projects, and other actions (Anon. 1998; Phillips 1999).

Effects to the Paradine Plains Cactus

The GIS layer identifying the *Pediocactus* Conservation Area was overlaid with Warm Fire BARC vegetation mortality GIS layer and used to identify areas in different burn mortality classifications. Additionally, field visits were made to observe effects the *Pediocactus* habitat and monitor populations.

The Warm Fire burned through approximately 5,735 acres of the *Pediocactus* Conservation Area. Most of the area impacted was characterized by high vegetation mortality (Figure 9, Table 12). The above-ground portions of nearly all trees, shrubs, forbs, and grasses were killed, and it is expected that many of the *Pediocactus* plants were also killed. It is possible, but unlikely, that due to drought conditions some of the *Pediocactus* may not have emerged, survived, and will become re-established (USDA Forest Service 2006).

Table 12. Acres in the *Pediocactus* Conservation Area from the suppression portion of the Warm Fire, identified by vegetation mortality mapping.

Mortality Class	Acres Affected
Low	164
Mixed Low	275
Mixed High	636
High	4,660

Recently completed surveys did not locate any live plants in the high vegetation mortality areas (Frye personal communication to B.G. Phillips, September 30, 2006). The population with the greatest number of healthy reproductive plants in 2005 (Frye and Phillips 2005, personal observations) was not in the Warm Fire burn area. However, summer monsoon runoff has resulted in erosion and soil deposition in the small drainages beside the slopes and terraces where this *Pediocactus* population occurs, resulting in probable minor loss of plants and habitat either through erosion or burial (Phillips et al. personal observations July13 and September 26, 2006).

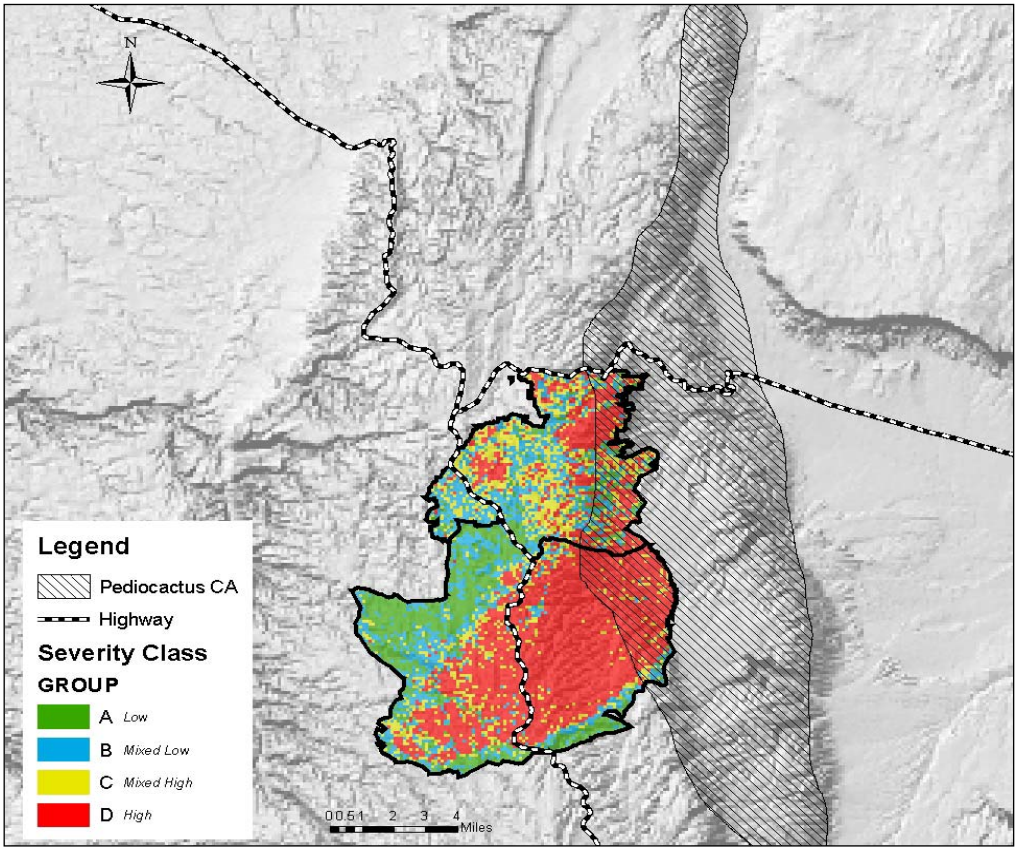


Figure 9. Map of the Pediocactus Conservation Area overlaid with the Warm Fire vegetation mortality.

Management Considerations

Desired management is outlined in the *Pediocactus* Conservation Assessment. Objectives focus on maintaining and increasing populations, reducing known threats and concerns, and increasing knowledge of the species, especially as it relates to management actions.

1. Protect and maintain the existing populations of *Pediocactus paradinei* (in the context of a metapopulation) to insure their long-term viability and conservation on the Kaibab National Forest and Arizona Strip District by monitoring.
2. Promptly treat invasive noxious weeds, restrict access within the burned area, and monitor the effects of the fire on the cactus populations.
3. Develop opportunities to increase the number or size of populations of *P. paradinei* on the Kaibab National Forest and Arizona Strip District to increase its potential at the species level by observing plant responses to different intensities and severities of fire effects to inform future fire management and suppression efforts.
4. Address the potential opportunities for populations of *P. paradinei* within the context of conservation and enhancement of the pinyon-juniper and sagebrush-grassland ecosystems of which they are a component.
5. Apply new information about the cactus' response to the fire and suppression activities to the next revision of the Conservation Strategy and Agreement.

Existing and potential concerns for Paradine plains cactus that are addressed in the Conservation Assessment and Strategy include changes in the pinyon-juniper and shrub/grassland ecosystems by livestock grazing; recreational impacts; road construction, realignment, and maintenance; fuel wood harvesting; plant collection; California condor tracking off-road; vegetation manipulation in Pinyon-juniper woodland; other human-caused impacts, and natural factors. The plants occur on open, flat sites making them susceptible to disturbance by camping and road construction. Tree and shrub encroachment resulting from various natural and human causes may be causing some habitat loss. Threats to this species also include trampling by livestock and buffalo, insect predation, and predation by rodents and rabbits during droughts.

Natural factors that are affecting the continued existence of *Pediocactus paradinei* throughout its range include restriction to a limited geographic area; low population levels and disjunct, isolated colonies with resultant restricted gene pool. *Pediocacti* are also subject to root rot, so this may be a factor reducing the populations during very wet years, and frost heaving can also affect plants by dislodging them. Successful synchronicity of good seed crops with appropriate weather conditions for germination and seedling survival may require many years to achieve (Phillips et al. 1996).

As noted by Frye and Phillips (Frye 2002a; Phillips et al. 2001, Frye 2005), the geographic range of Paradine plains cactus seems to be contracting. The recruitment of this species is likely very episodic in nature. Given that the data acquired between the 1980s and 2005 only covers less than half of the average lifespan of individual cacti, several good years in a row could significantly improve population numbers. However, re-colonization of formerly occupied areas will take considerable time. Management activities should be evaluated with the goal of ensuring that the habitats of this species are suitable for these re-colonization events when they do occur. In light of the documented continued decline in population numbers throughout the range of this species, a comprehensive review of the status of Paradine plains cactus by the signers of the Conservation Agreement (USDI and USDA 1998) should be considered.

Noxious Weeds

Current Condition

No systematic noxious plant surveys were conducted in the Warm Fire area prior to the fire. There have been incidental observations of musk thistle (*Carduus nutans*) in the Jacob Lake area (outside the burned area) and scattered cheatgrass (*Bromus tectorum*) populations throughout the fire. Other fires on the North Kaibab Ranger District (Bridger-Knoll Fire, 1996; Nail Fire, 2005) have been rapidly colonized by cheatgrass, despite its apparent patchiness and low density across the Forest. Dense cheatgrass populations have persisted for 10 years on the Bridger-Knoll Fire. In addition to compromising the development of native plant communities, cheatgrass provides little forage value for wildlife or livestock. Because it forms a continuous fuel layer that dries out prior to the beginning of our fire season, it can cause a shift in fire regimes outside of the evolutionary environment that native species are adapted to.

The risk of noxious weed establishment in the low and moderate intensity burn areas is low because native vegetation will re-establish quickly, capturing resources before the weed species can utilize them. High-intensity-burn sites, however, are vulnerable to invasion by noxious and invasive exotic plants due to exposed soils. In the high intensity locations, the native vegetation and seed banks were compromised. It can take years for native perennial species to become reestablished in these areas. Noxious weeds often establish more quickly than the native species, monopolizing required resources, and preventing or retarding the development of native vegetation.

Management Considerations

Cheatgrass tends to be very persistent once it becomes established (Zouhar 2003). Ripe cheatgrass seeds can survive burning and germinate as soon as weather conditions are right, generally in late fall. Several techniques to control cheatgrass have been investigated, including timing of burns, herbicide treatments, grazing and competitive planting. Controlling cheatgrass requires early detection and treatment of live cheatgrass plants on the site, prevention of seed formation and elimination of emerging seedlings.

Keeping weed populations from becoming established is a high priority on most Federal, State, and private lands. The University of Arizona Cooperative Extension has estimated that invasive plant species are spreading at the rate of about 200 acres per hour on federal lands in the West. Prevention of invasive species is key to restoring the desired native vegetation on the burn area. The best prevention for noxious weeds is competition. Part of the goal for the emergency stabilization seeding in August 2006 was to establish sterile annual grasses to out-compete potential weed infestations and provide for faster establishment of native perennials. Additional seeding of native grasses, forbs, and shrubs would assist in preventing weed infestations.

Heritage Resources

The heritage resource program area has identified resource concerns within the entire 58,568 acres encompassed in the greater Warm Fire boundary (wildland fire-use and suppression area). Although the focus of these efforts has been within the fire suppression boundaries of the Warm Fire, effects to heritage resources throughout the fire area are also discussed.

Background

The Rocky Mountain Fire Use Management Team began working with North Kaibab heritage resource staff on June 13, 2006 to determine protection strategies for heritage resource sites within the proposed Warm Fire Maximum Manageable Area (MMA). Previously recorded sites susceptible to fire damage within the initial 13,417 acre MMA were pretreated to minimize adverse effects from the fire. Dozer lines were put in key locations as a contingency in case the fire expanded outside the MMA. The expansion of the MMA boundary (approximately 130,000 acres), lack of resources, and the rapid progress of the fire did not permit pretreatment of known sites within the expanded boundary. However, archaeologists worked with dozer bosses and operators to insure that heritage resources were avoided and/or documented during dozer line installation. This work continued through the transition and implementation of active fire suppression. Numerous previously undocumented sites were located by archaeologists working on the fire. The documentation of these sites is currently being completed by North Kaibab archaeologists. Additional sites have been located during efforts to record those sites discovered during suppression activities.

Kaibab National Forest heritage specialists were consulted by the Burned Area Emergency Response (BAER) team assigned to the Warm Fire suppression area. Because most of the high sensitivity areas within the fire perimeter had not been formally inventoried for heritage resources prior to the fire, the initial assessment criteria indicated that no documented heritage resource sites qualified for treatments under the emergency requirements proposed in BAER guidelines. Because fire-qualified archaeologists were not available to assist, District heritage specialists were unable to complete the assessment of sites located during the suppression effort within the time frame available for initial BAER requests. The staff did not anticipate the significant erosion related damage that occurred following the fire with the monsoon rains.

Current Condition

The Warm Fire area is known to have contained a wide array of heritage resource site types prior to the fire. These sites included a historic lookout tree on the National Register, historic corrals and aspen carvings, as well as an array of prehistoric sites ranging from rock art to artifact scatters and pueblo village sites with agricultural features such as garden enclosures, terraces, and water retention systems. Much of the land on the top of the Plateau east of Highway 67 had been intensively surveyed prior to the fire, and site densities in this area were determined to be low. Survey on the east flanks of the Kaibab Plateau into Houserock Valley focused historically on water developments and roads with some block survey conducted during the Telephone Hill assessment. These limited surveys indicated that a high prehistoric site density was present in the area. Houserock Valley contains some of the largest known and most important heritage resources on the Arizona Strip.

Three decades of systematic archaeological survey across the North Kaibab Ranger District has revealed moderate site densities in ponderosa pine and low site densities in the mixed conifer vegetation type. Site types in ponderosa pine and mixed conifer stands generally include artifact scatters, occasional rock shelters, pueblos, rock art and historic period sites. The pinyon-juniper woodlands, including the upper and lower transition zones are known to contain a high density of prehistoric heritage resource sites. Site types include artifact scatters, masonry structures, agricultural features, rock shelters, rock art and some historic sites (Reid and Hanson 2006). Although all heritage resources are susceptible to fire damage from intense heat, masonry structures, agricultural features, rock art, and historic sites are particularly vulnerable.

Site types and anticipated densities were shared with the Wildfire Use Team during the initial meeting. Because the heritage staff expressed concerns about the potential for adverse fire effects to occur to structural sites in the pinyon–juniper woodlands on the east side of the fire, attempts were made to monitor fire effects within the MMA by the Fire Behavior Assessment Team. However, fire conditions were so intense that the monitoring equipment was destroyed. During the suppression phase of the fire, archaeologists were assigned to work with dozers and only locations subject to active suppression efforts were examined for the presence of heritage resources.

Fire Effects to Heritage Resources

There are 145 known sites within the Warm Fire boundaries. One hundred and nine of these are within the suppression fire boundary (Table 13). Heritage resource sites were classified into six site types during the Warm Fire. This same classification system was used during post-fire assessment. Sites types were prioritized during the fire as follows: look out trees, wood structures and/or features (because both are highly susceptible to combustion in fire); rock art and rock shelters; stone structures and features; and lithic and ceramic scatters.

Table 13. Heritage site types and associated features of heritage sites in the Warm Fire boundary.

Site Type	Associated Artifacts or Features	Entire Fire Boundary	Suppression Boundary	Damage
Historic	Including but not limited to cabins, fences, corrals, dendroglyphs, lookout trees, brush structures, old portions of Hwy 89, logging camps, can dump	20	9	13
Lithic and/or Ceramic Scatters	Any combinations of stone tools, associated debris from stone tool production, pottery, and/or ground stone	56	42	Unknown
Stone Structures and Features	Separate or combinations of field house, pueblo, single and multiple units, check dams, cobble mulch piles,	67	57	63
Rock Art and/or Rock Shelters	Petroglyphs or pictographs on rock faces and/or outcropping often with overhangs with associated artifacts	2	1	0

Efforts to document and record sites located during "pre-fire" preparation and suppression efforts are ongoing, and as part of the post-fire assessment effort, known heritage resource sites within the suppression area were monitored to determine fire related effects and possible rehabilitation strategies. Most affected sites are located within the pinyon-juniper woodlands in areas identified as high severity. All burned sites have suffered adverse effects. Large portions of the pinyon-juniper woodlands have not been systematically surveyed for heritage resources. It is presumed that the actual number of sites in the burn area is much higher than what is currently documented; effects to these sites are expected to be similar.

In addition to effects on prehistoric sites, 13 of the 20 known historic sites had wooden components that were consumed by fire. These include two lookout trees, one which was listed on the National Register of historic places, several National Register eligible segments of old Highway 89A that contained wood cribbing and an associated highway construction camp, several corrals, a historic

cabin site and several Navajo brush structures. The eligible portions of Highway 89A and associated features (a brush structure, logging camp, corral and dump site) were located in the wildland use portion of the fire. The lookout trees were located in the suppression fire area.

Prehistoric sites within the higher elevation mixed conifer stands have been subjected to historic fire regimes for thousands of years. It can be assumed that most of these sites burned repeatedly during this time under low intensity burn conditions. The stone and ceramic artifact types found on the North Kaibab are resistant to damage from low intensity fire. However, under moderate to high fire intensities, artifacts spall and ceramics become vitrified or permanently stained. Limestone used to construct pueblos and prehistoric agricultural features or used as a surface for rock art is also friable and will crack and exfoliate following exposure to a high intensity burn. Comparison of similar sites within the burn area to those just outside the burn reveal significant differences when it is assumed that all of these have been exposed to many low-intensity fires.

Post-fire monitoring in the high severity burn areas focused on sites with wood and stone features and structures. Most of the sites with exposed wood were in the upper elevations, while sites with stone features and structures are on the east side of the Plateau in the pinyon-juniper woodlands. Sites located within the pinyon-juniper woodlands have experienced more post-fire impacts (Table 13) than other areas within the burn. Sites exhibit many physical impacts that range from eroding ground surfaces to physical changes in artifacts and features. Sites located within areas that burned moderate or severe all display adverse effect and have suffered irreversible damage from the fire to varying degrees.

Vandalism is likely to increase over the next several years, particularly in Houserock Valley. A number of structural sites are now clearly visible from Forest roads. An increase in artifact collecting and digging followed the Bridger Fire of 1996. There is also a potential that erosion may expose prehistoric human burials, commonly associated with structural sites. Common impacts include:

- Sedimentation, sheet wash, and scouring
- Rill and gully formation
- Cracking, spalling, and sooting of limestone features and artifacts
- Fire-killed trees that have or will fall on sites
- Vandalism

The fire burned in multiple vegetation types including ponderosa pine, pinyon-juniper, and mixed conifer. Post-fire effects such as increased runoff, accelerated soil erosion, hydrophobic soils, sheet wash, rill and gully erosion, ash deposition, and increased flash flood flows have already compromised the integrity of heritage resource sites within and downslope of the burn. The sites receiving the greatest impacts are located on the eastern side of the burn in an area formerly dominated by pinyon-juniper woodlands that had high severity fire effects. This area also contains the highest number of archaeological sites.

Because there has been little inventory in much of the high probability areas of the Warm Fire, most sites have yet to be located or recorded. Within the entire fire approximately 30,000 acres are unsurveyed, including 20,000 acres within the suppression area.

Desired Condition

The desired condition is for heritage resources to be protected and managed in compliance with the National Historic Preservation Act (NHPA) of 1966 and other statutes and regulations, mitigating adverse effects to those resources that could occur as the result of agency actions. This includes consulting with and addressing concerns of area Tribes that attach religious or cultural significance to those sites.

Regulations and Direction

Section 106 of NHPA, as amended, and its accompanying regulations in 36 CFR 800, require that agencies consider the effects of their actions on significant heritage resource sites and to protect or mitigate adverse effects to them. Federal agencies are required to consult on a government to government basis with American Indian Tribes that attach religious or cultural significance to sites managed by the agencies. The Hopi Tribe and Kaibab Band of Paiute Indians attach cultural significance to the sites within the Warm Fire. Both Tribes have an active interest in the management sites on the North Kaibab Ranger District.

Possible Management

Damage to artifacts and features in heritage sites from the fire and post-fire flooding is irreversible. However, post-fire effects can be reduced through an expeditious and intensive effort to locate, document, and stabilize sites that are susceptible to damage. Measures can be taken to mitigate on-going post-fire impacts such as erosion, artifact collecting, and the damage to features from “tip ups” and “burn outs” of residual tree skeletons.

While survey is recommended for all areas of the fire, the highest priority is in the lower elevations of the pinyon-juniper woodlands, especially in areas prone to flood damage and ongoing erosion. Much of this area burned at high intensity and many sites have already had adverse effects from the fire and post-fire flooding. Inventory would provide the opportunity to locate and protect significant sites that are at risk of destruction. Without additional inventory, it is likely that many currently undocumented heritage resources will be lost with no record of their existence. Heritage resources are finite, fragile, non-renewable, and unique in time and space. Because only minimal inventory had been accomplished in many of these vulnerable areas prior to the fire, this loss is could be particularly acute. Additional heritage inventory in these areas would at least provide a record of the resources before they disappear.

Mitigations and Measures

The following recommendations would help to mitigate adverse effects to heritage resources generated by the Warm Fire:

- Continue to monitor sensitive heritage resources for future post-fire and cumulative effects.
- Monitor known sites outside of the fire boundary that have a high potential for downstream flood damage as a result of the fire.
- Establish effective and efficient measures for site rehabilitation.
- Rehabilitate heritage resources affected by the fire (seeding and contour felling to slow erosion, and removal of tree carcasses to prevent post-fire damage to features*).

- Establish a temporary road closure on FS Road 220 except for administrative purposes to limit artifact collecting. Re-open when ground cover becomes established and flash flooding potential is reduced.
- Authorize funding to conduct inventory in unsurveyed high probability areas, focusing available resources on those areas subject to erosion and flooding as well as vandalism. Apply the above procedures to affected sites

*Straw mulch and matting can also be very effective. However, these treatments are very costly. Applications would need to focus on areas where the treatment would be highly effective. In locations visible from roads and view points, these materials could make a site more vulnerable to vandalism by drawing attention to it.

Recreation and Scenery

Recreation

The Warm Fire area is located where visitors might consider the "center" of the North Kaibab Ranger District to be, as it is located adjacent to the first real developed area one encounters on the Kaibab Plateau. To many visitors, this is a "familiar, settled" place after a long trip through miles of unpopulated high desert lands and then forest as one climbs up the plateau. It is a place to get oriented, pick up needed supplies, have a meal, or perhaps stay overnight. As the visitor continues on to their primary destination, the North Rim of Grand Canyon National Park, they pass through three to four miles of fire affected area. In the 1997 North Kaibab Ranger District Recreation Strategy (USDA Forest Service 1997a), eighty-eight percent of visitors were going to the National Park via Highway 67, and passing through the Kaibab National Forest enroute.

Highway 67 is designated as an Arizona State Scenic Road, a National Forest Scenic Byway, and a National Scenic Byway. Under the National Scenic Byway program, the U.S. Secretary of Transportation recognizes and supports certain roads as National Scenic Byways or All-American Roads based on their outstanding archaeological, cultural, historic, natural, recreational, and scenic qualities. There are 126 such designated Byways in 39 states. It provides resources to help manage the intrinsic qualities within the broader Byway corridor to be treasured and shared.

The Kaibab Plateau-North Rim Parkway was so designated because of its scenic beauty, and natural and cultural qualities. In the Byway nomination, it mentioned that Highway 67 is unique in that the entire route is located on National Forest and National Park lands and there is an opportunity to highlight natural resource management activities. Highway 89A is an Arizona State Scenic Road and the route from Bitter Springs to Fredonia is the "Fredonia-Vermilion Cliffs Scenic Road." The road was designated as a “Scenic Road” based on its unique biotic communities (both plant and animal) and cultural history.

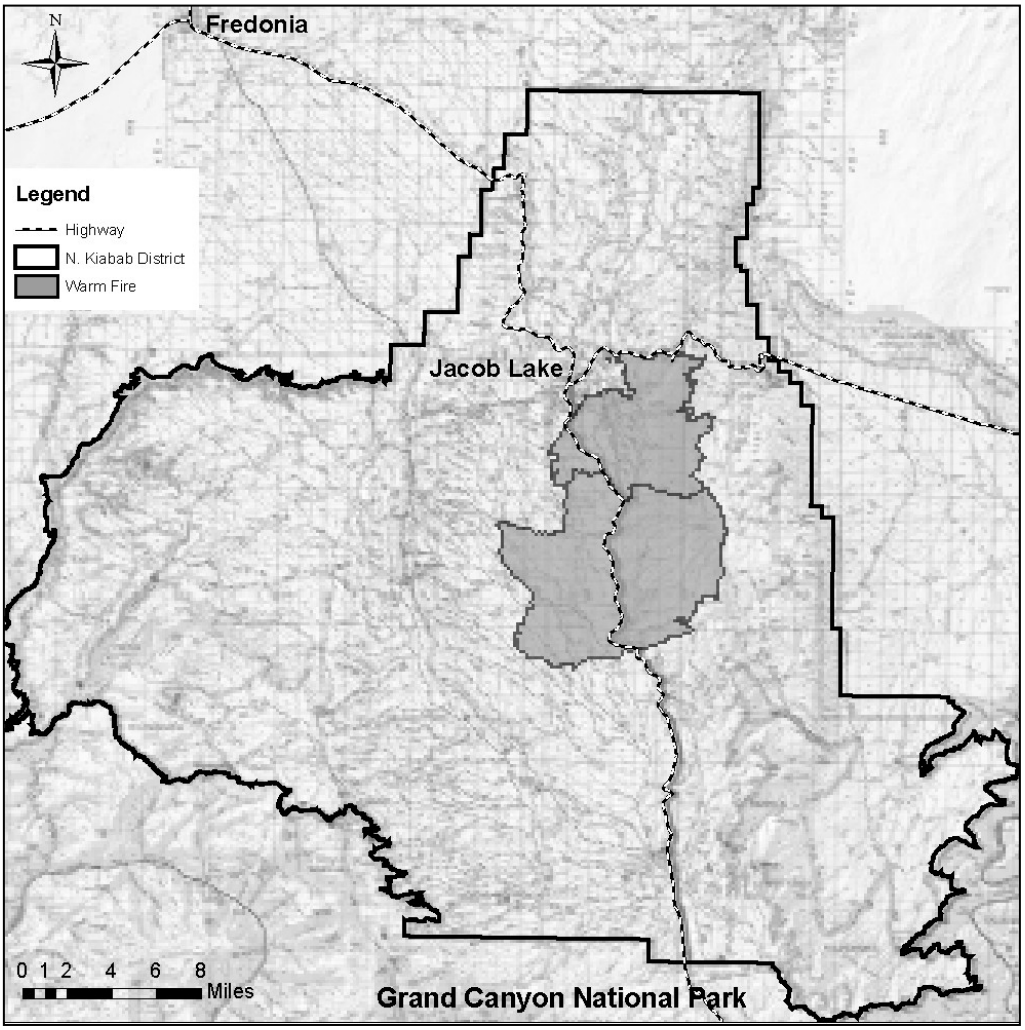


Figure 10. Vicinity map and recreation context of the Warm Fire.

Recreation Opportunity Spectrum

Visitors choose specific settings for their activities in order to enjoy desired experiences. These settings vary by Ecosystem Management Area (EMA). On the Kaibab National Forest, EMAs are based on vegetation types and are further defined by their qualities relative to the Recreation Opportunity Spectrum (ROS). ROS is a classification system that describes different outdoor recreation settings across the Forest using seven standard classes that range from primitive, undeveloped settings to urban, highly developed settings. Attributes typically considered in describing the settings are size, scenic quality, type and degree of access, remoteness, level of development, social encounters, and the amount of on-site management. By describing existing recreation opportunities in each class, ROS helps match visitors with their preferred recreation setting. ROS can also be used to plan how areas should be managed for recreation in the future (USDA-Forest Service 1986). Changes in the mix of a national forest's ROS classes affect the recreation opportunities offered.

The existing ROS for the North Kaibab Ranger District are shown in Figure 11. The District is currently involved in a NEPA project which proposes to update the ROS as shown in Figure 12. The NEPA project proposes a programmatic change in goals, mapping, and guidelines, and proposes to

amend the existing forest plan to adopt these changes. A decision on this project is expected soon. One of the primary changes proposed in the ROS is to acknowledge the need to manage the Inventoried Roadless Areas per the Roadless Area Conservation Rule. The rule requires the areas be managed primarily for their roadless characteristics and values. The rule establishes nationwide prohibitions, generally prohibiting, with some exceptions, timber harvest, road construction, and road reconstruction within the IRA on National Forest lands (Federal Register 2005).

The existing ROS are primarily Rural, Roaded Natural, and Semi-primitive Motorized. The proposed ROS mapping includes the same acres of Rural (at Jacob Lake and Kaibab Lodge), less Roaded Natural acres, and increases in Semi-primitive Motorized, and Semi-primitive Non-motorized areas. The majority of the wildfire area is currently mapped with the ROS classes of Roaded Natural and Semi-primitive Motorized. Table 14 below provides a brief description of the ROS classes.

Table 14. Recreation Opportunity Spectrum (ROS) classes.

Primitive-Wilderness	Semi-Primitive Non-Motorized-Wilderness	Semi-Primitive Non-Motorized	Semi-Primitive Motorized	Roaded Natural	Roaded Modified	Rural
Within designated Wilderness, manage according to the Wilderness Act.	Within designated Wilderness, manage according to the Wilderness Act.	Undeveloped scenic vistas, non-motor-ized recrea-tion oppor-tunities. Resource management subtle, may be restricted.	Undeveloped scenic vistas, motorized access and recreation opportunities. Resource management subtle, may be restricted.	Areas with high recrea-tional and scenic values. Resource management protects or enhances these values.	Areas where recreation values and scenic resources generally not sensitive, except in a few limited travelways.	Areas with high cultural, recreational, and scenic values. Resource management protects or enhances these values.

The post-fire condition after the wildfire is not representative of the descriptions above. This table should be used when considering the extent and quantity of management actions that may be proposed. While the terms are not quantified here, the ROS-SMS Guidebook that is proposed for the North Zone gives more details about acceptable area and desired conditions for the ROS classes (Federal Register 2005).

Scenery Management

Scenery management is defined as the art and science of arranging, planning, and designing landscape attributes relative to the appearance of places and expanses in outdoor settings. The Scenery Management System (SMS) developed by the Forest Service provides a vocabulary and a systematic approach for managing scenery in a national forest. The system is used in the context of ecosystem management to inventory and analyze scenery, to assist in establishment of overall resource goals and objectives, for site-specific project analysis, to monitor scenic resources, and finally to ensure high-quality scenery for future generations. SMS provides standard guidance about the general approach for applying the elements on National Forests, and is flexible enough to fit each forest and its unique characteristics.

Table 15. Summary descriptions of Visual Quality Objectives (VQO).

Visual Quality Objective	Description
Retention	Management activities are not visually evident.
Partial Retention	Management activities are visually subordinate.
Modification	Management activities are visually dominant, but natural appearing.

The primary difference between the existing VQO mapping, and the proposed SIO mapping is the comprehensive nature of the mapping. Where only corridors or sites were mapped for VQO, all land areas are mapped with the proposed SIO. The proposed SIO for the area are very high (wilderness), high, and moderate. These correspond to the old visual management system as preservation, retention and partial retention. Table 16 defines the high and moderate SIOs applicable to the Warm Fire area.

Table 16. Scenic Integrity Objective (SIO) definitions.

SIO	Setting Description	Level of Human Disturbance/Activity
High	The valued landscape character "appears" intact. Deviations may be present but must repeat form, line, color, texture and pattern common to the landscape character so completely and at such a scale that they are not evident. Viewing locations are based on the distance from a person or vehicle, usually on a major road, trail or from a recreation site, and refer to: foreground (generally 300' from the viewer, but up to 1/2 mile), middleground (1/2 to 4 miles from the viewer), and background (4 miles and beyond from viewer).	Deviations from level would be based on views from identified viewing locations of foreground, middleground, and background. Deviations blend so well that the change is not evident to the casual observer by the end of the project activity.
Moderate	Scenic integrity level is Moderate (slightly altered) or Level 3. The valued landscape character "appears slightly altered". Deviations must remain visually subordinate to the landscape character being viewed. Activities may borrow from form, line, color, texture, pattern and scale of areas of similar landscape character outside that being viewed.	Deviations from level would be based on views from identified viewing locations (foreground, middleground, background). Noticeable deviations remain visually subordinate to the landscape character being viewed at the end of the project activity.

The current Forest Plan direction for the North Kaibab Ranger District uses the older Visual Management System. When the forest plan was finalized in 1988, comprehensive mapping for visual quality objectives (VQO) had not been completed. Forest managers included an interim VQO map that delineated important road corridors and recreation sites. The existing VQO for the North Kaibab Ranger District are shown in Figure 13. The District is currently involved in a NEPA project which proposes to update the VQO and adopt the new handbook direction of Scenery Management. The proposed scenic integrity objectives are shown in Figure 14. The NEPA project proposes a programmatic change in goals, mapping, and guidelines, and proposes to amend the existing Forest Plan to adopt these changes.

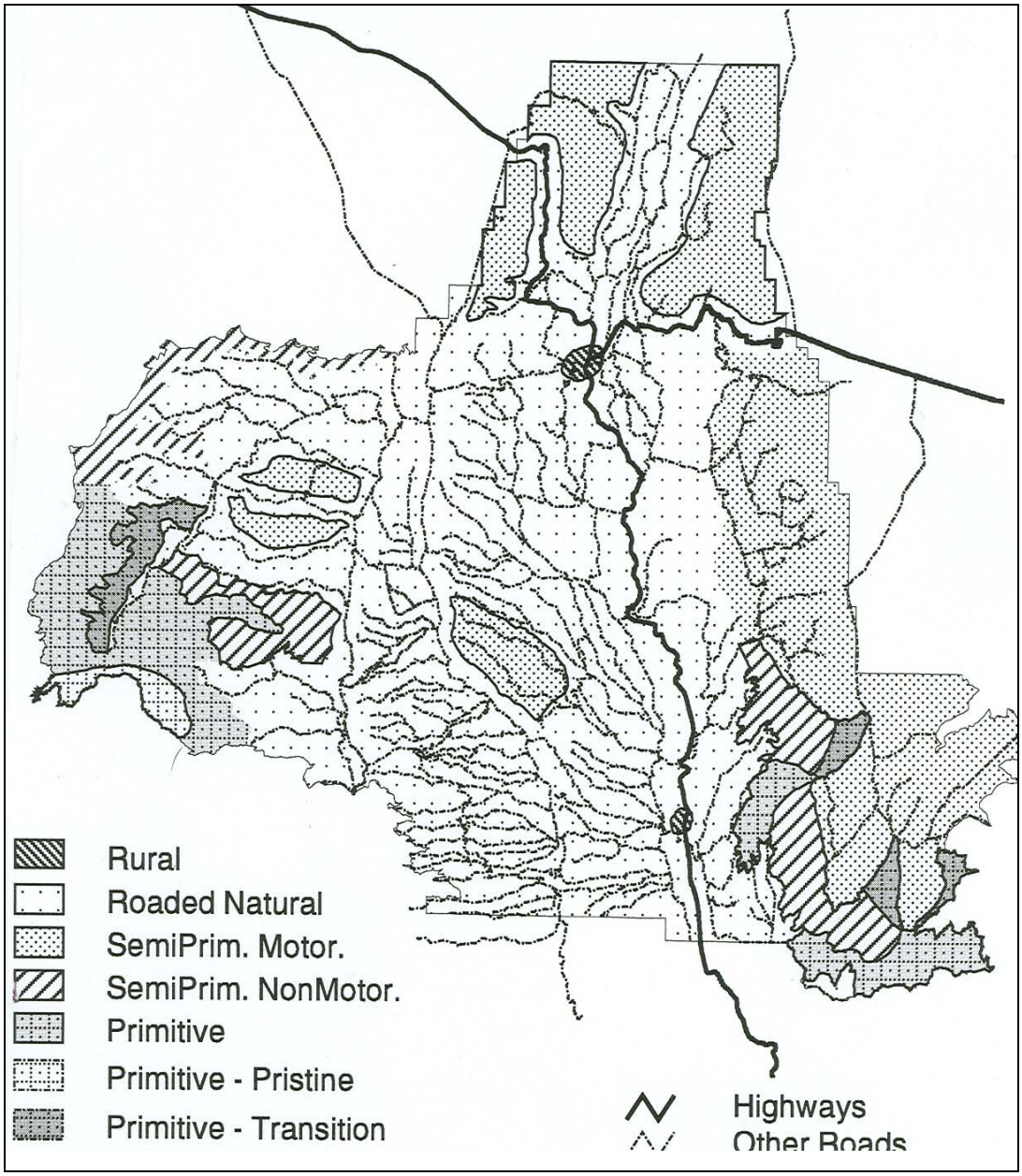


Figure 11. Existing ROS Mapping for the North Kaibab Ranger District.

The existing VQO for the analysis area are retention and partial retention along the road and trail corridors, as well as partial retention for developed recreation sites. Much of the remaining area is currently mapped as "modification."

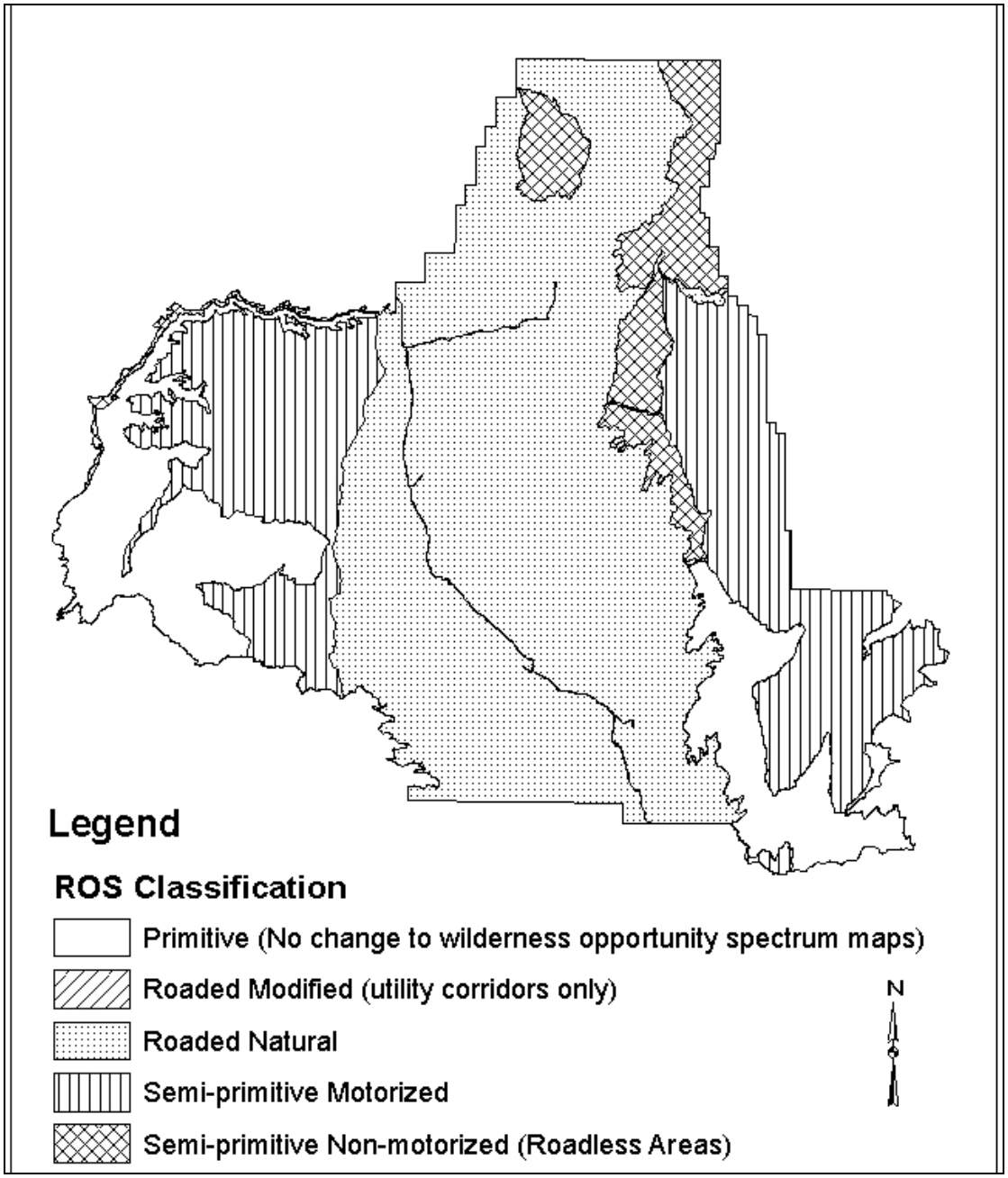


Figure 12. Map of the proposed Recreation Opportunity Spectrum map.

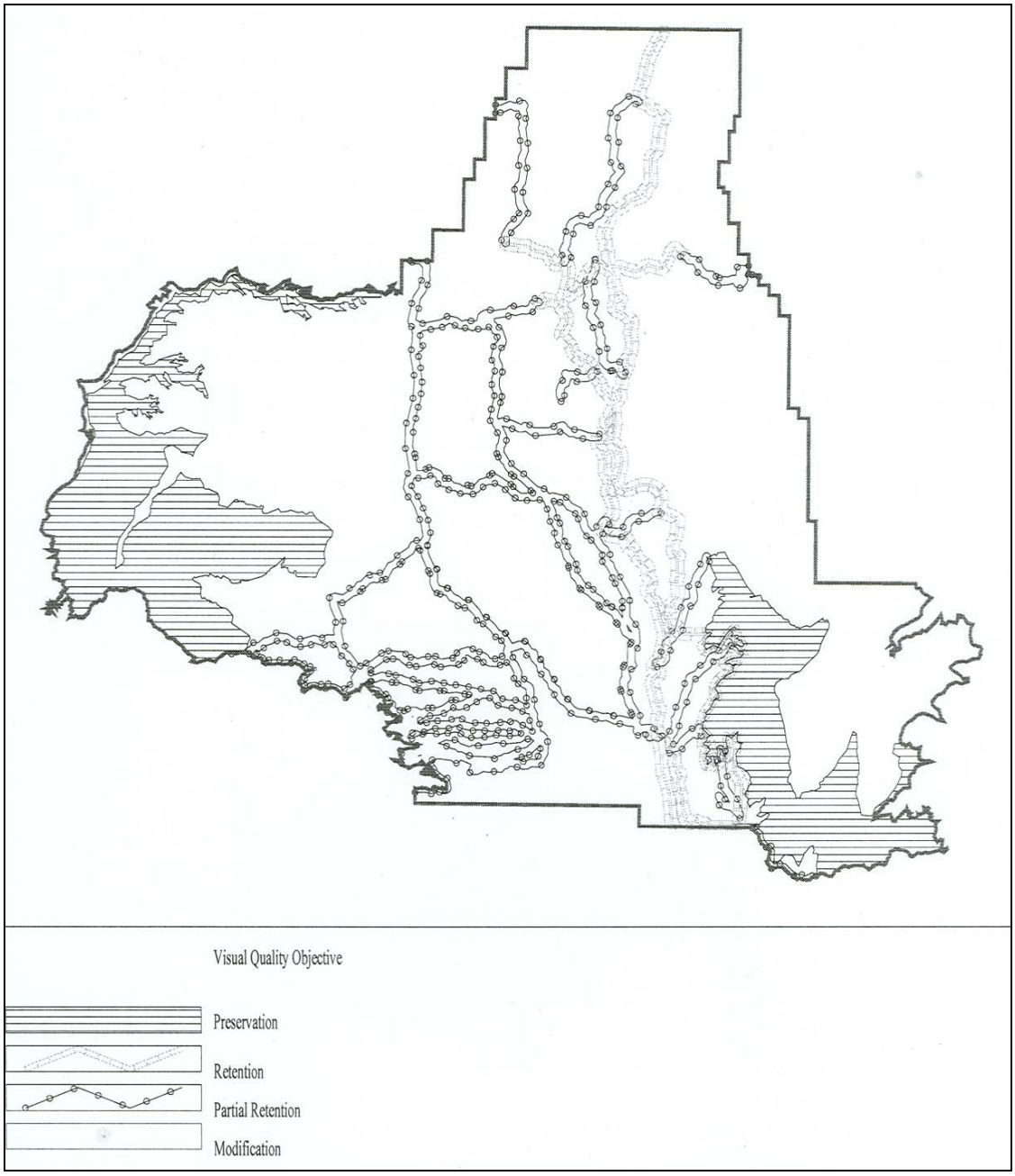


Figure 13. Map of the North Kaibab Forest Plan Visual Quality Objectives.

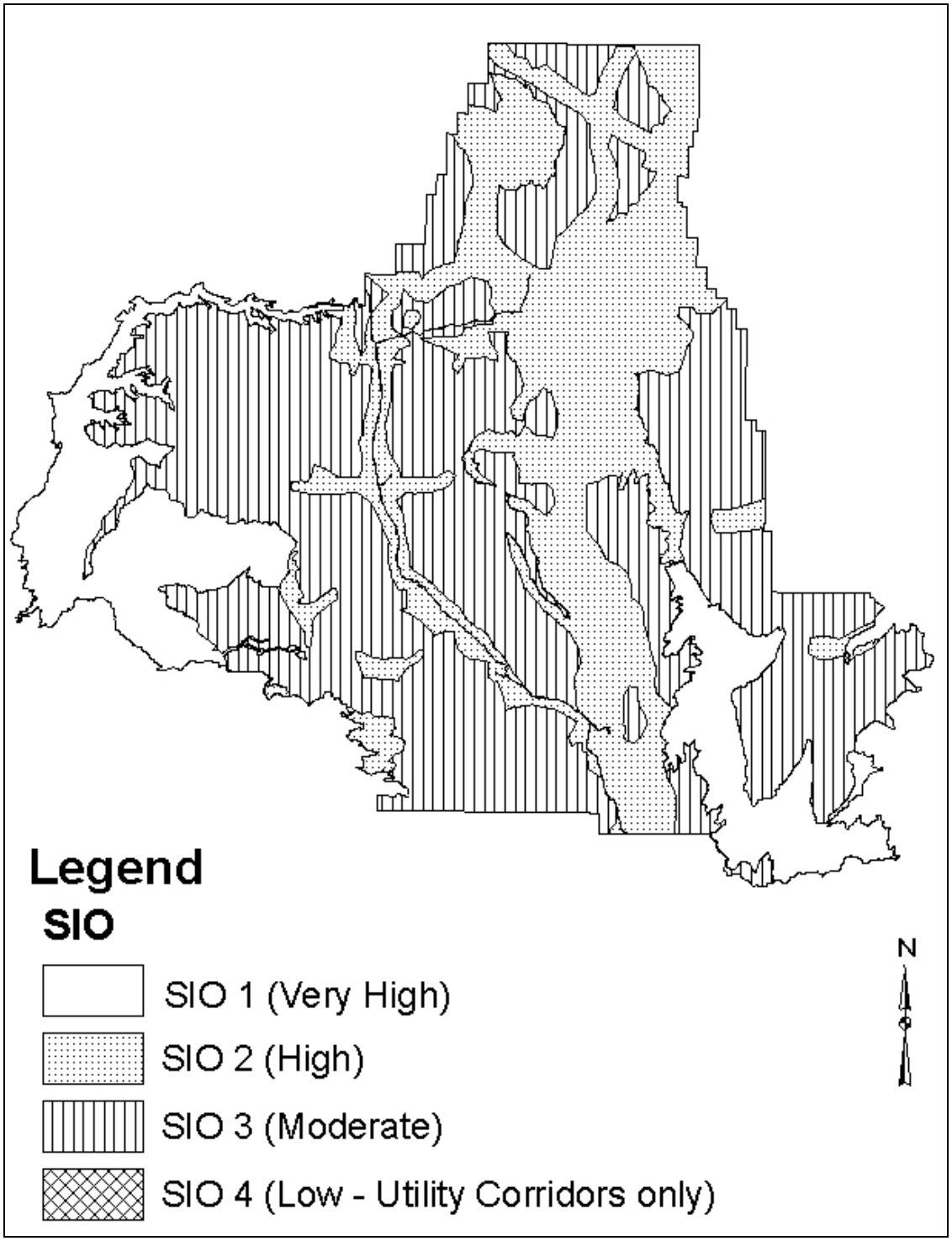


Figure 14. Proposed Scenic Integrity Objectives map.

The moderate to severe wildfire area is outside of the characteristic landscape for the area. This is not to say that fire in general is outside of the desired condition for the characteristic landscape. On the contrary, if fire is within the more typical presettlement fire regimes, it is part of the characteristic landscape (there is some discussion of this in the landscape characteristics section of

the ROS-SMS Guidebook). When the uncharacteristic fires occur, it is difficult to apply the SIO, as the characteristic landscape no longer exists. Heavily disturbed landscapes take more than 100 years to restore, with or without management activities.

Effects to Recreation Use

As earlier noted, the majority of users on the Kaibab Plateau are enroute to the Grand Canyon National Park. North Rim visitation is approximately 300,000 per year. Those visitors are concentrated into a season of about five months, May through October, because the highway is closed the rest of the year. Most visitors drive the route, but an increasing number of bike tour groups use the route as well. These visitors have an expectation for a scenic route to the National Park, the scenery is important and a large part of many people's experience of the area. For a bicyclist, the scenery is experienced at a much slower pace and with much more detail. The highway has not been damaged by the wildfire and visitors will continue to use Highway 67 as their primary route to access the Grand Canyon National Park.

There were no developed recreation sites within the wildfire boundaries. The main uses of the area have been dispersed hunting, camping, picnicking, and limited day-use. Hunting occurred throughout the area. Dispersed camping has been concentrated along forest roads and at roaded view points into Marble Canyon (not developed sites, but places where there was a view at the end of a road). Use is not limited to the higher maintenance level roads; most routes out to view points have evidence of dispersed use. Hunters and dispersed campers will be displaced as a result of the fire. The Arizona Trail was impacted by the wildfire as it parallels Highway 67 much of the way. Use of the trail is fairly light. Users include hikers, mountain bikers, bike tour groups, and equestrians. At least one permittee is affected and may be displaced as a result of the fire.

Desired Condition

The desired condition for recreation and scenery in the pinyon-juniper and ponderosa pine vegetation types are forests within their historic range of variation including density of tree, presence of understory shrubs and forbs, and fire frequency. Multiple use and fire are integrated as part of a healthy ecosystem.

Current Condition

Due to the heavy fuel loads, high tree densities, and potential for ignition, the major threat to recreation and scenery is high intensity wildfire. These systems are considered unstable as a result of this threat. Within the Warm Wildfire area, there are many acres that do not meet the desired condition because of the intensity of the burn and the uncharacteristic landscape that resulted. In the moderate and severe areas of the burn, there is a need to:

- Restore and sustain the valued landscape character (primarily based on vegetation, but also land and water forms) to provide the highest scenic quality possible, and to enrich society through the benefits that scenic landscapes provide including valued recreation settings, tourism, and community quality of life.
- Provide a wide range of recreation opportunities in predominantly natural appearing settings that meet public preferences and contribute to ecosystem and community health, well-being, and quality of life.

Management Recommendations

The low intensity areas of the Warm Fire Suppression Area (WFSA) are at lower risk, and should move towards the desired condition without significant management activities. The moderate and severe areas of the WFSA area do not meet the requirements for ROS classes or Scenic Integrity/Visual Quality. These areas are severely diminished in their existing condition, and need to be set on a trajectory so that they are moving toward the desired conditions.

Depending on the VQOs and the ROS of an area, there is specific guidance for whether these resources would be positively or negatively affected by restoration activities. For example, in sensitive foreground areas in the mixed burn severity areas, removal of dead and blackened trees could have beneficial effects. In the larger high severity burn areas, the scale is such that there would be minimal scenic benefit. Because restoration activities may take on many forms, it will be necessary to assess effects to recreation and scenic resources on a project-specific basis.

Restoration activities need to be considered for both the short and long term. It is important to realize that the forest will not regrow in our lifetime. While we may have social or economic desires to restore the landscape as soon as possible, ecosystem restoration will take time. Potential restoration activities include:

- Seeding with native seed/forb mixture. Initial stabilization was attempted with aerial seeding. There are areas where following up with a native seed mix would help establish a ground cover that will hold the soil, and help keep invasive species from getting established. This is suggested along roadsides in a 25 foot wide strip. The pinyon-juniper and high grasslands on the east side of the District need to have native plants reestablished as soon as possible. Pinyon-juniper areas often are lower priority for restoration because they have little economic value. These areas are particularly vulnerable to invasive weed infestations (e.g. the lower elevation west side of the Bridger Fire). Time and money invested in the pinyon-juniper areas could prevent the need for large scale invasive weed treatments, and the loss of precious non-renewable assets, such as heritage sites.

- Developing interpretive information for the Arizona Trail trailhead bulletin boards and brochures to hand out at the visitor center and the concessionaire resorts and store. Consider replacing the existing signs at the aspen restoration area and develop new signs about wildfire and ecosystem restoration at this specific location along the scenic byway. Interpretive media that could be updated every few years would show the changes from burn to recovery.

Range

Current Condition

Ninety-five percent of the Warm Fire area was in the North Pasture of the Central Summer Allotment (Figure 15). This allotment is managed in a rest-rotation pasture system. The North pasture was greatly impacted by the fire with over half the 102,346 acres in the pasture burned. The allotment is normally permitted for 800 head of livestock during a season of use from July 1 to October 15.

Once the fire started, the grazing strategy on the Central Summer Allotment was modified to graze the South Pasture instead of the North Pasture. The fire burned just inside the boundary of the

South Pasture, damaging the northern boundary fence, but did not affect the potential for this pasture to continue to be grazed. The fire also burned along the edge of the Houserock Allotment, damaging the western boundary fence and one corral. The planned grazing rotation was not affected.

Several range and wildlife structures were damaged during the fire. The Central Summer North Pasture received damages to six livestock handling facilities (corrals). Three wildlife guzzlers and nine exclosures built to exclude livestock from wildlife waters were also damaged

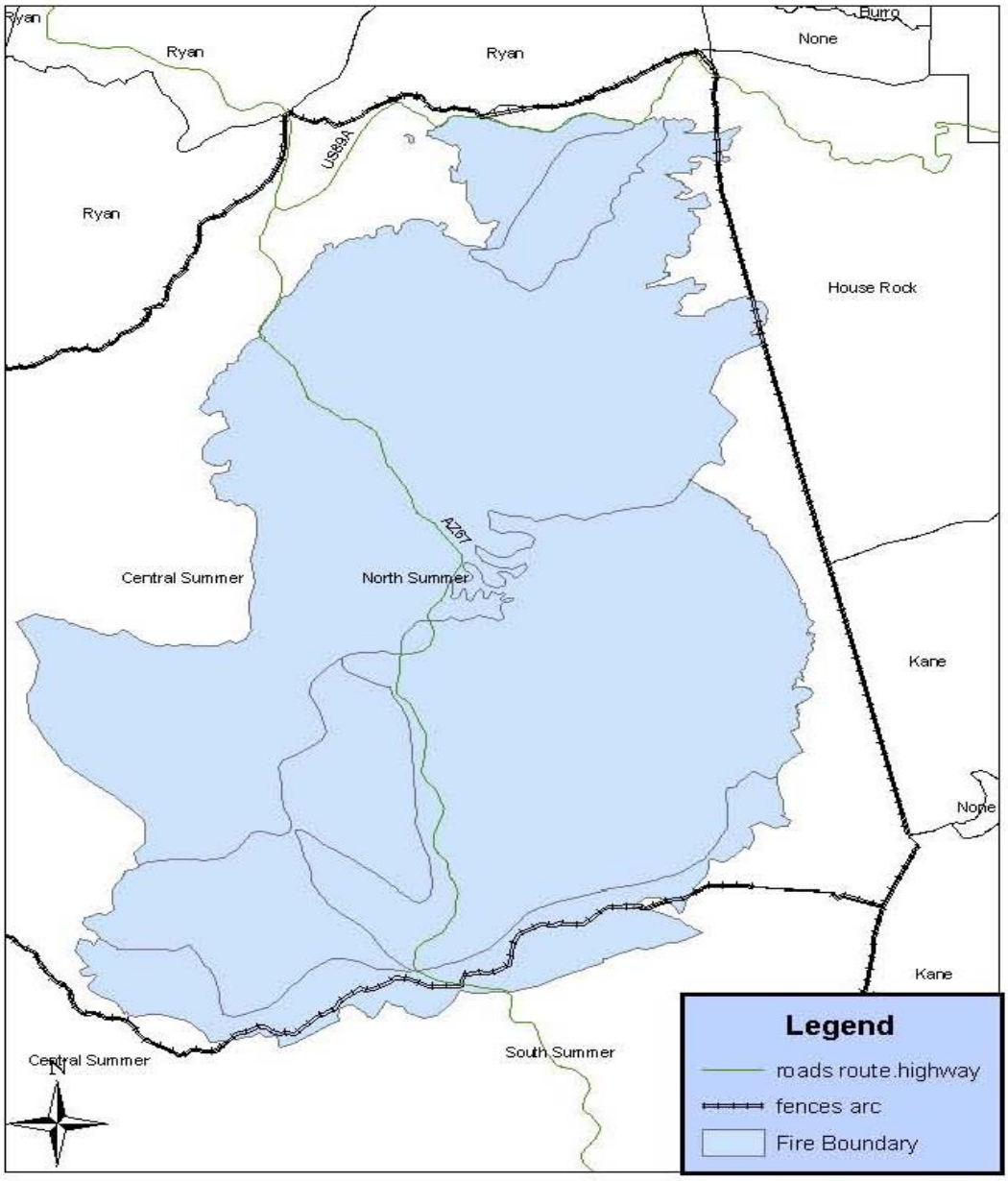


Figure 15. Pastures and allotments in the Warm Fire area.

The Kaibab National Forest Plan contains direction that areas impacted by fire are to be excluded from livestock grazing for at least two growing seasons. Even after two growing seasons of rest, the burned areas would need to be assessed before cattle are allowed to enter. This would require keeping livestock off of the burned portions of Central Summer North until at least 2008.

The majority of the "fully capable" and "potentially capable" acres of the Central Summer and North Pasture are either outside of the burned area or in the low to moderate intensity burn areas. The low intensity burn areas had tremendous cool season grass and forb production following the post-fire monsoon rains. These areas traditionally have the highest livestock use.

The areas of high fire intensity will take the longest to recover. The process will be benefited to some degree from the emergency stabilization seeding that occurred in August 2006. Seeding of native perennials in these areas would further promote vegetation reestablishment.

The majority of the high severity areas are located in portions of the allotment that have traditionally seen light use from livestock due to steep slopes, low forage availability, and few reliable water sources. This would indicate that light grazing pressure would resume once livestock are reintroduced to the pasture and impacts to reestablishing plants in the majority of the high severity areas would be minimal.

Repairs to the damaged fences have mostly been completed. Labor for repairs to the damaged livestock handling facilities, wildlife waters, and exclosures is being planned collaboratively between the Central Summer permittee, interested volunteer groups, and the North Kaibab Ranger District. The Forest Service will provide as much material as possible for these repairs. The goal is to have the repairs completed prior to livestock reentering the allotment.

Management Considerations

Forest Service personnel will assess the vegetative condition inside the burned area on an annual basis. Criteria for determining when conditions are ready for grazing again will be based on forage production of native perennials, plant vigor, noxious and invasive species, and species diversity that is consistent with the potential for the soil type. After the 2008 growing season and once the vegetative conditions are suitable, livestock will be authorized to graze inside the Warm Fire boundary.

Until the North Pasture is at full capacity, management actions will be taken for the permitted livestock. This can be managed through a combination of grazing the higher capacity South Pasture multiple years, grazing the unburned portions of the North Pasture, or requiring the permittee to take some degree of non-use. Monitoring will be done to ensure that the vegetative conditions of the allotments unburned portions do not decline during this time.

Chapter 3 - Management Considerations

Because the wildfire had unintended and undesirable effects, there are unresolved needs that call for management actions to protect public safety and vulnerable resources, and restore desired resources conditions. In addressing these needs, there are also opportunities to support the local community and economy and to learn more about fire effects and the effectiveness of post-fire management. Considering the current and desired conditions, the interdisciplinary team identified the priority needs and a menu of possible actions to address those needs.

Purpose and Need

The primary needs identified by the interdisciplinary team are to:

- Provide for public safety.
- Prevent further fire-related resource damage.
- Restore the structure and function of the forest.
- Support the local community and economy.
- Learn through monitoring and research to improve management over time.

Possible Management Actions

Hazard Tree Removal

In order to address the immediate risk to motorists and hikers within the Warm Fire due to fire-killed dead trees falling, hazard tree removal is recommended. Standing dead trees occur throughout the fire area that will eventually fall. The potential hazard of falling trees can go unrealized because much of the damage is below ground and is not readily apparent. The determination of whether a tree is considered a “hazard” depends on the use of the area and the level of risk to a target.

Hazard tree removal along the highways and major forest system roads is a high priority. Within the highway right-of-way, hazard tree removal is already underway. Approximately 17 miles of Forest Service “Class 3” and high use “Class 2” roads have been identified for hazard tree removal.

Along the Arizona trail, there are approximately 6.5 miles of trail that need hazard tree removal. Due to potential negative effects to visual quality and recreation experience, a standard clearing width corridor should not be used. Individual dead trees should be marked. Priority should be given to those that would fall towards the trail or pose an eminent hazard to likely rest stops. Maintenance to the trail will likely be needed several times a year until most of the dead trees have fallen.

It may also be desirable to remove some fire-killed trees at some dispersed camp sites. Even in areas where evidence of dispersed camping is not found, it would be desirable to provide some open areas where it is safe to camp. Not all burned trees need to be removed; consideration should be given to retain some snags if they do not pose a significant risk.

Hazard tree removal would best be accomplished using categorical exclusion for road maintenance, salvaging marketable trees for utilization. A categorical exclusion is appropriate because of the urgency associated with addressing safety issues.

Road and Trail Maintenance

Damage to infrastructure including roads, trails and signs may also pose a risk to health and safety. The highest priority road maintenance needs were addressed immediately following the fire by the Burned Area Emergency Response team (BAER). Actions were taken on Forests Roads (FR) 429 and 212 to prevent breaching of the road fill. Regular follow up maintenance to inside ditches and culverts over the next few years will be required due to increased erosion, especially from the slopes north of FR 429. Recent rain events and flash flooding across FR 8910 has cut the road prism and filled the road bed with ash.

Forest Roads 220, 224, and 284 have received significant erosion, sedimentation, and flash flooding. This is expected to continue with seasonal damage for several years. Over the summer of 2006, a bulldozer was used once a month to remove sediment and restore the road profile on FRs 220 and 224. There are no culverts on these roads, only low water crossings that are not armored. These measures should prevent further breaching of the fills on these roads. However, due to the increased erosion from the slopes that are north of FR 429, inside ditches and culverts will require more frequent routine maintenance over the next few years. Long-term maintenance costs will increase due to bank sloughing, increased runoff and erosion, and falling snags. Funds have been requested to address these road maintenance needs.

Reforestation

Large areas of conifer stands were killed by the fire and now have few and poorly distributed seed sources. There is a need to promote the desired forest structure and accelerate the recovery of habitat conditions for native wildlife species. Natural regeneration will occur in areas where cone producing trees are present, but many acres are far from viable seed sources. Planting ponderosa pine and Douglas fir seedlings is recommended. Plantings should be designed so that they meet desired conditions (i.e. uneven-aged forest that meet direction in the Kaibab Forest Plan and the Goshawk guidelines). Planting prioritization should be planned within the landscape context, and implementation would need to occur for many years.

Because reforestation is costly and labor intensive, reforestation should be done in areas where the investments can be protected and where minimal site preparation would be required. Appropriate areas include existing regeneration harvest units where regeneration and seed sources were killed. These areas generally have less competing vegetation, a high probability of successful establishment, and low reburn potential. Reforesting these areas is consistent with direction contained in the National Forest Management Act of 1976 (16 U.S.C. 1600).

The lowest planting priority is areas with high concentrations of aspen regeneration. Throughout the Intermountain West, aspen is disappearing. There is an opportunity to actively manage these areas for their continued presence on the plateau. Aspen is a valuable species for wildlife and for its scenic and recreation values. It is a fast growing species, and its establishment is part of the natural succession cycle.

The following should be considered in the design of reforestation projects:

- Potential for natural regeneration;
- Foreseeable ground disturbing activities (i.e. salvage operations);
- Scientific literature and research on historic reference conditions;
- Future forest structure and composition as it relates to wildlife habitat needs and potential fire behavior;
- Suitability for reforestation based on TES map units (USDA Forest Service 1991);
- Plant associations of Arizona and New Mexico (USDA Forest Service 1997b).

Salvage of Dead Timber

Thousands of acres containing large ponderosa pine and Douglas fir trees burned in the Warm Fire. Many of these were killed from high intensity fire and now this area has hundreds of thousands of dead trees. One of the goals in the Kaibab Forest Plan is to “manage suitable timberland to provide a sustained level of timber outputs to support local dependent industries.” The Plan also includes a guideline for EMA 13 to “salvage stands, or parts thereof, that are severely damaged by dwarf mistletoe, insects, fires, or windthrow”. Jobs created from the sale of salvage material would provide positive benefits to the local community. Appropriately designed, a salvage harvest could help reduce the costs of restoring historic levels of downed woody debris and offset the costs of restoring the desired forest structure.

There is potentially 200 MMBF of standing dead timber as a result of the Warm Fire. Due to stumpage deterioration rates and associated limited timeframes, salvage project planning should be focused on recovering the economic value of the burned timber before its commercial value is lost. Implementation of a salvage operation would require a comprehensive effects analysis to identify areas appropriate for salvage and the subsequent reforestation needs. Any salvage proposal should be consistent with the long-term desired conditions for soils, watershed, vegetation, fuels, and wildlife.

Best Management Practices (FSH 2509.22, Soil and Water Conservation Practices) are means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals. The FSH provides a catalog of possible Best Management Practices (BMPs) for a variety of management activities that can be incorporated in project design, such as "Limiting the Operating Period of Timber Sale Activities" and "Tractor Skidding Location and Design". In addition to the set of BMPs for timber management listed in the FSH, it is recommended that other BMPs be considered where needed. Others to consider include ground-based logging over snow-covered or frozen ground conditions and lopping and scattering fuels to create cover to protect soil and watershed conditions.

Planting of Browse Species for Mule Deer

Vegetation mortality was high in mule deer winter and transitional range on the east side of the fire. The Kaibab National Forest and the Arizona Game and Fish Department are currently working together to identify areas within the Warm Fire for possible planting of native browse species such as cliffrose, four-wing salt bush, winterfat, and mountain big sagebrush. This habitat

improvement project meets the criteria for a habitat improvement categorical exclusion and would be most efficiently addressed as a stand-alone project.

Heritage Site Protection

The pinyon-juniper woodlands contain a high density of prehistoric heritage resources sites. Monitoring has shown that these sites are washing away with each successive rainfall. Heritage resources are non-renewable and are of significant cultural value to the Hopi, Paiute and Navajo Tribes. There is a need to stabilize heritage sites by implementing contour felling of dead trees in the vicinity of sites to decrease erosion. Tree carcasses should be removed from within features to limit potential damage from blow down and tree “tip-ups” which can cause damage to heritage sites. Seeding with native grasses and forbs in and around sites would help stabilize soils and reduce the potential for vandalism by obscuring surface structures and artifacts. Timely active stabilization is necessary to prevent continued destruction of sites. Funds have been requested to do this work. Site protection will be implemented to the extent funded.

Weed Management

Due to exposed soils, the fire area has the potential to be invaded by noxious and invasive weeds. This threat is higher in areas with severe fire effects. In the high severity areas, vegetation and seed sources were compromised. It will take years for the native perennial species to reestablish in these areas, leaving open disturbed areas where noxious weeds can become introduced and established before the native species can compete.

A strategy that includes a combination of early detection, treatment, and facilitation of native plant competition is most effective. Additional seeding of native perennial grasses, forbs, and shrubs would assist in preventing weed infestations. Funds have been requested to monitor and treat noxious weeds in the Warm Fire area. This work can be done under the Coconino, Kaibab, and Prescott National Forest Environmental Impact Statement for Integrated Treatment of Noxious or Invasive Weeds (USDA Forest Service 2005).

Fuelwood Collection

There is a need to reduce fuels in certain areas in order to increase the likelihood of safe and successful fire protection efforts in the future. Strategic use of authorized fuelwood collection could help to achieve this objective. Making fuelwood available also benefits the local community. Fuelwood cutting could be managed to achieve desired conditions by moving the dead fuel loads towards levels more typical of the natural historic range of variability.

Research / Adaptive Management

Opportunities exist to learn about fire effects and post-recovery under various management scenarios. There are many unanswered questions about fire effects to wildlife species, heritage sites, BAER effectiveness, *Pediocactus* survival and recovery, future fire behavior, and the effectiveness of post-fire management design features and mitigations. The Forest, and forest management in general, could benefit if research is encouraged and supported in the Warm Fire area.

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The following individuals provided invaluable support: Stu Lovejoy, Jill Leonard, John Hanson, Scott Clemens, Paul Calloway, Roy Mita, Daniel Gonzalez, Pete Fulé, Wayne Robbie, Penny Leuring, Louise Congdon, and Susan Brown.

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Glossary

Critical habitat: that portion of a wild animal's habitat that is critical for the continued survival of the species. Under Endangered Species Act, specific area designated for that species that is essential to survival of the species and which may require special management or protection.
Duff: humus layer of decaying plant material between the surface litter and mineral soil.
Fire frequency: number of fires occurring within a specified area and time period.
Fire size or fire extent: the size (hectares) of an individual fire, or the statistical distribution of individual fire sizes, or the total area burned by all fires within a specified time period.
Fire interval: the number of years between successive fires, either within a recurrence interval, specified landscape, or at any single point within the landscape.
Fire season: the time of year at which fires occur, for example, spring and fall fires, when most plants are semi-dormant and relatively less vulnerable to fire injury, or summer fires when most plants are metabolically active and relatively more vulnerable to fire injury.
Fire intensity: amount of heat energy released during a fire, rarely measured directly, but sometimes inferred indirectly from fire severity.
Fire severity: fire effects on organisms and the physical environment.
Homogenous: all of the same or similar kind or nature.
Hydrophobic: water repellent
Litter: organic material including grasses, needles, twigs, and leaves on the soils surface.
Mesic: adapted to an environment having a balanced supply of moisture
Noxious weed: a legal term applied to plants regulated by Federal and State Laws, such as the Secretary of Agriculture or responsible State official. Noxious weeds generally possess one or more of the following characteristics: aggressive and difficult to manage, poisonous, toxic, parasitic, a carrier or host of serious insect or disease, and being not native or new or not common to the United States.
Rill erosion: erosion that forms many small but conspicuous water channels.
Scorch: brown needles due to proximal heating where foliage did not catch fire.
Sheet erosion: the removal of a fairly uniform layer of soil from the land surface by runoff water, without the development of conspicuous water channels.
Snag: Standing dead tree larger than six inches in diameter at breast height.
Soil wood: Small bits of wood in the soil.
Spall: a chip, fragment, or flake from a piece of stone.
Wildland Fire Use: the management of naturally ignited wildland fires to accomplish specific resource management objectives in predefined geographic areas.