

EVALUATING PRESCRIBED FIRES

Kevin C. Ryan and Nonan V. Noste

ABSTRACT: A preliminary method for classifying fire severity permits managers to predict fire effects with reasonable accuracy and thus assists them in prescription development. The classification described here consists of a two-dimensional matrix of flame length classes and depth of char classes. Flame length classes are derived from direct observation or are inferred from postburn observations and reconstruction of the fire environment. Depth of char class is derived from postburn observations of the extent to which fuels were burned, particularly on the soil surface. The relationship between fire severity and vegetation response is useful in understanding postfire survival and recovery of vegetation.

INTRODUCTION

Wilderness fire monitors are responsible for providing information that can be used to decide whether a fire is within prescription. They typically collect information on fuel, weather, and fire behavior; map fire perimeters by burning period; and document fire effects. Feedback from wilderness fire monitoring has played a major role in the initial phase of prescription development, which is a basis for wilderness fire management programs.

An evaluation of fire behavior and effects is essential to deciding if a fire meets land management objectives. A practical means for describing fire behavior and the effects of fire on the soil and vegetation is needed in fire management. This paper describes a method currently being developed to classify the ecological severity of a fire. The technique can be applied to grass, shrub, and forested sites and allows the monitor to make inferences about the survival of meristematic plant tissue on the site and thus about postburn succession.

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Kevin C. Ryan is Research Forester, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, Missoula, Mont.

Nonan V. Noste is Research Forester, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, Missoula, Mont.

Fire severity is the effect of the fire on the ecosystem, whether it affects the forest floor, tree canopy, or some other part of the ecosystem (Vierick and Schandelmeier 1980). Fire severity relates to the degree that on-site plants survive a fire or reproduce from on-site meristematic tissue such as rhizomes, root crowns, underground stems, and seeds or the extent to which the site is invaded by seed from off-site plants (Lyon and Stickney 1976). Fire severity is also based on the amount and location of organic matter lost by burning, decreases in the protective forest floor, volatilization of nitrogen and other elements, and transformation of less volatile elements to soluble mineral forms (Wells and others 1979).

To characterize fire severity, it is necessary to classify the heat pulse received by above-ground vegetation and the heat pulse down in the soil. The heat pulse-up is directly related to the fire intensity. It can be classified by directly observing flame length, by observing scorch height and calculating flame length, or by calculating flame length from fire behavior prediction models. The heat pulse-down is termed ground char and relates to factors other than intensity, specifically on a classification of postburn soil and fuel features. (The term char is used here in a general sense, not as specifically defined in fuel chemistry). Fire severity is characterized by combining the flame length classes and ground char classes to yield a two-dimensional matrix. Each cell of the fire severity matrix can be used as an index of ecological change and compared to a variety of fire effects. Given similar phenology and vigor we can then hypothesize that similar fires on similar sites will have similar effects.

Part of the difficulty in characterizing fire severity results from an inconsistent use of terminology. Fire intensity has been variously defined as maximum temperature (Smith and James 1978) or the degree of litter consumption (Schier and Campbell 1978). Terms such as "hot" and "cool" burn are common and are usually unquantified. Stark and Steele (1977) used maximum soil surface temperature and degree of forest floor consumption to quantify hot, medium, and light burns. Numerous authors (Tarrant 1956; Bentley and Fenner 1958; Morris 1970; Wells and others 1979) have used visual observation of postburn soil characteristics to classify fire severity.

A recent trend toward a standard definition bases fire intensity (Alexander 1982; Cheney 1981; Rothermel and Deeming 1980) on the relationship between fireline intensity and flame length, a concept developed by Byram (1959). The use of flame length to classify fireline intensity is consistent with this trend.

A common misconception about fire intensity is that a "stand replacement fire"--one that destroys the overstory--represents the most severe disturbance. Although such a fire may destroy more above-ground vegetation, it is not necessarily as destructive of organisms in duff and underlying mineral soil. The crown fire phase of a wildfire involves primarily the combustion of fine fuels. It devastates the overstory but does little damage to subsurface regenerative organisms. Although the supporting surface fire during a crown fire usually causes some subsurface damage, it is the degree of burning in duff and larger fuels that determines the depth of lethal heat penetration into the soil. If the site is deeply charred, many species may be lost from the site, at least temporarily (Rowe 1983; Flinn and Wein 1977). Directly measuring the extent of residual burnout of fuels is not practical; however, postburn observation of char depth can be used to qualitatively describe the long-term burnout of fuels.

APPROACH TO FIRE SEVERITY RATING

Flame Length Classes

It is difficult to measure the length of pulsating flames accurately (Ryan 1981; Johnson 1982); use of flame length classes is more practical. Five flame length classes are sufficient to characterize flame lengths for most purposes (table 1). These five classes are based on two criteria. First, they are observable in the field. As flames become larger, however, observations become less precise. Thus, as flame length increases, class ranges become broader. Second, the classes are designed to predict what flame length makes death from crown scorch highly probable for different-size classes of trees in temperate forests of North America. If flame lengths exceed 12 feet (≈ 3.7 m), torching and crowning become a problem even for the largest trees.

It is preferable, if possible, to make direct field observations of flame length. This may not be practical for large prescribed or wildfires, particularly in wilderness areas. Because it is difficult to adequately estimate flame lengths on large fires, information collected by the monitoring team may be used with existing models to approximate flame length. If the fuel and environmental conditions prevailing at the time can be reconstructed, flame length can be approximated (Rothermel 1972, 1983; Albini 1976). It is also possible to calculate flame length from observed crown scorch (Albini 1976; Norum 1976) and estimates of temperature and windspeed. Thus, crown scorch is a valuable post-fire observation for assessing fire severity. When reporting fire severity estimates, the method and the inputs used for determining flame length class should be specified.

Table 1.--Flame length classes

Flame length class	Flame length range	Corresponding crown scorch height ¹	Corresponding tree mortality ₂ size class	Inches DBH (= 2.54 cm)
	Feet (= 0.3048 m)	Feet (= 0.3048 m)		
1	0-2	0-9	Seedling	<1.0
2	2-4	9-24	Sapling	1.0-4.9
3	4-8	24-64	Poles	5.0-8.9
4	8-12	64-116	Small saw timber	9.0-13.0
5	>12	>116	Large saw timber	>13.0

¹The range of crown scorch is based on Van Wagner's (1973) equation 10, assuming the flame length range for the class, 77° F (25° C), no wind, and no slope.

²Estimated mortality is based on review of the fire damage appraisal literature primarily for ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) (Dieterich 1979; Wagener 1961; Lynch 1959; Herman 1954; Bevins 1980). Based on height and diameter information for each class, trees of average height and crown ratio are unlikely to survive the scorching they can be expected to experience.

Ground Char Classes

Several authors have classified postburn ground characteristics. Although various terms such as intensity and severity were originally applied to them, the classifications are conceptually similar. We feel that they can be appropriately termed ground char classes. Postburn ground characteristics have been conceptually and quantitatively related to numerous physical and biological effects. After our review of the literature, we developed the class definitions in table 2.

The visual characterization described in table 2 applies to small areas and is appropriate for evaluating fire effects on single plants, groups of plants, and physical soil properties. Wells and others (1979) proposed extending the concept to stands or larger areas on the basis of a sample of small plots as follows:

1. Light ground char

<2 percent of the area deeply charred
<15 percent moderately charred
remaining area lightly charred or unburned

2. Moderate ground char

<10 percent of the area deeply charred
>15 percent moderately charred

3. Heavy ground char

>10 percent of the area deeply charred
>80 percent moderately or deeply charred
remaining area lightly charred

This classification of burned area is appropriate for evaluating larger-scale fire effects such as erosion, determining wildfire rehabilitation needs, and documenting effects of wilderness fires.

The flame length classes (table 1) can be combined with the ground char classes (table 2) to yield a fire severity matrix (figure 1). Each cell of the matrix can be used as an index of fire severity and compared to a variety of fire effects.

FLAME LENGTH CLASS	5	4	3	2	1
	5-U	5-L	5-M	5-D	
	4-U	4-L	4-M	4-D	
	3-U	3-L	3-M	3-D	
	2-U	2-L	2-M	2-D	
	1-U	1-L	1-M	1-D	
	UNBURNED LIGHT MODERATE DEEP				
	DEPTH OF CHAR CLASS				

Figure 1.--Two-dimensional fire severity matrix.

Increasing flame length is generally associated with the increasing availability of fine fuels and thus depends primarily on short-term weather conditions. Increasing depth of char depends on the increasing availability of duff, large woody fuels, or both and thus depends significantly on long-term drying.

VEGETATION RESPONSE RELATED TO FIRE SEVERITY

One possible use of a fire severity rating is to determine postfire survival and recovery of vegetation. The morphology and location of regenerating organs are critical to survival. Larger buds, thicker bark, deep rooting, and a high crown base make trees more resistant to damage from a fire. The opposite characteristics predispose a tree to damage. Factors that influence the potential survival of understory vegetation include

the type, size, and location of meristematic organs. Generally the deeper, larger, and more extensive the subterranean organs capable of initiating growth, the more likely the individual or species is to survive (McLean 1969; Flinn and Wein 1977; Rowe 1983).

Fires of low flame length and light ground char (1-L) are typical of many early season fires in the Northern Rocky Mountains. These fires should remove relatively few species from a site because many immature and most mature trees can survive them. In the herbaceous and shrub strata several individuals may be top-killed, but those capable of regeneration vegetatively or from stored seed can be expected to survive. The survival of understory species may depend on their phenological state.

Small flame length fires with heavy ground char (1-D) are more typical of late-season backing fires and head fires where dry fine fuels are scarce. These fires can be expected to kill most of the shallow-rooted individuals in the understory and all but the thicker-barked trees. These fires burn considerable duff and can kill much of the seed stored in the forest floor; however, they should have little effect on seed stored in the canopies of trees and larger shrubs. The mineral seedbed and reduced competition favor the establishment of new plants from seed stored in the canopy.

When fine fuels are dry and plentiful and when duff and large fuels are scarce or too wet to burn, fires may be expected to produce high flames and light ground char (5-L). These fires can kill much above-ground vegetation; however, seed stored in the ground and plants capable of vegetative regeneration from subterranean organs are likely to survive these fires.

When fine fuels, duff, and large fuels are plentiful and dry, conditions are suitable for large flame length and deep ground char fires (5-D). Many mid-fire-season wildfires and some slash fires are of this type. These fires remove much of the existing vegetation and seed stored on a site; the aftermath favors light-seeded, highly mobile pioneer species capable of rapidly invading and exploiting an environment where competition has been reduced to a minimum. Nevertheless, Lyon and Stickney (1976) found that after large wildfires, such as Sleeping Child in 1961 and Sundance in 1967, preburn species will make up a large portion of the postburn vegetation. Because fire severity varies within a burn, numerous species can be expected to have viable propagules left on the site. Even in fires classified as severe by the criteria of Wells and others (1979) a considerable portion of the area is not deeply charred.

Between these four extremes is a broad range of fire severity that should produce vegetation responses intermediate to those previously discussed. Noble and Slatyer (1977) and Rowe (1983) have developed conceptual models of plant adaptations to fires; additional work is underway to relate these concepts to fire severity.

Table 2.--Visual character of ground char from observation of depth of burn¹

Ground char class	Site		
	Timber/slash	Shrub fields	Grass lands
Unburned	The fire did not burn on the forest floor. Some damage may occur to vegetation due to radiated or convected heat from adjacent areas. Ten to twenty percent of the area within slash burns is commonly unburned.² There is a wide range in the percent of unburned area within fires in natural fuels.	See timber/slash	See timber/slash
Light ground char	Leaf litter is charred or consumed. Upper duff may be charred, but the duff layer is not altered over the entire depth. The surface generally appears black immediately after the fire Woody debris is partially burned. Some small twigs and much of the branch wood remain. Logs are scorched or blackened but not charred. Crumbled, rotten wood is scorched to partially burned. Light ground char commonly makes up 0-100 percent of burned areas with natural fuels and 45-75 percent of slash areas.	Leaf litter is charred or consumed, and some leaf structure is still discernible. The surface is predominantly black, although some gray ash may be present immediately after the fire. Gray ash soon becomes inconspicuous. Charring may extend slightly into soil surface where leaf litter is sparse, but the mineral soil is not otherwise altered. Some leaves and small twigs remain on the plants. Burns are irregular and spotty. Less than 60 percent of the brush canopy is commonly consumed.	Litter is charred or consumed, but some plant parts are still discernible. Charring may extend slightly into the soil surface, but the mineral soil is not otherwise altered. Some plant parts may still be standing. Bases of plants are not deeply burned and are still recognizable. Surface is predominantly black immediately after the burn, but this soon becomes inconspicuous. Burns may be spotty to uniform, depending on the continuity of the grass.
Moderate ground char	Litter is consumed.³ Duff is deeply charred or consumed but the underlying mineral soil is not visibly altered. Light-colored ash prevails immediately after the fire. Woody debris is largely consumed. Some branch wood is present, but no foliage or twigs remain. Logs are deeply charred.	Surface leaf litter is consumed. Some charred litter may remain but is sparse. Charring extends up to 0.5 inches into mineral soil but does not otherwise alter the mineral soil. Gray or white ash is conspicuous immediately after the burn, but this quickly disappears.	Litter is consumed, and the surface is covered with gray or white ash immediately after the burn Ash soon disappears, leaving bare mineral soil. Charring extends slightly into mineral soil, but the soil is not otherwise altered. Plant parts are no longer discernible, no plant parts standing, and the bases of plants are burned to ground level.

continued

¹ See footnotes at end of table.

Table 2.--continued

	Moderate ground char commonly occurs on 0-100 percent of natural burned areas and 10-75 percent on slash burns.	Some charred stems remain on the plants, and these are generally greater than 0.25-0.50 inches in diameter.	Plant bases are obscured in the ash immediately after burning.
	Trees with lateral roots in the duff are often left on pedestals or topple. Burned-out stump holes are common.	Burns are more uniform than in previous classes.	Burns tend to be uniform.
		Between 40 and 80 percent of the brush canopy is commonly consumed.	Moderate ground char is generally limited to backing fires and fires burning during dry conditions.
Deep ground char	Litter and duff are completely consumed, and the top layer of mineral soil is visibly altered, often reddish.	Leaf litter is completely consumed, leaving a fluffy white ash surface.	Deep ground char is uncommon due to short burnout time of grasses.
	Structure of the surface soil may be altered.	All organic matter is consumed in the mineral soil to a depth of 0.5-1.0 inches. This is underlain by a zone of black organic material.	Surface consists of fluffy white ash immediately after the burn. This soon disappears, leaving bare mineral soil.
	Below the colored zone $\frac{1}{2}$ inch or more of the mineral soil is blackened from organic material that has been charred or deposited by heat conducted downward.	Colloidal structure of the surface mineral soil may be altered.	Charring extends up to 0.5 inches into soil.
	Twigs and small branches are completely consumed.	Large branches with main stems are burned, and only stubs greater than 0.5 inches in diameter remain.	Soil structure is slightly altered (for consistency with other fuel types, no citations specifically mention soil alteration).
	Few large branches may remain, but those are deeply charred.		Deep ground char is generally limited to situations where heavy loadings on mesic sites have burned under dry conditions and low wind.
	Sound logs are deeply charred, and rotten logs are completely consumed.		
	Deep ground char occurs in scattered patches under slash concentrations or where logs or stumps produced prolonged, intense heat.		
	Deep ground char generally covers less than 10 percent of natural and slash areas.		
	One extreme case of 31 percent was reported in a slash burn.		
	In extreme cases, clinkers or fused soil may be present.		
	These are generally restricted to areas where slash was piled.		

¹Visual characteristics were developed from the following literature sources and combined for consistency: Bever 1954; Tarrant 1956; Dyrness and Youngberg 1957; Bentley and Fenner 1958; Daubenmire 1968; Morris 1970; Ralston and Hatchell 1971; Vogl 1974; and Wells and others 1979.

²The area coverage estimates for each of the ground char classes are ranges encountered in the literature and experienced by the authors. Obviously, any combination of depth of char classes is possible. The inclusion of these ranges points out the variability that may be encountered within a given fuel situation.

³Some late-season fires have been observed to spread by glowing combustion in the duff, leaving the charred remains of the litter on top of the mineral soil and ash. This should not be confused with light ground char because temperature measurements indicate a considerable heat pulse is received by the mineral soil.

Case Examples

The fire severity rating system has been used to rate fire severity of 22 prescribed slash fires in partial cut stands and of two fires (described below) in the spring of 1983. The Galena Gulch prescribed fire burned May 23, 1983, near Boulder, Mont., and was designed to treat sagebrush and conifer encroachment into natural grass openings and ultimately to improve wildlife habitat. Burning conditions were marginal, and flame lengths were estimated to be 4 to 6 feet in dense patches of sagebrush and conifers. Because the fire did not carry where grass fuels predominated, it produced only a patch burn. The Dismal-October wildfire burned May 30, 1983, near Wallace, Idaho, in a cedar-hemlock stand with heavy dead and down fuels. The fire occurred during a period of high winds and low humidity not commonly encountered at that time of year. Flame lengths were estimated from observations to be 11 feet.

Plots measuring 2.69 ft² (0.25 m²) were placed along a transect and the percentage of each plot meeting the ground char (table 2) was determined. Table 3 shows examples of ground char ratings.

Table 3.--An example of ground char ratings on the Galena and Dismal-October fires

Plot number	Ground char rating			
	Unburned	Light	Moderate	Deep
- - - - - Percent - - - - -				
Galena fire ¹				
1	100			
2	60	40		
3	100			
4	40	60		
5	100			
6	10	80	10	
7	10	90		
8	30	70		
9	30	70		
10	30	70		
Average	51	48	1	0
Dismal-October fire ²				
1			100	
2			100	
3		25	75	
4			100	
5		40	60	
6		100		
7		40	60	
8		85	15	
9		100		
10		100		
Average	0	49	51	0

¹Grassland criteria applied.

²Timber/slash criteria applied.

The Galena Gulch prescribed burn was classified into flame length class 1 based on the average observed flame length. It was classed in the low ground char class. This combination yields a fire severity index of 1-L. Almost all sagebrush and conifers were killed in burned areas, but most bunchgrass survived.

The Dismal-October Fire was classified as 4-M. The mortality rate for all size classes of trees was high. Many of the taller trees, although not completely scorched, were girdled because of cambium heating. Numerous woody and herbaceous understory plants sprouted within 3 weeks of the fire, and many seeds were germinating.

Discussion

A fire severity rating method should possess several attributes. Obviously, any method should be a meaningful index of ecological change and should be broadly applicable. It should be useful for predicting with moderate accuracy a number of fire effects, such as tree mortality and on-site seed survival, and should apply to prescribed fires and wildfires and to many vegetation types. The method should be relatively easy to apply so that it can be used and reported in conjunction with more specific ecological measurements. Its application to wilderness fires especially requires alternatives, such as relying primarily on postfire observations, to minimize the logistical problems of direct observations. Finally, the system should enable managers to evaluate their observations in light of research results. The fire severity classification is an attempt to satisfy these criteria.

Fire severity cannot be interpreted without understanding the burned ecosystem. Stand history, phenology, vigor, and soils must also be considered when interpreting fire severity and effects. For example, if an area burned before a species reached reproductive maturity, this species could be lost from the site. The same species might survive a similar fire at reproductive maturity. Also, if a soil conducts heat relatively well, the soil surface might not be as deeply charred as it might when a soil conducts heat poorly. A lethal heat load, however, might penetrate more deeply in the first instance. In ecosystems having no woody material and little accumulation of organic material on the soil surface, there may be little seasonal variability in depth of char. In such cases the vigor and phenology of understory vegetation may significantly affect the response. In ecosystems where duff accumulates over time, the zone of highest biological activity tends to move upward. Thus, a species that might sprout after a moderate burn in an early successional stage may be lost in a moderate burn in a later successional stage.

The fire severity ratings integrate prefire conditions, fire behavior, and fire effects. Opportunities to evaluate the system with prescribed fires and wildfires provide a basis for improving the classification criteria. Preburn plant survey transects at Galena Gulch were rated using the ground char classification. Transects on the Dismal-October burn were located after the fact, so less is known about the prefire vegetation. Nevertheless, much valuable information can be gained by examining seed germination and vegetative sprouting by ground char classes.

Placing flame lengths into appropriate classes is easier than attempting to define them on a continuum, whether they are based on observations or reconstructions. Classes are easier to observe and should facilitate agreement among observers. Postburn observation of crown scorch is the most practical means of determining flame length classes for rating fire severity. If weather conditions at the time of the fire can be ascertained, flame lengths can be determined from observed crown scorch height for any combination of temperature and wind-speed (Albini 1976; Norum 1977). Reconstruction of flame lengths after a fire from fire behavior models is subject to a number of interpretive errors and may therefore not be precise. It nevertheless provides a basis for classification. Despite the lack of precision, the classification should not be off by more than one category.

Because there are few quantitative links between flame length and fire effects, other than crown scorching, more precise definitions appear unwarranted at this time. Managers are able to classify and can therefore use them to document and evaluate fire effects.

Numerous fire effects on soils and vegetation have been related to the criteria similar to depth of char. For example, Tarrant (1956) found that severe burning (equivalent to deep depth char) significantly reduced movement of water into pumice sandy loam and sandy loam clay soils on the H. J. Andrews Experimental Forest in the Cascades of Oregon, while light burning (light depth of char) did not. Other examples are presented in Wells and others (1979) and Miller and others (1974). Fire effects in chaparral (DeBano and others 1979) and in tiaga forests (Vierick and Schandelmeier (1980) have also been related to criteria similar to depth of char. Additional research is needed to define specific plant responses to depth of char.

Other research intended to improve the classification criteria will examine variations among observers in classification, number of plots needed to sample the variation in fire severity on an area, and the relationship between fire behavior and postburn evidence of severity. Operationally oriented questions involve levels of useful information. Can severity ratings be satisfactorily estimated from aerial photographs of low, slow-flying aircraft, or during a reconnaissance walk? Trial use and training sessions will provide opportunities to answer these questions. We also solicit comments from field and research users on the successful or unsuccessful use of the system.

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Technical Coordinators:

JAMES E. LOTAN, Program Manager, Intermountain Forest and Range
Experiment Station, Missoula, Mont.

BRUCE M. KILGORE, Project Leader, Intermountain Forest and Range
Experiment Station, Missoula, Mont.

WILLIAM C. FISCHER, Research Forester, Intermountain Forest and Range
Experiment Station, Missoula, Mont.

ROBERT W. MUTCH, Fuels and Fire Ecology Specialist, Northern Region,
Missoula, Mont.

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