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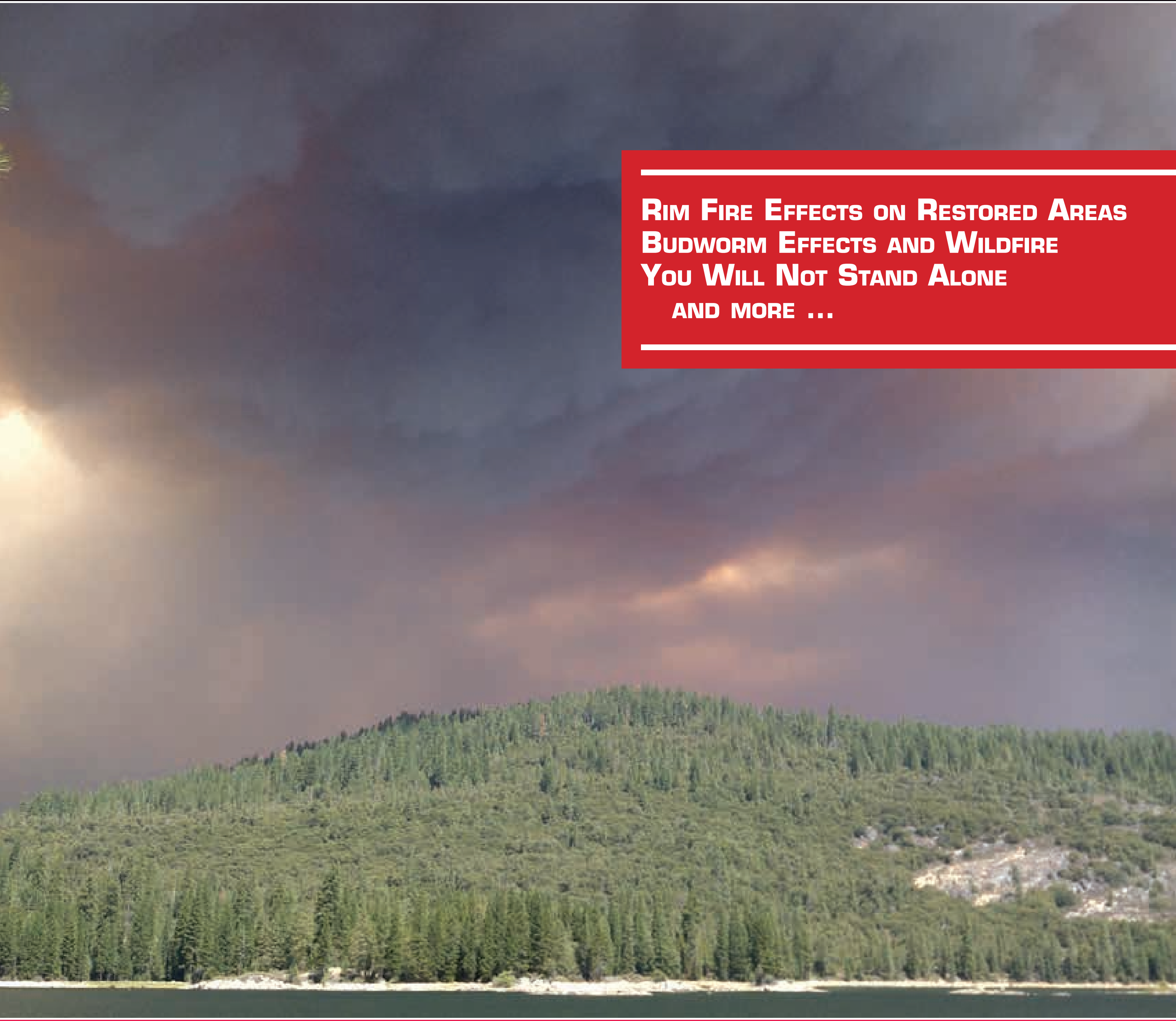

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Rim Fire Severity in Forests With Relatively Restored Frequent Fire Regimes*

Jamie M. Lydersen, Malcolm P. North, and Brandon M. Collins

Forests that evolved under the influence of frequent low-severity fire have undergone dramatic change following a century of fire suppression, including a buildup of surface fuels; greater density of small, shade-tolerant trees; and a loss of spatial heterogeneity (Lydersen and others 2013; Parsons and Debenedetti 1979; Scholl and Taylor 2010). Following these changes, a greater proportion of the fires in low- and mid-elevation forests are burning with high severity than they did historically, and high-severity fires are burning larger patch sizes in these forests than before (Mallek and others 2013). These uncharacteristically large and severe wildfires have significant impacts on sensitive wildlife habitat (North and others 2010), air quality (Fowler 2003), and greenhouse gas concentrations (Liu and others 2014; Muhle and others 2007). In addition, the costs of fire suppression and postfire rehabilitation associated with these fires continue to increase (NIFC 2013).

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Contemporary forests with restored fire regimes should burn with a lower proportion of high-severity fire under most wildfire conditions.

Research in Relatively Restored Forests

Restoration of forests with altered structure due to a history of fire suppression is of high interest to managers and stakeholders of Sierra Nevada forests (North 2012). Since the late 1960s, following the recognition of fire as an important ecosystem process, Yosemite National Park has made use of prescribed and wildland fires burning under moderate weather conditions to meet management objectives (Stephens and Ruth 2005; van Wagtendonk 2007). This has resulted in a number of forest stands in the park with repeated burning at frequencies and intensities similar to the historical fire regime (Collins and Stephens 2007; Lydersen and North 2012). There is considerable interest in characterizing ecosystem structure and function within these stands because frequent-fire reference conditions under recent patterns of climate are rare (Stephens and Fule 2005).

Under a frequent low-severity fire regime, forests are characterized spatially by diverse sizes of tree clumps interspersed with forest gaps and widely spaced single trees (Larson and Churchill 2012; Show and Kotok 1924). This heterogeneity was likely the product of an intact fire regime that allowed fires to burn under a range of weather and fuel conditions (Skinner and Taylor 2006). In addition to creating and maintaining spatial heterogeneity, repeated fire in these forests maintains a lower fuel load and tree density (Webster and Halpern 2010). Collectively, these forest conditions have been associated with increased resilience in relation to environmental stressors (such as drought, insects, and disease) and wildfire (Stephens and others 2008). Contemporary forests with restored fire regimes should burn with a lower proportion of high-severity fire under most wildfire conditions, as compared to areas

* This article is a condensed and slightly edited version of a previously published article in *Forest Ecology and Management* (Lydersen and others 2014). For more detail on study methods and relevant literature and for the full presentation of results, you can access the article in its entirety at <http://www.treesearch.fs.fed.us/pubs/46372>.

with ongoing fire suppression that have not burned in over a century. However, even areas that have recently burned in multiple low- and moderate-severity fires have a persistent legacy of tree densification due to fire exclusion before the reintroduction of fire in these stands (Collins and Stephens 2007; Collins and others 2011). The question remains as to whether these relatively restored forests are resilient in relation to wildfire burning under extreme weather conditions.

The 2013 Rim Fire is the largest fire on record in the Sierra Nevada and the third largest in California. It burned 257,313 acres (104,131 ha), mostly forest stands, including reburned stands in Yosemite National Park with a diverse recent fire history. The Rim Fire occurred under extreme drought and fire weather conditions, with notably unstable weather occurring soon after ignition, leading to 2 days of extreme fire growth characterized by a large smoke plume. Plumes often form when atmospheric conditions are unstable, resulting in erratic fire behavior that is driven by the fire's own local effects on surface wind and temperatures. The effects of such fires often exceed the influence of more generalized climate factors measured at nearby weather stations (Werth and others 2011). In this study, we took advantage of a unique opportunity to use extensive on-the-ground measurements collected prior to the Rim Fire in forests that previously experienced at least two low- to moderate-severity fires to explain observed fire effects in stands with relatively restored fire regimes. The objective of our study was to identify factors that influenced Rim Fire burn severity in these forests. Note that this study does not compare fire effects between previously burned and unburned areas.

We assessed the influence of forest structure, fuel load, topography, fire history, and weather on satellite-derived fire severity, using field data from 53 plots collected 3–4 years prior to burning in the Rim Fire (fig. 1; table 1). Field data were collected in 2009 and 2010 as part of a study on topographic variation in forest structure in Sierra Nevada mixed-conifer forests with a frequent low-severity fire regime that was active or restored (Lydersen and North 2012). Fire severity for the Rim Fire was calculated using the relative differenced normalized burn ratio (RdNBR) (Miller and Thode 2007) based on imagery collected following fire containment in 2013. Random forests and regression trees were used to assess relationships between Rim Fire severity and a variety of covariates, including topographic, forest structure, fuels, weather, and fire history variables. The analysis was performed twice, with and without plots that burned under plume conditions.

Variables Influencing Fire Behavior

Out of 53 plots, 12 (23 percent) were classified as burning at a high severity in the Rim Fire.

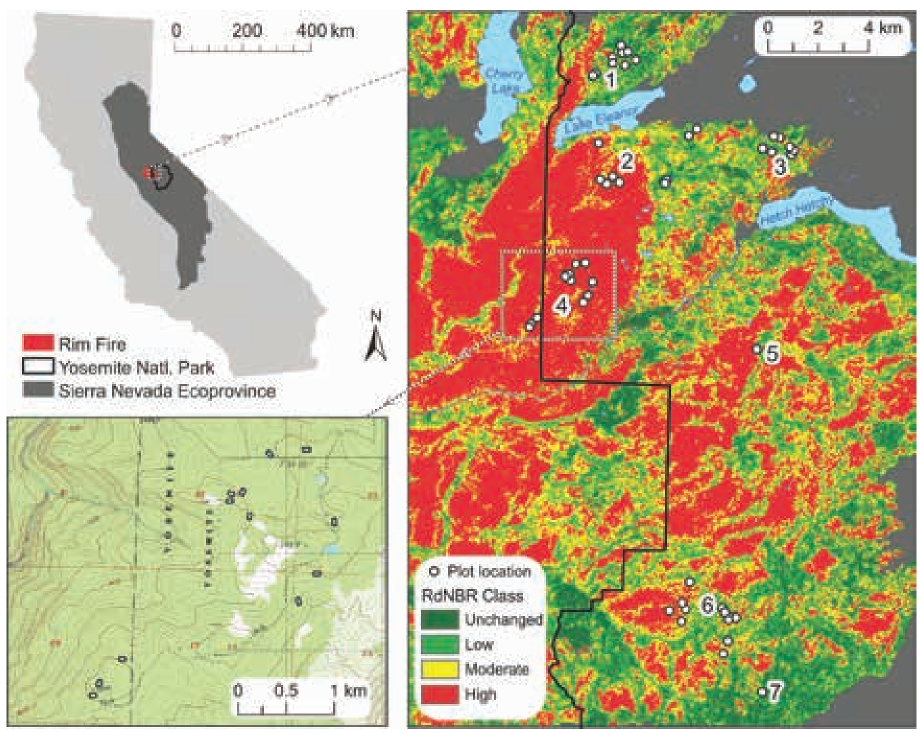

Figure 1—*Location of study areas from Lydersen and North (2012) that burned in the Rim Fire in California's Sierra Nevada Mountains. Inset on right shows the area where the Rim Fire crossed the boundary into Yosemite National Park, corresponding to the area within the black-and-white dashed box on the map of California. Numbers represent study areas 1–7, shown in table 1. Fire severity shown is for the Rim Fire. Inset on the bottom left shows the plot locations at the North Mountain study area in relation to site topography, corresponding to the area within the black-and-white dashed box on the severity map inset. Dimensions of the plots after addition of a 32.8-foot (10-m) buffer are shown. RdNBR = relative differenced normalized burn ratio.*

Table 1—Study areas (from Lydersen and North (2012)), by number of plots, previous fire history, elevation, size, and RdNBR (numbers correspond to figure 1). Note that some study areas had multiple fire histories.

Study area (#)	# of plots	Recent fires[a] (yr)	Elevation (ft [m])	Size (ac [ha])	RdNBR Avg. ± St. Dev.[b]
N. Eleanor (1)	9	1986, 1999	5,590–6,550 (1,700–1,200)	1,500 (610)	68 ±70
S. Eleanor (2)	9	1978, 1996	4,880–5,840 (1,490–1,780)	2,500 (1,000)	500 ±397
Laurel Lake (3)	9	1978, 1991, 2005	5,940–6,350 (1,810–1,940)	900 (360)	124 ±108
North Mountain (4)	4	1950, 1987, 1996	4,990–5,080 (1,520–1,550)	4,900 (1,980)	718 ±148
North Mountain (4)	3	1987, 1996	5,020–5,220 (1,530–1,590)	--	851 ±163
North Mountain (4)	2	1993, 1996	5,120–5,200 (1,560–1,580)	--	1,232 ±25
North Mountain (4)	3	1994, 1996	5,260–5,320 (1,600–1,620)	--	520 ±85
Cottonwood Crk (5)	1	1996, 2009	5,860 (1,790)	100 (40)	202
Aspen Valley (6)	10	1983, 1998	5,080–5,920 (1,550–1,800)	3,000 (1,200)	454 ±173
Aspen Valley (6)	1	1983, 1990, 1998	5,360 (1,630)	--	483
Aspen Valley (6)	1	1983, 1990, 1999	5,540 (1,690)	--	1,017
Gin Flat (7)	1	1989, 2000, 2002	6,550 (2,000)	250 (100)	262

[a] Includes fires from 1949 to 2011.
[b] RdNBR = relative differenced normalized burn ratio; St. Dev. = standard deviation.

Plots that had previously burned within 14 years of the Rim Fire burned mainly at low severity, whereas those that had not seen fire in over 14 years burned predominately at moderate to high severity.

Seventeen plots (32 percent) burned at moderate severity, and the remaining 24 plots were classified as unchanged or having burned at a low severity. Elevation, followed by plume effects, had the most influence on observed fire severities in our plots (fig. 2). Burning index, time since the last fire, and shrub cover were also highly associated with differences in fire severity. When plume-dominated fire plots were removed from the random forests analysis, many of the same variables remained highly ranked (fig. 2), indicating that their effect was not entirely due to correlation with plume-dominated burning. The variables identified as important in both analyses were shrub cover, burning index, elevation, years since last fire, proportion of shade-intolerant species, duff depth, and white fir basal area.

Plots that burned on plume-dominated fire days had higher severity overall. Among plots

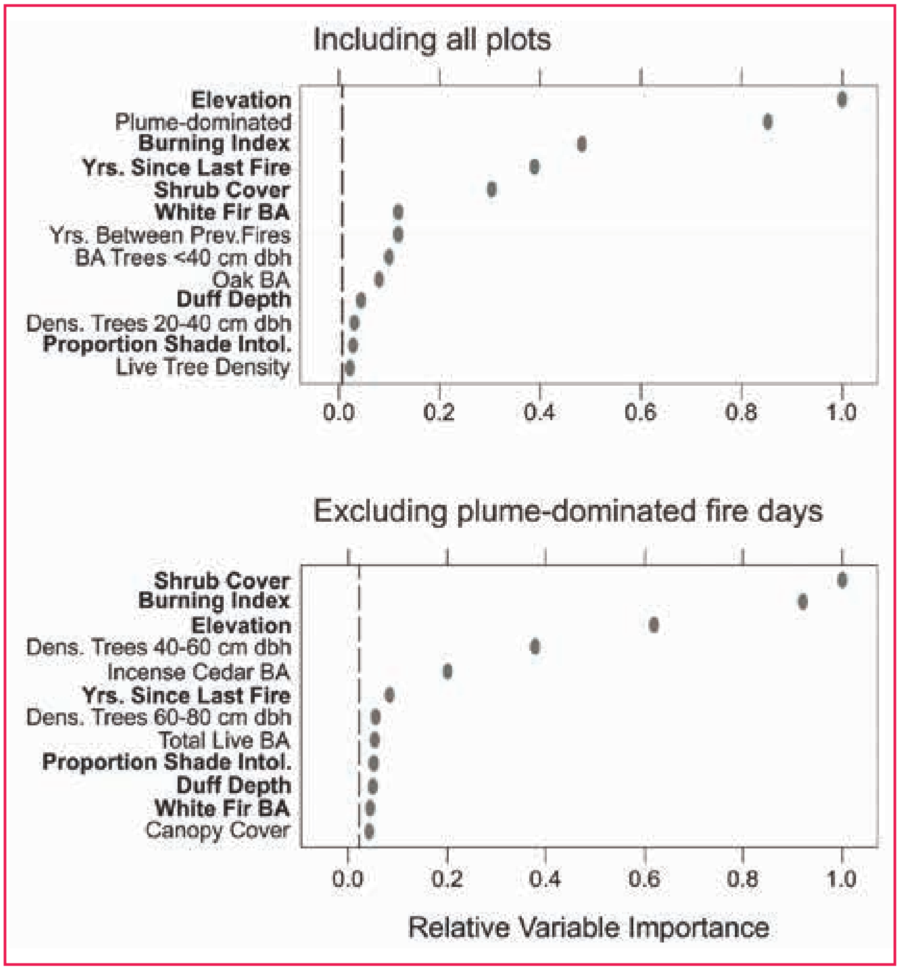

Figure 2—*Variable importance ranking of the influential variables on observed fire severity, as determined by random forests analysis. Variables with importance values higher than the absolute value of the lowest negative importance value (dashed vertical line) are considered influential. The upper chart shows results when all plots were included in the analysis; the lower chart shows results after excluding plots burned on a day when the Rim Fire was plume dominated. Variables in bold text appear in both charts. BA = basal area; dbh = diameter at breast height.*

that burned after the plume subsided, greater shrub abundance was associated with greater fire severity. Elevation was negatively correlated with Rim Fire severity, with lower severity observed in plots above 5,558 feet (1,694 m) in elevation. Plots that had previously burned within 14 years of the Rim Fire burned mainly at low severity, whereas those that had not seen fire in over 14 years burned predominately at moderate to high severity (fig. 3).

Fire Resistance in Relatively Restored Forests

Our study suggests that even fire-restored forests may not be resistant to high-intensity wildfire that escapes suppression during extreme weather conditions. All of our plots previously burned at low to moderate severity in the recent (1949–2011) fire record (table 1); high-severity burning during the Rim Fire left new high-severity burn patches in this landscape. Fire severity in reburns can depend strongly on the severity of previous fires (Parks and others 2013). Although areas that burned with high severity in previous fires are more likely to reburn with high severity, researchers have found a less consistent pattern for areas previously burned at low or moderate severity (Holden and others 2010; Parks and others 2013; Thompson and Spies 2010; van Wagtendonk and others 2012). Our study supports their finding. Char height from previous low- to moderate-severity fire was not associated with Rim Fire severity in our plots. Instead, we found that time since last fire, shrub cover, elevation, and the burning index were associated with Rim Fire severity (fig. 2), indicating that the interaction between fire history, understory, and fire weather influenced fire effects.

Most of the plots classified as high severity (10 out of 12) burned on a day when the fire was plume dominated and exhibited unprecedented fire growth for this region. The high burning index value of 85 recorded on this day reflects the greater potential for more intense fire behavior, but the contribution of high fuel loads outside our study site to fire energy presumably also contributed to the transition to plume-dominated fire. Local factors related to the plume's influence on surface wind dynamics, including increased speed and turbulence (Rothermel 1991; Werth and others 2011), likely affected fire intensity in our plots and may not be reflected in the burning index value derived from a weather station 12 miles (19 km) away. Interestingly, many plots burned at high severity despite multiple previous burns, suggesting the influence of the plume on fire behavior and, ultimately, fire severity. This suggests in turn that extreme fire behavior can overwhelm well-designed fuel treatments, as demonstrated in other extreme fire events (Finney and others 2003). Perhaps the extreme burning conditions created when untreated areas burn under weather conditions favorable to plume formation can create enough inertia to maintain high fire intensity in previously burned areas despite the ameliorated fuel conditions.

Time since fire and the burning index were also highly related to Rim Fire severity (fig. 2), in line with results from other studies on reburns (Collins and others 2009; Parks and others 2013; van Wagtendonk and others 2012). In our study, plots that had a previous fire within 14 years of the Rim Fire burned predominately at low severity (fig. 3), regardless of weather conditions. The reason might be that a longer time since the previous fire allows for the accumulation of surface (dead woody and live shrub/herbaceous) and ladder fuels, which then contribute to greater flame lengths and, ultimately, higher severity fire effects. For plots where the previous fire was more than 14 years earlier, burning under extreme fire weather conditions (with a burning index greater than 75 and on the day of plume-dominated burning) produced mainly high-severity fire effects, whereas moderate-severity burning occurred under milder conditions. This suggests that even in areas without recent fire activity, fires allowed to burn under conditions that are not extreme can benefit the ecosystem, assuming that moderate-severity fire effects are a desired objective (Collins and others 2011).

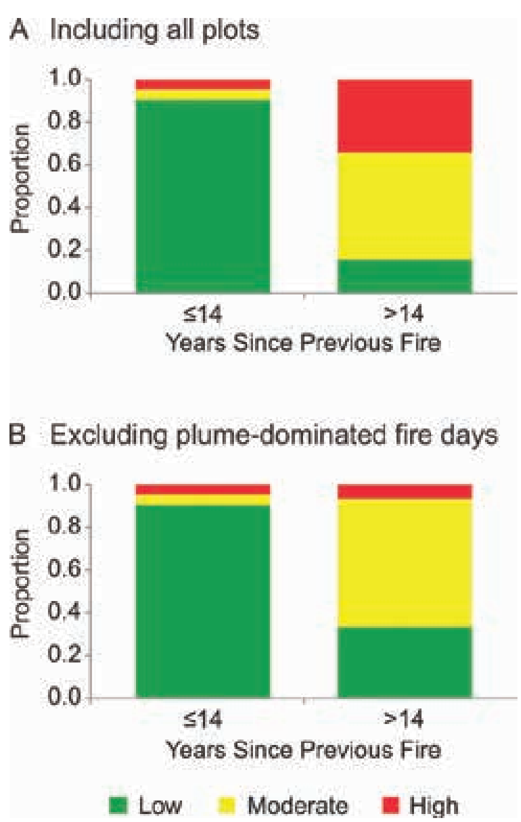

Figure 3—*Fire severity classes observed in plots reburned by the Rim Fire, by time since the previous fire. A comparison of A (showing all plots) to B (excluding plots burned on a day when the Rim Fire was plume dominated) suggests that plots without a fire in the previous 14 years are more susceptible to high fire severity during a plume-dominated fire.*

The inverse relationship of elevation and fire severity observed in our study was the opposite of what has been reported for other western forests (Parks and others 2013), but this may be due to the different vegetation, which also varied with elevation. Some of the lower elevation plots in our study corresponded to a drier vegetation type with greater shrub cover and sparser forest cover. The greater shrub cover coupled with sparser canopy may lead to an overestimation of fire severity, because consumption of the shrub layer might be high yet overstory mortality low, particularly in plots categorized as having moderate fire severity (Miller and others 2009). Without field data or some measure of overstory mortality and shrub regeneration, it is hard to determine to what extent high RdNBR values reflect ecological change, such as shifts in species composition or vegetation type (Holden and others 2010).

Implications for Management

Our results suggest that even in forests with a restored fire regime, wildfires can produce large-scale, high-severity fire effects under the type of weather and fuel conditions that often prevail when wildfire escapes initial suppression efforts. During the period when the Rim Fire had heightened plume activity, Results suggest that forests with restored frequent-fire regimes are resistant to wildfire under fire weather conditions that are less than extreme.

10 of the 17 plots burned were classified with high fire severity and 7 were classified with moderate severity. No low fire severity was observed, regardless of fuel load, forest type, or topographic position. High fire severity appears to have been exacerbated by the longer time period since the previous fire (greater than 14 years) in these plots.

Areas that burn at high severity often grow back as montane chaparral rather than forest. They are likely to reburn with high severity in future fires, preventing or delaying the return of tree cover (Parks and others 2013; Thompson and Spies 2010; van Wagtendonk and others 2012). Management actions can help conifer regeneration (Collins and Roller 2013); however, the vegetation trajectory of the high-severity burn patches found in the lower elevation sites in this study is uncertain, given projections of increasing wildfire activity, particularly since lower elevations may have higher burn probability (Parks and others 2011). Long-term monitoring of these patches could provide useful insight.

Plots located at higher elevations (5,590–6,550 feet (1,700–2,000 m)) and those that had burned more recently burned predominately at low severity, despite drought conditions at the time of the Rim Fire. Results suggest that forests with restored frequent-fire regimes are resistant to wildfire under fire weather conditions that are less than extreme. To effectively influence fire behavior, agencies should coordinate fuel reduction and wildfire policies across large landscapes if neighboring jurisdictions are within the same potential "fireshed." ■

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