Influences of Previous Wildfires on Change, Resistance, and Resilience to Reburning in a Montane Southwestern Landscape

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Land use legacies and climate have altered fire regimes across montane forests of much of the southwestern US (Allen and others 2002), and several recent wildfires have been extremely large and severe (Dennison and others 2014). Large openings resulting from high-severity fire in former ponderosa pine (*Pinus ponderosa*) and mixed conifer forests may be persistent given the lack of sufficient tree seed sources, climatic constraints on reproduction and survival, and competition from herbaceous and shrubby vegetation (Bonnet and others 2005; Haire and McGarigal 2010). Additionally, subsequent burning is hypothesized to reinforce vegetation changes originating from the initial fire (Savage and Mast 2005). Consequently, there are growing concerns that recent wildfires have exceeded thresholds of ecological resilience for these forests (Savage and Mast 2005).

In 2011, the 63,000-ha Las Conchas fire reburned portions of several earlier high-severity burns in the eastern Jemez Mountains of northern New Mexico. Montane forests in this landscape historically were largely composed of ponderosa pine and mixed-conifer types, and characterized by frequent, low-severity fires (Touchan and others 1996). Fires essentially ceased with the onset of heavy livestock grazing in the 1890's, until the 1977 La Mesa fire, which was the first in a series of increasingly large (6000-20,000 ha), severe fires to burn the area (Foxx and others 2013). The purpose of our research was to examine how previous fires influenced the Las Conchas burn pattern and attendant vegetation changes. We hypothesized that prior exposure to fire, across a range of burn severities, would (1) foster ecological resistance to subsequent wildfire via reduced reburn severity, imparted by changes in fuel type, availability, and continuity, and (2) enhance resilience to reburning via the establishment and maintenance of vegetation types better adapted to rapid post-fire recovery—meaning also that changes wrought by previous wildfires would be reinforced by subsequent reburning in the Las Conchas fire.

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Methods

We evaluated how fire severity of the Las Conchas fire varied by time since previous fire and severity of previous fire. Fire severity was measured using the delta normalized burn ratio (dNBR; Key and Benson 2006) and the relativized burn ratio (RBR; Parks and others 2014a), which are Landsat Thematic Mapper satellite-inferred measures fire-induced ecosystem change. For each pixel within the Las Conchas fire perimeter that reburned in a recent (since 1984) fire, we extracted the severity of the Las Conchas fire, time since previous fire, and severity of previous fire. Using both dNBR and RBR, we utilized linear models to test for the influences of previous burn severity and time since previous fire on the Las Conchas burn severity. To minimize the influence of spatial autocorrelation (Legendre and Fortin, 1989), we randomly subsampled our data at a frequency of 0.13%, and averaged p-values of 2500 models, following the methods described by Parks and others (2014b).

To examine relationships between previous wildfires, vegetation pattern, and vegetation change following the Las Conchas fire, we utilized field-sampled vegetation data from 335 plots sampled pre-Las Conchas (2003-2007; Muldavin and others 2011) and a subset of 80 of these plots that burned during the Las Conchas fire and were resampled in 2013. Pre-Las Conchas vegetation data were originally collected for a vegetation map of Bandelier National Monument; sampling methods are described fully in Muldavin and others (2011). Percent cover by all species and strata (tree, woody plants ≥ 5 m; shrub, woody plants < 5 m, includes tree seedlings and saplings; graminoid; and forb) were visually estimated in 20 x 20-m plots centered in vegetation polygons selected to maximize the range of variability captured by sampling while facilitating field sampling logistics (e.g., sampling plots in adjacent polygons with divergent vegetation types). Resampling was conducted utilized identical sampling methods.

[1] Severity of the 1977 La Mesa fire, which predated Landsat Thematic Mapper (TM) imagery, was quantified using dNDVI derived from Landsat Multispectral Scanner (MSS) imagery. We used the robust relationship between dNDVI and both dNBR and RBR from the Gila Wilderness ($r^2 > 0.7$; Parks and Holsinger, unpublished data) to calculate predicted values of RBR for the La Mesa fire.

Relationships between pre-Las Conchas vegetation and burn severity were assessed through non-metric multidimensional scaling (NMS). Burn severity at each plot location was extracted from the dNBR and RBR grids described above[1] using bilinear interpolation. To assess patterns of vegetation response to reburning by the Las Conchas fire, we tested for differences in burn severity and vegetation change in the 80 plots resampled in 2013 for four groups differentiated by NMS scores: (1) unburned forest, not previously impacted by wildfire; (2) savanna and meadow, with low densities of trees and high cover by native grasses, burned previously at low to moderate severity; (3) oak scrub, resprouting shrubs and trees that burned previously at moderate to high severity; and (4) ruderal burn, high-severity burn interior patches with variable dominance by seeded grasses and/or New Mexico locust (*Robinia neomexicana*). We used ANOVA to test for differences in previous burn severity, Las Conchas burn severity, and pre- to post-Las Conchas change in vegetation composition (Sørensen distance) and cover.

Results

Previous wildfires strongly modulated the impacts of the Las Conchas fire through influences on burn severity and patterns of vegetation change. Consistent with expectations and the findings of studies elsewhere (for example, Parks and others 2014b), Las Conchas burn severity was strongly reduced in previous burns—mean Las Conchas RBR was 118 in reburned pixels, in comparison with 194 in pixels that had not previously burned. Though there is high variability, linear models show that this effect diminished with time since previous fire and increased with previous burn severity (Fig. 1; $r^2 = 0.12$, $P < 0.05$, RBR model; $r^2 = 0.10$, $P < 0.05$, dNBR model, not shown). Prior to the Las Conchas fire, previous burns showed pronounced structural and compositional differences compared to unburned areas, including reduced conifer canopy cover, expanded cover by resprouting shrubs, and increased native and introduced grasses (Fig. 2). These communities showed striking and significant differences in subsequent burn severity and post-fire recovery (Table 1; only RBR presented; dNBR results were similar but are not shown). Forested stands that had not recently been affected by fire tended to burn most severely and exhibited the largest changes in community composition (Sørensen distance) and losses in cover (Table 1), while communities previously exposed to wildfire exhibited decreased burn severity and/or reduced impacts of fire on vegetation composition and cover (Table 1).

Discussion and Conclusions

Our findings illustrate both the self-limiting and self-reinforcing tendencies of wildfire-vegetation interactions (for example, McKenzie and others 2011). Reductions in fuel consumed by previous wildfires created negative feedbacks limiting subsequent burn severity. However, previous burn severity was also positively linked to Las Conchas burn severity (Fig. 1), indicating positive feedbacks mediated through vegetation composition and fuel structure. Lastly, as hypothesized by Savage and Mast (2005), shifts away from conifer forest and towards alternative vegetation types were reinforced by reburning; decreased losses and/or more rapid recovery of vegetation composition and cover in the second burn.

While prior wildfires underlay major shifts away from the forest types that formerly dominated the study landscape, they also engendered considerable resistance (reduced burn severity) and resilience (recovery to pre-Las Conchas conditions) to subsequent fire. These findings have implications for fire and fuels management and post-fire rehabilitation strategies. In particular, our findings support the view of wildfire as a fuel treatment that reduces subsequent burn severity, though these effects diminished over 20-30 years. Our findings also indicate that, even over a wide range of severities, prior exposure to recent wildfire increases the capacity of vegetation to absorb and recover from subsequent fire. While this is to be expected—and is the basis of restoration treatments—for open, savanna-like ponderosa and mixed conifer forests preconditioned for low-severity fire (for example, Allen and others 2002), it also applies to alternative vegetation types generated and maintained by high-severity fire, such as communities dominated by resprouting shrubs. As such, a policy of

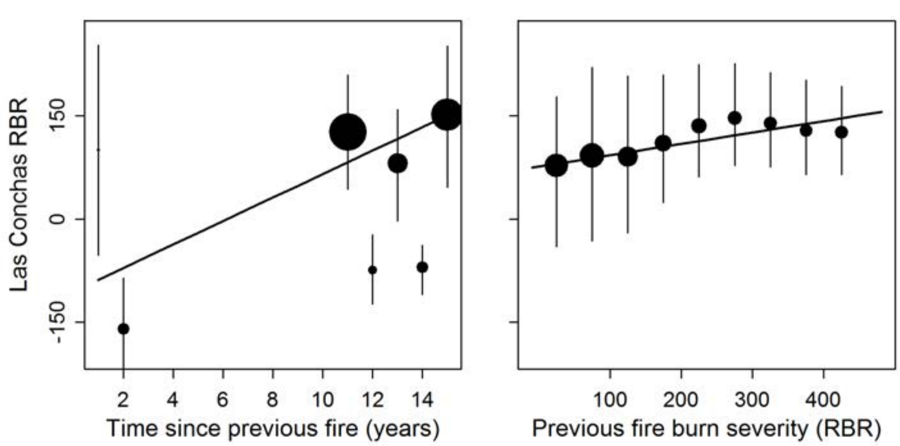

Figure 1—Relationships between the burn severity of previous wildfires, time since fire, and the severity of the Las Conchas fire. Shown are results from the model that utilized relative burn severity (RBR) as a metric burn severity; the dNBR model showed a similar relationship. Size of dots represents burn area for each year (time since previous fire) and bins representing 50 RBR units (previous fire burn severity); error bars represent 25th-75th percentile ranges.

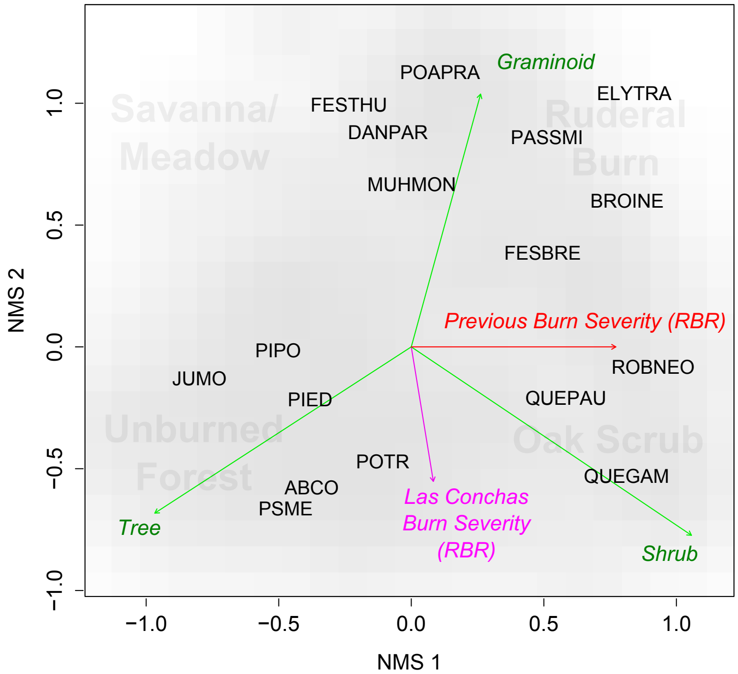

Figure 2—Non-metric multidimensional scaling (NMS) axes 1 and 2 of pre-Las Conchas vegetation. Axis 1 was closely related to previous burn severity. Axis 2 represents a transition from woody to grass-dominated communities, and is also negatively correlated with subsequent Las Conchas burn severity. Axis 3 (not shown) was strongly correlated with elevation. Vector direction and length indicates the correspondence and strength of relationships between vegetation, burn severity, and ordination axes. Locations of species codes indicates the centers of their distribution in ordination space. Species codes (4-letter codes for trees; 6 letter codes for shrubs and herbs) are as follows: ABCO, *Abies concolor*, JUMO, *Juniperus monosperma*; PIED, *Pinus edulis*; PIPO, *Pinus ponderosa*; POTR, *Populus tremuloides*; PSME, *Pseudotsuga menziesii*; BROINE, *Bromus inermis*, DANPAR, *Danthonia parryi*, ELYTRA, *Elymus trachycaulus*; FESBRE, *Festuca brevipila*; FESTHU, *Festuca thurberi*, MUHMON, *Muhlenbergia montana*; PASSMI; *Pascopyrum smithii*; POAPRA; *Poa pratensis*, QUEGAM, *Quercus gambelii*; QUEPAU; *Quercus pauciloba*; ROBNEO, *Robinia neomexicana*.

Table 1—Differences between pre-Las Conchas vegetation types in previous burn severity, Las Conchas burn severity, and changes in composition and cover two years after Las Conchas. Values given are means ± 1 standard deviation. Significant differences (Tukey's HSD <0.05) across vegetation types (rows) are indicated with different superscript letters.

	Group 1 Unburned Forest	Group 2 Savanna & Meadow	Group 3 Oak Scrub	Group 4 Ruderal Burn
Previous Fire Severity (RBR)	18.3 ± 63.4^{a}	58.3 ± 84.14^{ab}	190.3 ± 146.6^{bc}	272.0 ± 202.3^{c}
Las Conchas Burn Severity (RBR)	325.0 ± 174.8^{a}	10.6 ± 176.2^{b}	229.7 ± 121.2^{a}	75.9 ± 157.5^{b}
Compositional Distance	0.76 ± 0.17^{a}	0.42 ± 0.22^{b}	0.55 ± 0.19^{b}	0.55 ± 0.17^{b}
Cover Change	-52.8 ± 42.7^{a}	-31.3 ± 28.9^{ab}	-42.9 ± 37.4^{ab}	-19.7 ± 39.3^{b}

perpetual fire exclusion may both exacerbate severity and reduce resilience to inevitable future fire.

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