DO POST-FIRE MULCHING TREATMENTS AFFECT REGENERATION IN SEROTINOUS LODGEPOLE PINE?

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ABSTRACT	RESUMEN
Broadcast mulching is a widely implemented post-fire erosion control method, although it remains uncertain how it affects post-fire regeneration in serotinous conifers. We used field data and unbiased conditional inference trees with random effects to test if mulching affects lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm. ex S. Watson) regeneration following a wildfire in northern Colorado, USA. Our results suggest that post-fire application of straw mulch may have modest beneficial effects for regenerating lodgepole pine. However, these effects were minor compared to other spatial predictors of seedling density, including whether or not tree crowns were consumed in the fire and the presence of post-fire needle cast. These results suggest that post-fire mulching treatments in lodgepole pine ecosystems will have minimal effect on tree regeneration, and that managers need not be concerned about hindering regeneration when considering whether to use straw mulch for post-fire erosion mitigation in this forest type.	El desparramado de mulching es un método ampliamente implementado para controlar la erosión post-fuego, a pesar de que es incierto el cómo afecta la regeneración en coníferas serotinas luego de un incendio. Usando datos de campo e inferencias sobre árboles testigo no sesgados con efectos aleatorios, determinamos si el mulching afecta la regeneración del pino contorta (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm. ex S. Watson), después de un fuego natural en el norte de Colorado, EEUU. Nuestros resultados sugieren que la aplicación de mulch post-fuego puede tener efectos benéficos modestos para la regeneración de pino contorta. Sin embargo, estos efectos fueron menores comparados con otros predictores espaciales de densidad de plantines, incluyendo el hecho de que las copas de los árboles hayan sido consumidas o no durante el fuego, y por la presencia de acículas secas post-fuego. Estos resultados sugieren que los tratamientos post-fuego en ecosistemas de pino contorta tendrán un efecto mínimo en la regeneración, y que los gestores no necesitan preocuparse por la regeneración que podría perturbar la posibilidad de utilizar paja como mulch para mitigar la erosión post-fuego en este tipo forestal.

INTRODUCTION

Dry mulches are commonly applied following wildfire to mitigate post-fire erosion (Robichaud *et al.* 2010) until recovery of local vegetation stabilizes soils (Kruse *et al.* 2004). Moisture retained by mulch may be beneficial to regenerating vegetation in water-stressed areas (Fernandez *et al.* 2016), whereas deep mulch applications may inhibit vegetation establishment by creating physical barriers for germination or emergence (Cirelli *et al.* 2016) or by reducing the availability of key resources such as light and nitrogen (Kruse *et al.* 2004). However, whether straw mulch hinders the post-fire regeneration of serotinous conifer species such as Rocky Mountain lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm. ex S. Watson) remains unclear. Serotinous lodgepole pine trees release stored seed en masse from the canopy soon after a fire event (Lotan and Critchfield 1990). Thus, seedlings may have the opportunity to establish prior to the application of mulch, allowing them to avoid the negative effects of mulching treatments more easily than do seedlings of other conifer species.

In this study, we investigated how post-fire mulching treatments influenced the regeneration success of lodgepole pine following a 2012 wildfire in Colorado, USA. We used field data collected two years after the fire to examine whether or not straw mulch, which was applied within one year of the fire event, affected the abundance of lodgepole pine seedlings.

METHODS

Study Area

The High Park Fire was located in Larimer County at the northern end of the Front Range, Colorado (Figure 1). The fire was ignited by lightning on 9 June 2012 and burned more than 35 000 hectares over the course of 22 days (NWCG 2012). The burned area included approximately 5000 hectares of mature lodgepole pine. Soil burn severity was high in much of the area that had been dominated by lodgepole pine, leading the Burned Area Emergency Response (BAER) team to recommend extensive aerial mulching treatments within severely burned areas, particularly those with steep slopes or where excessive erosion would threaten public health or safety (NWCG 2012). The initial treatments were completed during April 2013, less than one year after the fire event but prior to the two-
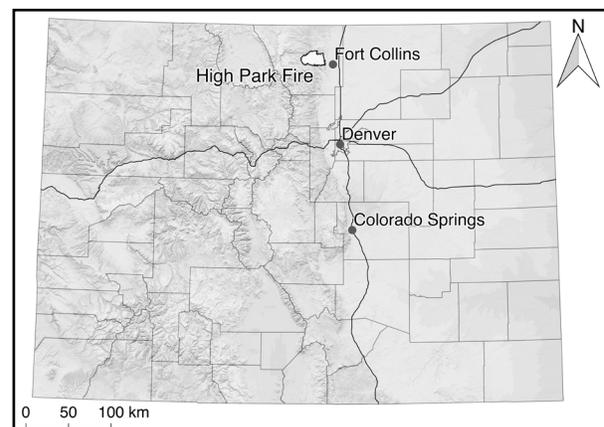

Figure 1. Map of Colorado, USA, showing the location and extent of the High Park Fire. The burned area is the area in white to the west of Fort Collins. Fire perimeter data created by Stone (2015).

year seedling germination pulse that has been observed in lodgepole pine ecosystems (Turner *et al.* 1999). Most of the treatments utilized straw mulch. While some of the fire area was mulched with wood, small sample sizes prevented us from considering wood mulch.

Data Collection

Twelve field sites were sampled between June and August 2014 as part of a larger study on the combined effects of mountain pine beetle (MPB; *Dendroctonus ponderosae* Hopkins) mortality and fire on lodgepole pine regeneration. We located the study sites randomly, stratifying for MPB mortality and crown consumption based on 25 m resolution raster layers created by Stone (2015). During the stratification, we elected to combine the low and moderate burn severity classifications because moderate severity areas occupied narrow transition zones surrounding high severity patches, and both low (minimal needle scorch) and moderate (needles mostly scorched) severity represented the effects of surface fire (Stone 2015). We did not stratify field sites based on the presence of mulch; instead, we recorded mulch cover as we encountered it within the field sites. At each field site, we systematically placed a 25 cm × 25 cm quadrat every 10 m within a 70 m × 70 m (approximately 0.5 hectare) grid, for a total of 64 quadrat locations per site (with the exception of the first site, which was 100 m × 100 m). In each quadrat, we recorded lodgepole pine seedling abundance, and visually estimated cover percentage of the following variables: mulch, litter, total vegetation, and growable area. Litter cover consisted largely of post-fire needlecast, as there was little unburned litter in the study area. Growable area is the inverse of rock + coarse wood cover (i.e., the portion of the quadrat in which a seedling could conceivably establish).

We included other covariates known to explain the distribution of post-fire lodgepole pine seedlings (Wright 2016). To estimate the potential seed source surrounding each quadrat, we used a wedge prism to record the basal area of lodgepole pine that bore cones. We also field-verified our crown consumption variable using the wedge prism to create a binary variable classifying whether the tree crowns at each quadrat location had been consumed. If fewer than 50 % of the trees tallied with the basal area prism retained needles at the time of sampling, that quadrat site was classified as high crown consumption. Otherwise, quadrat sites were classified as low crown consumption. Typically, tree crowns were either fully consumed or intact due to the stratified sampling design, which located sites in areas of more or less uniformly high or low crown consumption. We relied on the remotely sensed pre-fire MPB layer created by Stone (2015) to classify MPB mortality as "high" in a site if greater than 50 % of the pixels within that site were classified as MPB mortality; otherwise it was classified as "low." Most sites had close to 0 % or 100 % MPB mortality—again because our original site stratification selected areas with a uniform MPB mortality classification. We recorded the quadrat slope by placing an inclinometer along the quadrat frame. We calculated site-level elevation by averaging elevation data extracted from a 25 m digital elevation model (Stone 2015).

Analysis

We restricted our analysis to field sites in which at least one quadrat had been treated with straw mulch. Additionally, quadrats with growable area of less than 10 % were excluded from the analysis, leaving a total of 783 quadrats distributed over 12 sites. We used unbiased conditional inference trees with random effects (unbiased RE-EM trees; Fu and Simonoff 2015) to examine the drivers of lodgepole pine seedling abundance. Unbiased RE-EM tree algorithms improve upon previously available models by incorporating conditional

inference for recursive partitioning, which is less prone to bias than other recursive partitioning algorithms such as CART (classification and regression trees; Breiman *et al.* 1984), assumes no underlying distribution in the data, and does not require pruning to avoid over-fitting (Hothorn *et al.* 2006).. Additionally, unbiased RE-EM trees also incorporate random effects, which allows for the analysis of grouped data (Sela and Simonoff 2012, Fu and Simonoff 2015). We specified site as the random effect; all other variables were treated as fixed effects. All statistical analyses were performed in R (R Core Team 2015) using a function for unbiased RE-EM trees developed by Fu and Simonoff (2015).

counts (averaging 6 seedlings per quadrat, Figure 2) were found in quadrats that had abundant post-fire litter and elevations below 2648 m.

The lowest seedling counts were predicted to occur in quadrats in which tree crowns had been consumed and potential seed source was limited (averaging <1 seedling per quadrat). Where the tree crowns were not consumed, mulch cover was the discriminating variable, resulting in the second highest average seedling abundance predicted by the model (<3 seedlings per quadrat). The model explained approximately 30 % of the variation in lodgepole pine regeneration ($r^2 = 0.301$). No other variables were selected by the model.

RESULTS

Our model suggested that post-fire litter cover had the most discriminating power for seedling abundance. The highest seedling

DISCUSSION

Our data suggest that straw mulch may have modest beneficial effects for lodgepole pine regeneration, but only following burning
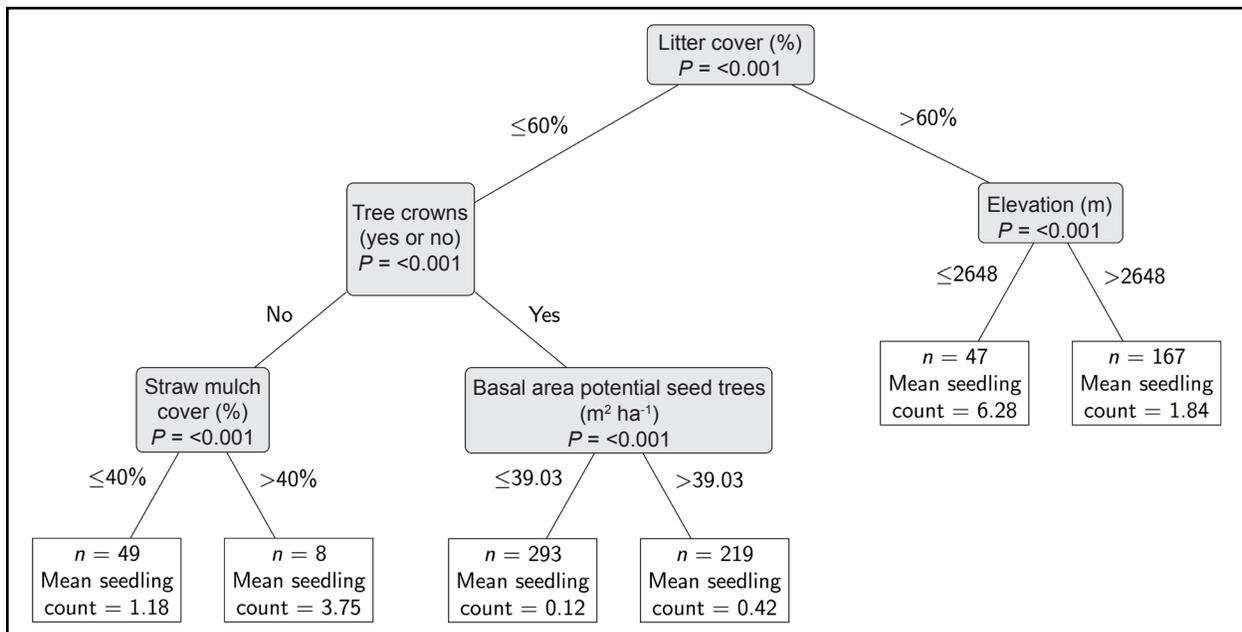

Figure 2. Plot of unbiased RE-EM tree. Each inner node (gray boxes) represents the partitioning variable, while the values for each partition are shown on the edges (lines) between the nodes. *P*-values in the inner nodes refer to tests of independence between the predictor and response. Mean predicted seedling abundance (mean seedling count) and sample size (*n*) are given in the terminal nodes (white boxes). Straw mulch had a modest benefit for lodgepole pine regeneration, but only when tree crowns were not consumed.

conditions that are already known to be favorable for lodgepole pine establishment—namely, when burning conditions are sufficient to release, but not destroy, the seed in the canopy seed bank (Anderson and Romme 1991, Turner *et al.* 1999, Schoennagel *et al.* 2003, Harvey *et al.* 2014). The positive relationship that we observed between straw mulch cover and lodgepole pine seedling abundance may be a result of increased soil moisture and lower soil temperatures typically associated with mulch applications (Amaranthus *et al.* 1993, Dodson and Peterson 2010, Santana *et al.* 2014). These mechanisms may also be at play in the strong relationship between post-fire litter and seedling abundance. However, areas with more post-fire litter also had more needles remaining in the crowns of surrounding trees, making it difficult to separate this effect from the overriding influence of fire in the canopy. While the mechanism behind the effects of elevation on seedling abundance in these high-litter areas remains uncertain, high-litter quadrats at elevations less than 2648 m had more cone-bearing trees on average than similar quadrats above 2648 m (data not shown), suggesting that differences in elevation may

have been confounded by differences in the potential seed source.

The relationship between mulch and post-fire lodgepole pine regeneration is likely influenced by additional factors that we were not able to measure. Mulching treatments may introduce non-native species (Kruse *et al.* 2004, Robichaud *et al.* 2010), which have been shown to compete with and inhibit the growth of native species (Harrod and Reichard 2000). While we did not separate native and introduced species, we did not detect any influence of competing vegetation as a whole. It is possible that mulch limited the establishment of competing vegetation at our sites (Amaranthus *et al.* 1993). Mulch may also be beneficial to post-fire regeneration by moderating any detrimental effects of erosion, especially during extreme runoff events. Indeed, field observations suggested that seedling abundance varied with apparent erosion and deposition of mineral soil.

Overall, these results suggest that post-fire mulching treatments do not negatively influence the post-fire recovery process in this forest type, and may even enhance regeneration under moderate burning conditions.

ACKNOWLEDGEMENTS

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