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Relationships between tree stand density and burn severity as measured by the Composite Burn Index following a ponderosa pine forest wildfire in the American Southwest

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ABSTRACT

The Trigo fire burned 5548 ha of the Manzano Mountains in central New Mexico in 2008. The fire burned with mixed severity through ponderosa pine (*Pinus ponderosa*) stands on the Cibola National Forest and private lands. The burned area exhibited a range of stand densities enabling this research to quantify the relationship between variation in tree density and burn severity using the Composite Burn Index (CBI) severity classification. Across 90 CBI plots, high tree density was strongly associated with high burn severity. The CBI method allowed classification of burn severity to a range of forest vertical fuels strata. Tree mortality and duff consumption are two attributes that recorded higher severity in plots with higher tree densities. The CBI approach is designed for rapid on-the-ground assessments; to compliment this procedure a rapid visual classification of stand density was tested to determine its accuracy for land managers. This visual assessment correlated well with quantitative measurements of tree density. Since density classes were also highly correlated with CBI scores they may therefore be a good predictor of burn severity in a stand. This is a more rapid way for land managers to categorize stand density than traditional density measurements. These findings demonstrate that reducing tree density in southwestern ponderosa pine stands may significantly lower burn severity resulting from wildfire.

1. Introduction

Ponderosa pine (*Pinus ponderosa*) forests in the American Southwest have experienced dramatic changes in physical structure, species composition, and ecological processes over the last century (Allen et al., 2002; Cooper, 1960; Covington et al., 1997; Fulé et al., 1997). Before Euro-American settlement, southwestern ponderosa pine forests were composed of low-density, park-like stands (Covington and Moore, 1994a) with dense grass understory and highly flammable leaf litter (Stone et al., 1999). Historically these forests experienced frequent low-severity surface wildfire (Kaufmann et al., 1998), creating heterogeneous forest spatial patterns at local and landscape scales (Allen et al., 2002). Disruption to the natural fire regime, harvesting, and intensive domestic livestock grazing practices of those forests have drastically altered their historic structure and has made them extremely vulnerable to unnaturally severe stand-replacing wildfires (Covington and Moore, 1994b; Swetnam et al., 1999), water stress, insect outbreaks (Kolb et al., 1998), and other deviations from historic conditions (Allen et al., 2002; Covington et al., 1997; Friederici, 2003; Moore et al., 2004).

In many watersheds throughout the Southwest, over 90% of ponderosa pine forests are considered at high risk of crown fires because of dense structure and unnaturally high levels of accumulated fuels (Allen et al., 2002; Covington and Moore, 1994a, 1994b). A major goal of ponderosa pine forest restoration is to renew natural stand structure and ecosystem function within a range of natural variability (Landres et al., 1999) and reverse unhealthy forest characteristics. Restoration usually includes some combination of reducing high-density stands through thinning, reintegrating natural disturbance through prescribed burning, and increasing species diversity and cover of native herbaceous understories (Brockway et al., 2002; Covington et al., 1997; Korb et al., 2003). Current understanding of fire behavior in the dry ponderosa pine forests of the Southwest is that crown fires occur as a transition from a surface fire to a crown fire, via ladder fuels (Graham et al., 2004), that then spread through the canopies, consuming tree crowns. Fuel management objectives therefore target the break down of fuel continuity both vertically and horizontally (Hunter et al.,

Abbreviations: CBI, Composite Burn Index; BAER, Burned Area Emergency Response.

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2007). The Southwest Forest Health and Wildfire Prevention Act (2004) (Public Law 108-317) was passed by the US Congress in 2004, outlining forest management measures to reduce the risk of wildfire to forests and municipalities in the Southwest. Forest thinning and prescribed fire treatments are recommended to improve overall forest health by enhancing wildlife habitat and biodiversity of forest communities; increasing tree growth and grass, forb, and shrub productivity; enhancing watershed values; and providing a basis for economically and environmentally sustainable forest uses.

A number of studies has evaluated the effectiveness of forest thinning on fire intensity and severity in southwestern ponderosa pine forests (Cram et al., 2006; Fulé et al., 2002, 2005; Pollet and Omi, 2002; Strom and Fulé, 2007), and all draw the common conclusion that untreated forests are at a higher risk of severe wildfire than treated areas. Agee and Skinner (2005) suggest that in order to make forests resilient to catastrophic wildfire, some form of forest thinning is required. The authors propose that forest treatments to reduce fire severity comprise four basic principles: (1) reduce surface fuels using mechanical methods or prescribed fire; (2) increase the height to the live crown; (3) decrease the crown density, reducing the chance of crown fire spread; and (4) keep mature trees of fire-resistant species (e.g., ponderosa pine) that would reduce overall mortality in the event of surface fire and move the forest back to historical stand structures.

Pollet and Omi (2002) suggest that the removal of small-diameter trees may be beneficial for reducing crown fire hazard in ponderosa pine sites. Prescribed fire may be effective at reducing these small-diameter trees, but only after some form of mechanical thinning has occurred to prevent these mid-canopy trees transmitting fire to the overstory canopy. In Pollet and Omi's (2002) study of four fires throughout western North America, treated stands with lower densities and larger trees have experienced lower burn severities than untreated stands. The authors attribute those findings to less continuous crowns and ladder fuels in stands with fewer trees (i.e., ladder fuels provide vertical continuity between the surface fuels and crown fuels, increasing the likelihood of torching and crowning [Pollet and Omi, 2002]). Cram and Baker (2003) have found similar results in that treatment areas up to 20 years old experience lower burn severity, ground char, and fireline intensity during wildfire. The researchers find that crown damage and fireline intensity are positively related to basal area and density. Similarly, Strom and Fulé (2007) have found that average tree density is substantially greater in untreated areas, and following a wildfire about half the trees survive in treated areas compared to only 5% in untreated areas.

The measure of burn severity in empirical studies has been complicated by its numerous definitions in the literature (Chappell and Agee, 1996; Lutes et al., 2003; Lyon and Stickney, 1976; Wang, 2002; Wells et al., 1979; Neary et al., 2005; Cocke et al., 2005), and as a result no universal measure of burn severity exists (Key and Benson 2006). Instead metrics are adopted for studies based on ecological and management objectives and scale (Cocke et al., 2005). One of the most applicable of definitions comes from Ryan and Noste (1983), who suggest that severity classification should be a combination of soil and overstory effects, stating that burn severities are fire effects that incorporate both upward (fireline intensity) and downward (heat per unit area) heat pulses. This incorporates parameters that are readily measurable. It is well accepted that burn severity essentially integrates the physical, chemical, and biological changes occurring in an area as a consequence of fire (White et al., 1996). Fire can have immediate effects on the aerial sections of trees, with canopy height dictating the impact from the flames. Applying the Ryan and Noste (1983) definition, burn severity to trees is related to the intensity of the fire (flame length). However, it is important to note that the most severe fires might not always be the ones in which a forest canopy is completely consumed. Damage to the underlying duff and forest floor may be more destructive to future tree regeneration. This emphasizes the relevance of measuring severity in more than one stratum.

In 1999, Key and Benson (1999) introduced the Composite Burn Index (CBI). Although this index was developed to provide a standardized method of burn severity classification and to overcome the ambiguity inherent in the literature, Key and Benson (2006) acknowledge that CBI does not represent the 'true' severity. Key and Benson (2006) describe burn severity as the magnitude of change to components existing at the time of the fire. Instead of focusing on individual strata as have past methods (Chappell and Agee, 1996; Whittle et al., 1997), the CBI adopts a multi-strata approach to severity, because according to Key and Benson (2006), vertical levels in a forest have different biophysical components and multiple levels impart structural complexities that profoundly influence fire behavior. Key and Benson (1999) suggest that ratings that incorporate all strata seem to improve the overall measure of severity because they incorporate damage to both the ground, surface and canopy layers (Key and Benson, 1999). CBI is described as being suitable for use in a variety of forest and woodland types, and thus is readily transferable between sites and the standard measuring tools ensure repeatability (Cocke et al., 2005; Lutes et al., 2003). A major focus of CBI is that it is considered to be a more cost-effective, efficient approach to burn severity monitoring, relying on visual assessment of conditions. CBI is designed specifically to be used in monitoring large-scale burns (Key and Benson, 1999), typically in conjunction with an imaging differencing methodology – Normalized Burn Ratio (NBR)(Key and Benson (2006)) which assesses differences in bands 4 and 7 from pre-fire and post-fire remote sensed images. CBI was developed as a means of ground truthing these images on large scale burns. The Trigo fire burned 5548 ha of the Manzano Mountains in central New Mexico in April and May 2008. The fire burned in ponderosa pine and mixed conifer forests, with mixed severity, and most of the area burned during singular wind-dominated runs (most notably a run on April 30, 2008). At the time of the fire researchers were involved in an un-related long-term study on the impact of hazardous fuels reduction on watershed health and water yield. Research plots from that longterm study were burned by the Trigo fire, providing the opportunity to investigate the impact of fire on watershed processes. Since that original research focused on the effect stand density had on watershed processes, similarly this wildfire provided us with the opportunity to quantify the relationship between ponderosa pine density and burn severity. Previous studies that have measured the effect of thinning treatments on burn severity have noted that treatment and control plots can often exhibit similar stand characteristics in terms of density and basal area (Pollet and Omi, 2002; Skinner et al., 2004; Strom and Fulé, 2007). The Trigo fire burned across private and public US Forest Service lands with various treatment histories and previous thinning prescriptions, resulting in a landscape of variable tree densities, including treated areas and untreated stands with similar tree densities. This variable treatment history hindered the direct comparison of stands based on pre-fire treatment status alone. Instead this study evaluates the burn severities recorded among a range of tree densities in stands that may be treated or untreated. The hypothesis of this study was that denser stands (those with more trees per hectare) experienced greater degrees of burn severity when compared to less dense stands.

In addition to studying the impact that tree density has on burn severity, this study also tested the utility of a rapid methodology for tree density classification to expedite assessments of density by land managers. A qualitative ocular methodology was compared to standard density measures to determine its accuracy and utility.