Fire Effects on Tree Overstories in the Oak Savannas of the Southwestern Borderlands Region

Peter F. Ffolliott, Gerald J. Gottfried,
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Research Paper RMRS-RP-86

United States Department of Agriculture / Forest Service
Rocky Mountain Research Station
May 2011

Ffolliott, Peter F.; Gottfried, Gerald J.; Stropki, Cody L.; Chen, Hui; Neary, Daniel G. 2011. **Fire effects on tree overstories in the oak savannas of the Southwestern Borderlands Region.** Res. Pap. RMRS-RP-86. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Abstract

Effects of cool-season and warm-season prescribed burning treatments and a wildfire on tree overstories in oak savannas on the Cascabel Watersheds of the Southwestern Borderlands Region are reported in this paper. Information on the initial survival, levels of crown damage, species compositions and densities, annual growth rates, and basal sprouting following these burning events is presented. Impact of the fires on spatial distributions of trees in the overstories is also described. These events were all of low fire severities. As a consequence, effects of the prescribed burning treatments and the wildfire on tree overstories of the watersheds were similar and, therefore, the data sets were pooled. Effects of these fires on the tree overstories were mostly minor and often insignificant in terms of management implications.

Keywords: fire effects, oak savannas, prescribed burning, southwestern United States, tree overstories, wildfire

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Acknowledgments

The research results presented in this paper were supported by the Southwestern Borderlands Ecosystem Management Unit of the Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona; and the Arizona Agricultural Experiment Station, University of Arizona, Tucson.

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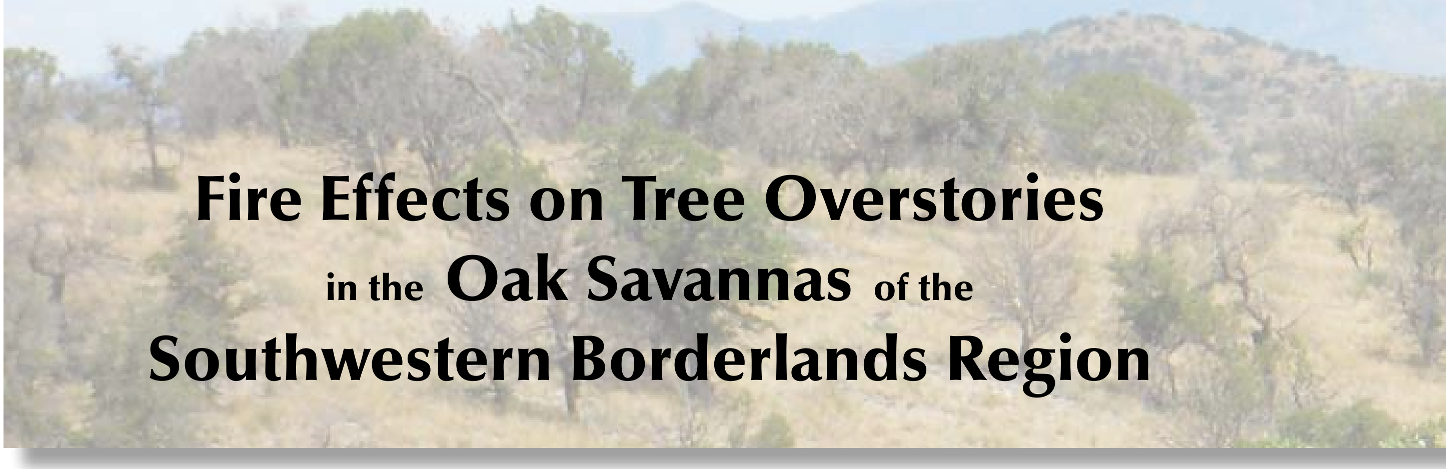

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Contents

Introduction

Fire was a natural part of the ecosystems of the Southwest Borderlands before Euro-American settlement of the Region. Fires caused by lightning activity in the spring and early summer, before the onset of monsoon rains, limited establishment of trees and maintained a diverse landscape of grasslands, savannas, and woodlands. Tree-ring evidence suggests that fires occurred every 5 to 10 years in the ecosystems along the United States-Mexico border prior to settlement (Kaib and others 1999). However, natural fire frequencies, their burning characteristics, and subsequent impacts on ecosystem resources have been altered since the late 1800s, largely because of past livestock grazing practices that removed significant portions of the fire-carrying herbaceous vegetation and because of past (aggressive) fire suppression policies of management agencies (Fulé and Covington 1995, Edminster and others 2000). These past practices and policies have resulted in unnaturally high tree densities on many sites, making trees more susceptible to insects, diseases, and stand-replacing wildfire and causing a decline in herbaceous plants in the understories. Excessive accumulations of flammable surface fuels are also found in the Region, and mesquite (*Prosopis*) and other woody plants have invaded many otherwise productive grasslands.

As a consequence of the generally undesirable conditions often encountered, land management agencies with support from their collaborators, including private organizations and local stakeholders, are interested in re-introducing more historical fire regimes into many of the ecosystems in the Region (Edminster and Gottfried 1999, Gottfried and others 2000, 2007, Gottfried and Edminster 2005). Included among these ecosystems are oak savannas—plant communities that are situated between the higher-elevation, more densely stocked oak woodlands and lower-elevation grassland and shrub communities. However, managers need more information about the impacts of burning on ecosystem resources in the oak savannas before they can initiate such a program. A first step in the process of obtaining this information is to evaluate the effects of prescribed burning treatments on ecosystems resources, specifically the important tree overstories.

The effect of cool-season (November through April) and warm-season (May through October) prescribed burning treatments and of a wildfire on tree overstories in the oak savannas of the Malpai Borderlands, an area of approximately 802,750 acres within the larger Southwestern Borderlands Region (fig. 1), is the focus of this paper. The information presented is useful in developing management strategies necessary for a re-introduction of more natural fire regimes into the oak savannas in order to increase site productivity and landscape diversity while maintaining environmental integrity.

Cascabel Watersheds

Twelve small watersheds, ranging from 20 to almost 60 acres in size, in the Peloncillo Mountains of southwestern New Mexico (Gottfried and others 2000, Gottfried and Edminster 2005) collectively comprise the study area (fig. 1). The areal aggregation of these watersheds, called the Cascabel Watersheds, is 451.3 acres. The watersheds are situated between 5380 and 5590 feet in elevation. The nearest long-term precipitation station indicates that annual precipitation averages 23.5 inches, with nearly one-half of the precipitation occurring in the summer monsoonal season between June 15 and September 30. However, a prolonged drought impacted the area from the middle of the 1990s through the time of the burning events on the watersheds. Precipitation during this drought period averaged 14.9 inches annually.

Emory oak (*Quercus emoryi*) was the dominant tree species in the overstories on the watersheds before the burns, followed by alligator juniper (*Juniperus deppeana*). Intermingling Arizona white (*Q. arizonica*) and Toumey *(Q. toumeyi*) oak, redberry juniper (*J. coahuilensis*), border pinyon (*Pinus discolor*), and the tree form of mesquite (*Prosopis glandulosa* var. *torreyana*) were minor overstory components (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). In this paper, the term "tree overstories" refers to these tree species regardless of their respective size or position in the canopy.

Perennial grasses were blue (*Bouteloua gracilis*), sideoats (*B. curtipendula*), slender (*B. repens*), and hairy *(B. hirsuta*) grama; bullgrass (*Muhlenbergia emersleyi*); common wolfstail (*Lycurus pheoides*); and Texas bluestem (*Schizachyrium cirratum*). Forb species of mariposa lily (*Calochortus* spp.), verbena (*Verbena* spp.), and lupine (*Lupinus* spp.) were minor components of the understory plants. Beargrass (*Nolina microcarpa*), fairyduster (*Calliandra eriophylla*), common sotol (*Dasylirion wheeleri*), manzanita (*Arctostaphylos pungens*), Fendler's ceanothus (*Ceanothus fendleri*), and Mexican cliffrose (*Purshia mexicana*) were among the occasional half-shrubs and shrubs. Shrub forms of mesquite were present on many sites. Palmer's century plant (*Agave palmeri*) and banana yucca (*Yucca baccata*) were scattered succulents on rocky slopes. Annual plants were largely absent.

Geologic, physiologic, and hydrologic characteristics of the Cascabel Watersheds are described elsewhere by Gottfried and others (2000, 2007), Hendricks (1985), Neary and Gottfried (2004), Osterkamp (1999), Robertson and others (2002), Vincent (1998), and Youberg and Ferguson (2001). Bedrock geology is Tertiary rhyolite overlain by Oligocene-Miocene conglomerates and sandstone. Soils are classified as Lithic Argustolls, Lithic Haplustrolls, or Lithic Ustorthents. These shallow soils are generally less than 20 inches to bedrock. Streamflows originating on the watersheds are intermittent with the larger flows generated by storms of high-intensity rainfall (Gottfried and others 2006).

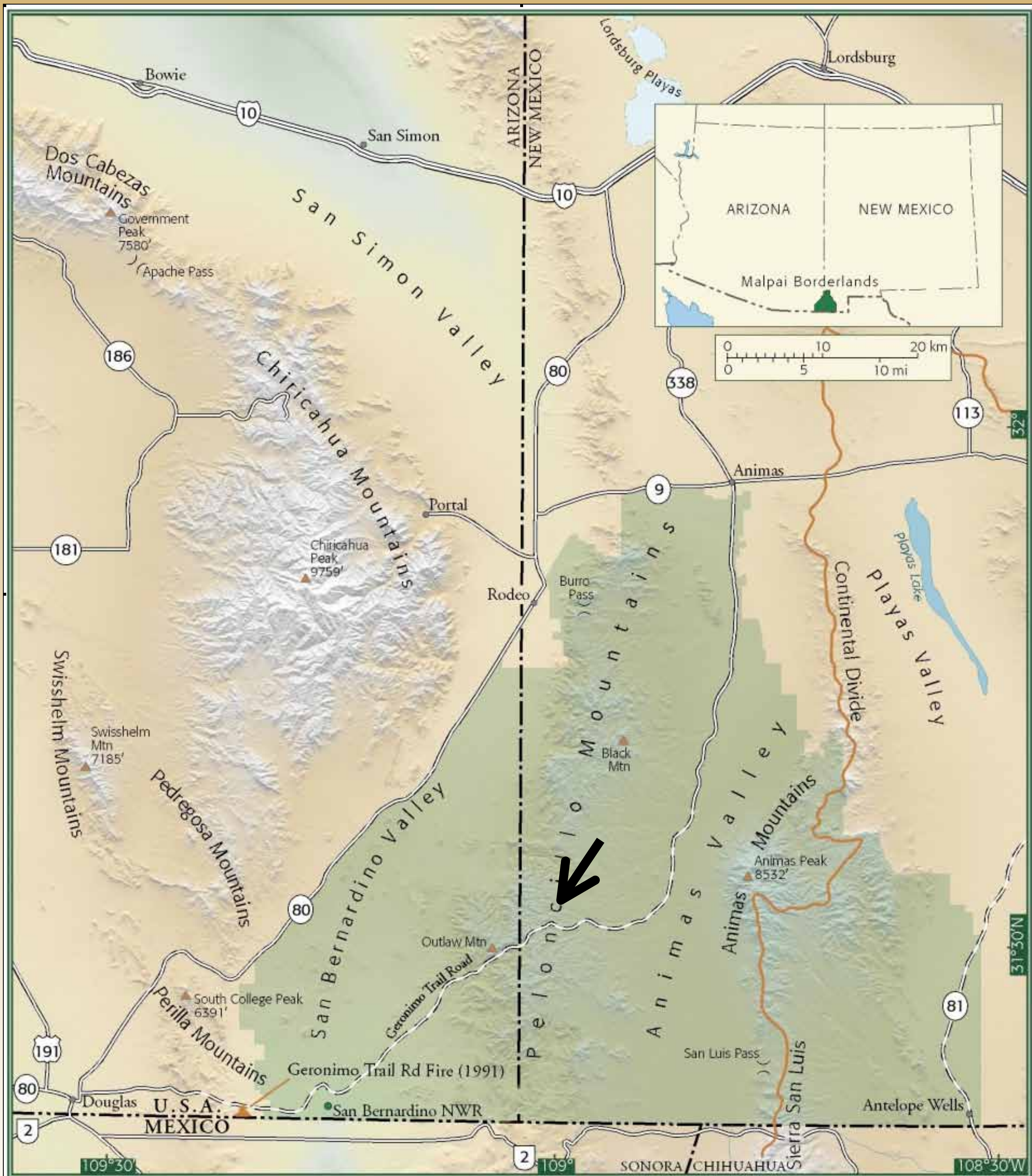


Figure 1. The Cascabel Watersheds (arrow) are located in the oak savannas of the Malpai Borderlands (shaded area), an area of approximately 802,750 acres within the larger Southwestern Borderlands Region (from Ffolliott and others 2008b).

Prescribed Burning Treatments and the Wildfire

The original objective of the research program on the Cascabel Watersheds was to evaluate the effects of warm-season (May through October) and cool-season (November through April) prescribed burning treatments on the natural resources of the watersheds, including the tree overstories. It was anticipated that these evaluations would be compared to control (unburned) watersheds in determining the fire effects. Following the required watershed calibration period, four of the watersheds (Watersheds C, H, K, and N) were burned during the cool-season in early March 2008 (fig. 2). Three of the four watersheds designated for warm-season burning (Watersheds A, E, and F) were ignited on May 20, 2008, and the fourth watershed (Watershed I) burn was delayed until a later date because of shifting weather conditions (table 1). However, wind gusts up to 60 mph on the morning of May 21, 2008, blew firebrands onto the remaining watershed that was scheduled for warm-season burning and onto the four control watersheds. The resulting wildfire, designated the Whitmire Wildfire, crossed the boundary lines of the watersheds and spread beyond them, burning almost 4000 acres. Average atmospheric conditions during the prescribed fires and wildfire are presented in table 1. The original objective of the research on the Cascabel Watersheds had to be modified, therefore, to evaluate the effects of cool-season and warm-season prescribed burning treatments as well as the Whitmire Wildfire on tree overstories of the watersheds (fig. 2).

Table 1. Average atmospheric conditions from 0700 to 1800 hours during the prescribed burning treatments and wildfire on the Cascabel Watersheds. The information presented in the table was obtained from a weather station located in the middle of the aggregated watershed area.

Treatment	Date	Temperature (°F)	Relative humidity (%)	Wind speed (MPH)
Cool season	March 4	56.2	15.6	4.7
Cool season	March 11	62.5	20.2	3.4
Warm season	May 20	89.7	15.8	8.3
Wildfire begins	May 21	85.3	15.6	17.1

Cascabel Watershed Boundaries and Treatment Types

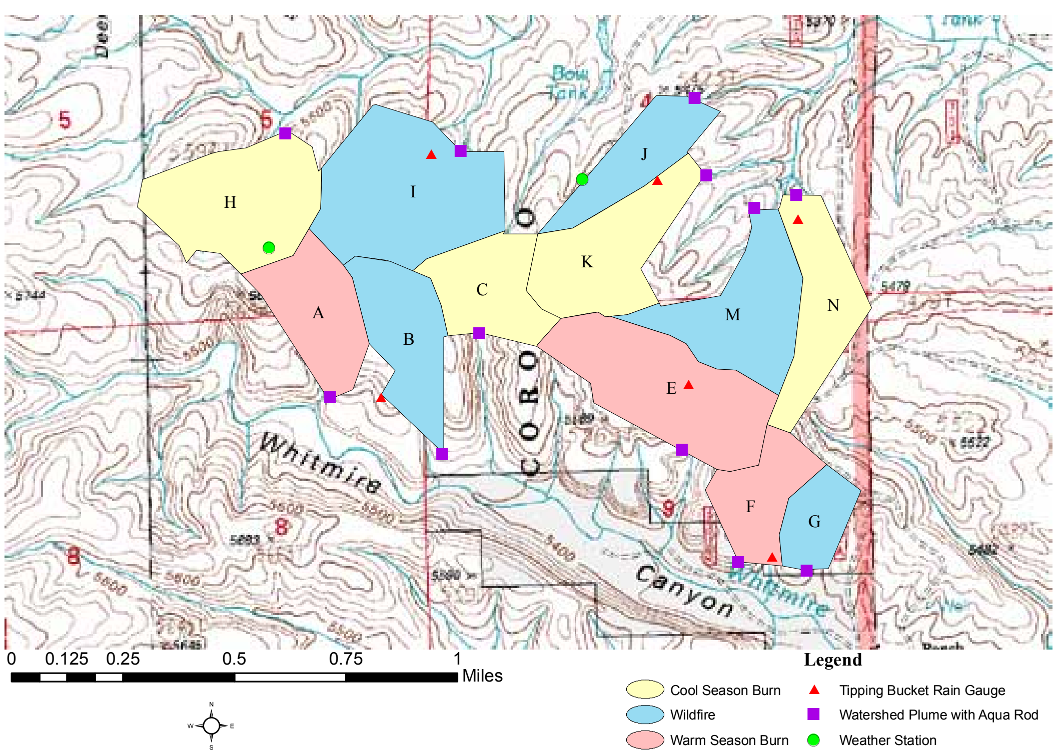


Figure 2. The original design at the Cascabel Watersheds was to treat four watersheds during the cool season, treat four during the warm season, and hold four as controls. The design was changed, as shown here, after the Whitmire Wildfire. Watershed I was originally designated to be burned during the warm season.

Fire Severities

A system that relates fire severity to the soil resource response to burning (Hungerford 1996) was the basis for classifying severities of the cool-season and warm-season prescribed burning treatments and the wildfire at the 421 sample plots on the watersheds. This system of classifying fire severities relates post-fire appearance of litter, duff, and woody material and soil conditions to discrete classes of severity that range from low to high. Details of the system are found in DeBano and others (1998), Neary and others (2005), and Wells and others (1979). Classifications of fire severity at the sample plots (fig. 3) were extrapolated to a watershed basis to determine the percentages of each of the Cascabel Watersheds that were unburned or burned at low, moderate, or high fire severities.

Extrapolations to a watershed basis indicated that 85 percent of the four watersheds experiencing the cool-season prescribed burn had been exposed to a low-severity fire; a moderate-fire severity had occurred on 5 percent of the watersheds; and the remaining 10 percent of the watersheds were unburned (Stropki and others 2009). Spatial distributions of fire severities on the watersheds that experienced the warm-season prescribed burn and wildfire were similar to the distributions of fire severities of the cool-season burn (fig. 3). It was concluded, therefore, that the Cascabel Watersheds (collectively) had been exposed to low fire severities by the three events. Occurrence of these low fire severities was attributed largely to the discontinuous and generally limited accumulations of flammable fuels before the burns (Ffolliott and others 2006, 2008a) and to the relatively high wind speeds during the burning events (M. Harrington, 2010, personal correspondence).

A high fire severity was not observed on the sample plots. However, there were scattered sites on the watersheds where high fire severities occurred in places where pockets of heavy accumulations of litter, duff, and other organic debris had built up before the burning events (Neary and others 2008).

Study Protocols

Sampling Basis

On each of the Cascabel Watersheds, between 35 and 45 sample plots were located along transects perpendicular to the main stream system and situated from ridge to ridge to provide the sampling basis to obtain data on ecosystem resources. Intervals between the plots varied with the size and configuration of the watershed sampled. In total, 421 sample plots were established on the watersheds. This sampling design was used to collect data necessary to determine effects of the prescribed burning treatments and wildfire on the tree overstories. It has also been the sampling basis for collecting data sets in other studies of the ecosystem resources on the watersheds (Ffolliott and Gottfried 2005, Ffolliott and others 2005, 2008b, Gottfried and others 2007, Stropki and others 2009).

It was necessary to delay the measurements of the effects of the prescribed burning treatments and wildfire on the tree overstories until the spring of 2009 to allow these effects to be fully expressed. A one- to two-year delay in determining the effects of fire on oak trees, the dominant trees in the overstories of the Cascabel Watersheds, had been recommended earlier by Plumb (1980), who investigated the response of California oak species to fire. Mortality of oak

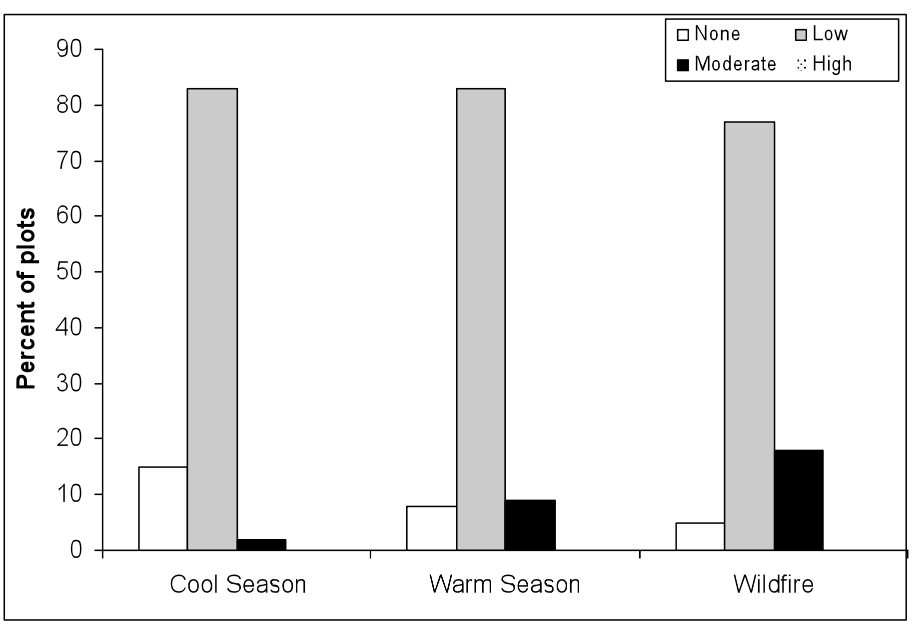


Figure 3. Fire severities of the cool-season and warm-season prescribed burning treatments and the Whitmire Wildfire on the Cascabel Watersheds based on percent of plots sampled (from Stropki and others 2009). Fire severities shown are based on a classification system relating fire severity to the soil resource response to burning (Hungerford 1996). These values were extrapolated to a watershed basis.

trees in this California study was observed up to two to three years following a fire.

Oak species on the Cascabel Watersheds become "drought-deciduous" in prolonged periods of drought. Because the Southwestern Borderlands Region experienced drought conditions before, during, and following the three burning events on the watersheds, it was necessary that measurements of fire effects be delayed until post-fire foliage was observed on the trees in order to distinguish effects of the burning events from effects of the prevailing drought conditions. Furthermore, post-fire basal sprouting of the tree species on the watersheds can be initiated up to one year after a fire (Caprio and Zwolinski 1992), and understanding the extent of this reproductive mechanism was necessary in determining the future sustainability of post-fire tree overstories.

Tree Overstory Measurements

Measurements to evaluate effects of the burning events on tree overstories were obtained on trees tallied on 1/4-acre plots centered over the established sample plot locations. Diameters at the root collar (drc) of single-stemmed trees surviving the burning events were measured, while equivalent diameters at the root collar (edrc) were measured on multiple-stemmed trees following the procedures outlined by Chojnacky (1988). These measurements had also been obtained in earlier studies of tree overstories on the watersheds (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). A relationship between drc or edrc and total height of the trees that was developed in the earlier studies was deemed appropriate for constructing a local volume table (Avery and Burkhart 2001) to estimate volumes of the tree overstories following the burns. Tallied trees were grouped into size classes corresponding to those specified by O'Brien (2002) to describe the tree resources of the woodland types of Arizona. Saplings were trees 1.0 to 4.9 inches drc (edrc), medium trees were 5.0 to 8.9 inches drc (edrc), and large trees were 9.0 inches drc (edrc) and larger. The tally protocol for saplings was different in 2002 (Ffolliott and others 2008b), but data have been adjusted so that both inventories are currently similar.

Crown damage to the tallied trees was classified as follows:

- No crown damage
- Less than 1/3 of the crown killed or scorched
- Between 1/3 and 2/3 of the crown killed or scorched
- More than 2/3 of the crown killed or scorched

It was unknown if the damage to tree crowns resulted from convection heat of a surface fire or from a crown fire that spread from one tree to another tree independent of a surface fire. Crown damage can also be caused by fire impingement to the tree bole. Because of the open tree overstories on the Cascabel Watersheds and because the three burning events on the watersheds were largely surface fires, convection heating from surface fire was assumed to be the primary cause of crown damage to the trees.

Annual volume growth of trees in the overstories (all species combined) was estimated by applying the variable-density yield table (Fowler and Ffolliott 1995) procedure that was followed in the earlier studies of tree overstories on the watersheds (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). This yield table presents estimates of cubic-foot volume per acre as a function of stand age, site quality values (Callison 1988), and tree overstory density in square feet of basal area per acre. Pre- and post-fire estimates of volumes obtained by this procedure were compared to determine the effects of the prescribed burning treatments and wildfire on one-year volume growth.

Basal sprouting by trees was recorded in terms of species, size class, and the level of crown damage to determine its status following the burning events. Many of the tree species inhabiting the oak ecosystems in the Southwestern Borderland Region are capable of reproducing vegetatively, with basal sprouting as the most common mechanism (McPherson 1992, 1997, Borelli and others 1994, Ffolliott 2002). It was not possible to adequately evaluate the effects of the burns on basal sprouting, however, because occurrences of basal sprouting had not been tallied before the burning events occurred. Such a comparison with unburned trees could have been made if the control watersheds had not burned.

Spatial distributions of the tree overstories following the burning events were compared to pre-fire spatial distributions (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) to determine the effects of the burning events on overstory stocking conditions. The respective pre- and post-fire coefficients of variation for the different parameters served as the basis for making the comparisons.

Analytical Procedures

Tallied trees grouped by size classes (O'Brien 2002) were evaluated to determine the effects of the burning events on initial survival, crown damage, densities, and basal sprouting of trees at a 0.10 level of significance. Because the three size classes (saplings, medium, and large trees) were nested within the overall tests of all of the size classes in the tree overstories, individual tests of the three size classes were evaluated separately by a Bonferroni adjustment to maintain the overall 0.10 level of significance. Pre-burning measurements of tree overstories on the watersheds were analyzed by the same protocols (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). Respective confidence intervals for pre- and post-fire annual growth estimates were compared at a 0.10 level of significance. Coefficients of variation for the pre- and post-fire spatial distributions of trees were also compared at a 0.10 level of significance. The number of tree species (species richness) and species evenness (how equally abundant species are) before and after the three burning events (Magurran 2004) were indicative of effects of the burns on ecological diversity of the tree overstories.

Results and Discussion

The data sets collected on the watersheds that experienced the prescribed burning treatments and wildfire were statistically similar. This finding was not surprising, however, because all of the Cascabel Watersheds had been exposed to low fire severities (Stropki and others 2009). Therefore, the respective data sets were combined to evaluate effects of the three burning events on the tree overstories.

Initial Survival of Trees

Almost 78 percent of the trees (all species and size classes combined) tallied on the watersheds before the prescribed burning treatments and wildfire (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) survived the burning events initially (fig. 4). More specifically, 80 percent of the oak trees (all three species and all size classes combined) survived the burns while 75 percent of the juniper trees (both species and all size classes combined) survived. Border pinyon trees and the tree form of mesquite were too few in number on the watersheds to effectively evaluate their respective survival. Oak trees continued to dominate in the overstories on the watersheds after the burning events, followed (in descending order) by juniper trees, border pinyon trees, and the tree form of mesquite.

Seven tree species were tallied on the watersheds before the burning events (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) and seven species were present after the events. Species richness of the tree overstories, therefore, was not impacted by the prescribed burning treatments. One species, Emory oak, was especially abundant both before and after the burns, however, indicating a limited ecological diversity of overstory trees on the watersheds.

Crown Damage

The numbers of oak (three species combined), juniper (both species combined), and border pinyon are shown in relation to their observed crown damage classes in fig. 5.

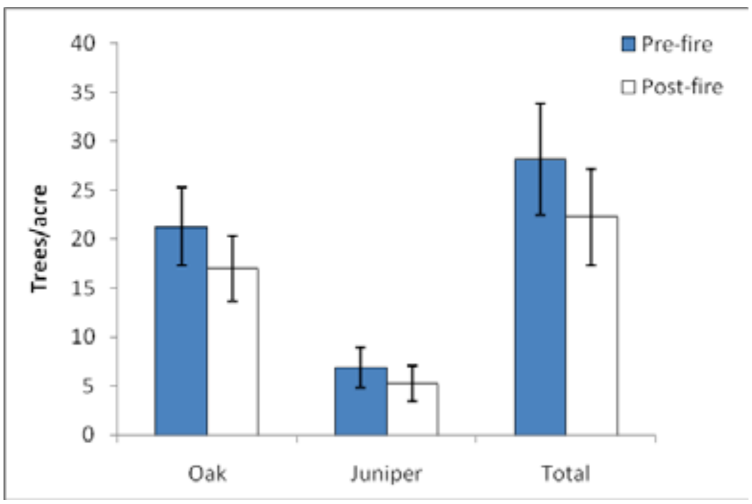


Figure 4. Average numbers of oak trees (three species combined) and juniper trees (both species combined) per acre and 90 percent confidence intervals before (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) and after the prescribed burning treatments and the wildfire on the Cascabel Watersheds. Border pinyon trees and the tree form of mesquite were too few in numbers to include in the figure.

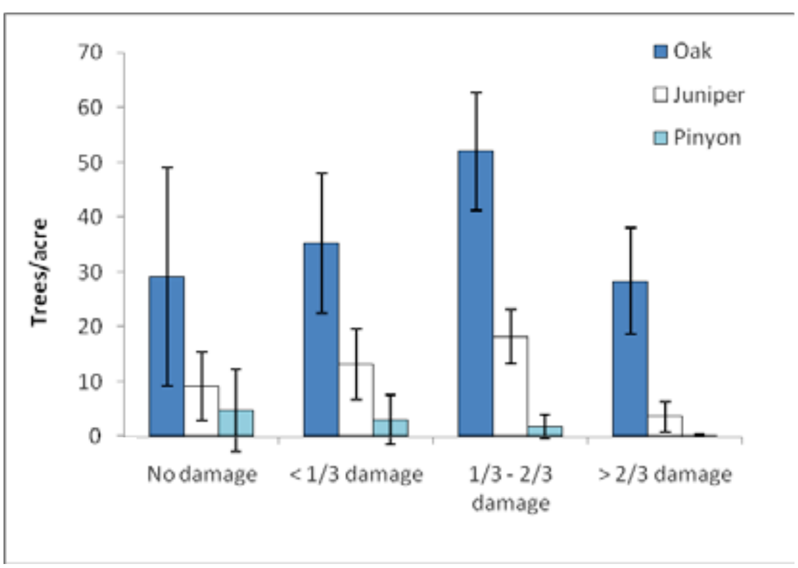


Figure 5. Levels of crown damage suffered by surviving oak trees (three species combined), juniper trees (both species combined), and border pinyon trees on the Cascabel Watersheds as a result of the prescribed burning treatments and wildfire. The tree form of mesquite was too few in numbers to include in the figure.

The crowns of 80 percent of the surviving oak trees were top-killed or scorched by the burning events, with 30 percent of the trees suffering damage to less than 1/3 of their crowns, 45 percent with damage to 1/3 to 2/3 of their crowns, and 25 percent with damage to more than 2/3 of their crowns. The crowns of 80 percent of the surviving juniper trees suffered damage from the burns, with 37 percent of the trees exhibiting damage to less than 1/3 of their crowns, 53 percent with damage to 1/3 to 2/3 of their crowns, and 10 percent with damage to more than 2/3 of their crowns. Crown damage to border pinyon was evaluated. The crowns of 51 percent of the surviving pinyon trees suffered damage, with 64 percent of the trees exhibiting damage to less than 1/3 of their crowns, 32 percent with damage to 1/3 to 2/3 of their crowns, and 4 percent with damage to more than 2/3 of their crowns. Crown damage to the tree form of mesquite was not evaluated in the study because of the limited occurrence of those trees on the watersheds. The observed levels of crown damage to the trees that survived the burning events on the Cascabel Watersheds were what one might expect following a low-severity surface fire in the oak savannas of the Region.

With all tree species considered together, there were no differences in the numbers of saplings or medium trees in the respective crown damage classes. However, the number of large trees with 1/3 or more of their crowns killed or scorched by the burning events was greater than the number of large trees that were undamaged or that suffered damage to less than 1/3 of their crowns. The more severe damage to the crowns of large trees was attributed mostly to the large accumulations of flammable fuels at the base of those trees before the burns.

Trees with crowns that were killed or severely scorched by the burning events (that is, more than 2/3 of their crowns damaged) often died eventually. This observation supports the work by Fowler and Sieg (2004) in their review of criteria for predicting post-fire tree mortality, that trees in montane forests of the western United States with severely scorched crowns frequently suffer mortality. However, it is possible that many of the oak and juniper trees at Cascabel were not root-killed and, therefore, are capable of producing basal sprouts in the future.

Densities

As a consequence of the burns, there was a reduction of almost 20 percent in the number of trees and of about 15 percent in the volume of trees (all species and size classes combined) in relation to those values before the burns (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). Some tree species and size classes (for example, oak and juniper trees in the two largest size classes) appeared to be more resilient to burning than others in terms of density reductions.

Numbers of Trees

Paralleling the data prior to burning (Ffolliott and Gottfried 2005, Ffolliott and others 2008b), oak (three species combined) dominated the numbers of trees after the burning events, followed by juniper trees (both species combined) (as shown in fig. 6). Though not presented in fig. 6, the number of juniper trees that survived the burns was greater than the number of either border pinyon trees or the tree form of mesquite following the burns.

A greater number of large trees (all species combined) survived the prescribed burning treatments and the wildfire than either the medium or small trees (fig. 6). However, there also were a greater number of large trees on the Cascabel Watersheds before the burning events occurred (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). In terms of percentages of the surviving trees, 86 percent of the large trees,

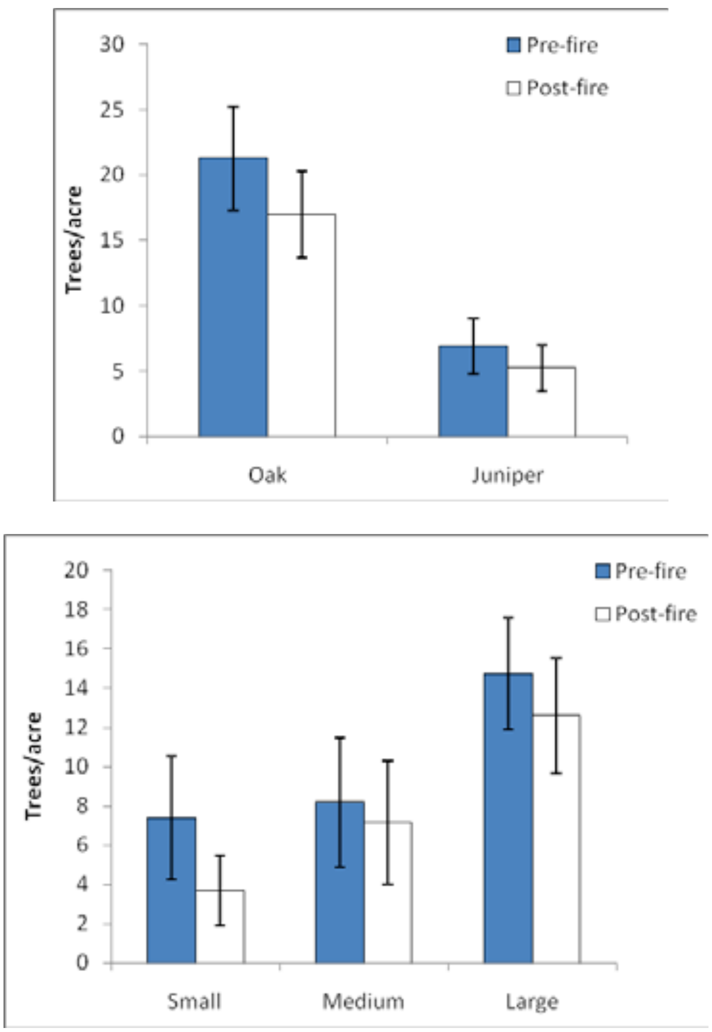


Figure 6. Average numbers of trees (all species combined) per acre (top) and trees by size classes (bottom) and 90 percent confidence intervals (both) before and after the prescribed burning treatments and the wildfire on the Cascabel Watersheds. Border pinyon trees and the tree form of mesquite were too few in numbers to include in the figure.

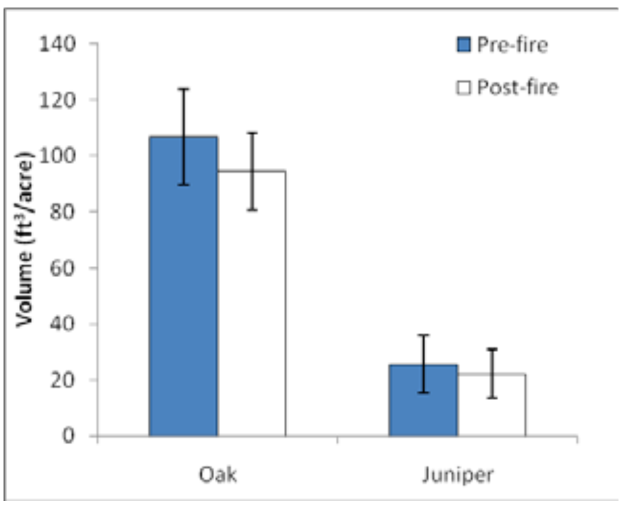
88 percent of the medium trees, and 50 percent of the small trees survived the burns.

Volumes of Trees

Following the burning events, a local volume table based on values calculated by Chojnacky (1988) was applied in converting the numbers of trees per acre to corresponding estimates of cubic-foot volumes. These values also were used in estimating the volumes of trees before burning occurred (Ffolliott and Gottfried 2005, Ffolliott and others 2008b).

Effects of the burning events on volumes of oak and juniper trees (all size classes combined) in comparison to the volumes before the burning events (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) are shown in the top of fig. 7. The dominance of oak relative to juniper trees on the Cascabel Watersheds can be seen in this portion of the figure. Both of the tree species lost essentially the same percentage of their volumes in the burns, however, with oak trees losing 12 percent and juniper trees losing 13 percent, respectively. Volumes of border pinyon trees and the tree form of mesquite lost to the burns were insignificant.

Not surprisingly, the volume of large trees (three oak species and both juniper species combined) after the burning events was greater than the volumes of small and medium trees, as shown in the bottom of fig. 7. In terms of percentages, the volume of small trees before the burns was reduced by 12 percent, the volume of medium trees was reduced by 11 percent, and the volume of large trees was reduced by 14 percent. The small differences in the volumes before and after the burning are attributed to the low fire severities of these events.



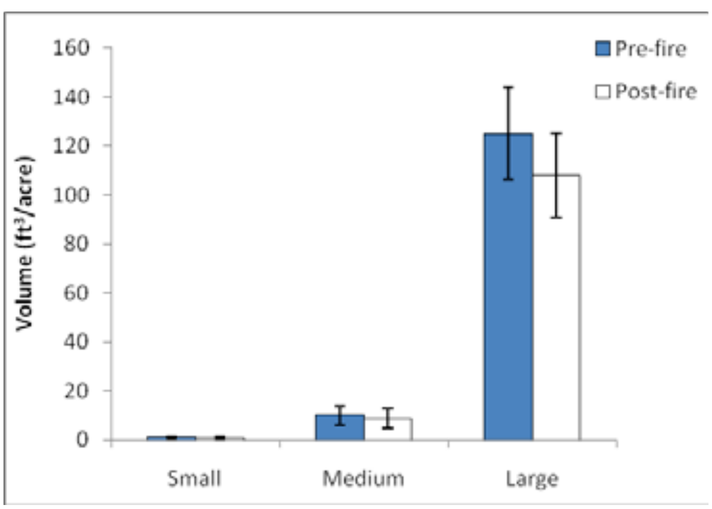


Figure 7. Impacts of the prescribed burning treatments and the wildfire on volumes of oak trees (three species combined) and juniper trees (both species combined) on the Cascabel Watersheds by species (top) and by size classes (bottom). Scales of the Y-axis are unique for each portion of the figure. Border pinyon trees and the tree form of mesquite were too limited in volume to include in the figure.

Annual Growth

Stand age and overstory density variables in the variable-density table developed for the Cascabel Watersheds were modified and used to estimate annual growth of trees (all species and size classes combined) following the three burning events and to determine change relative to pre-fire values. The stand age was increased and the tree overstory density was decreased by the burns. (Site quality values remained unchanged in this study, as these values are not impacted by short-term disturbances such as the occurrence of fire.) The appropriate changes in stand age and tree overstory density were made accordingly.

The estimated annual growth rate of 0.056 ± 0.017 ft^3/acre (mean ± standard error) of the tree overstories following the burning events was statistically similar to the estimate of 0.069 ± 0.023 ft^3/acre before the burns (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). Both of these estimates of annual growth were less than 1 percent of the respective tree volumes. This finding was expected, however, because trees in the oak ecosystems of the Southwestern Borderlands Region grow slowly, rarely exceeding a fraction of a cubic-foot annually (McPherson 1992, 1997, McClaran and McPherson 1999, Ffolliott 2002).

Basal Sprouting

Basal sprouting by the same tree species found on the Cascabel Watersheds is often observed following high-severity burning events in the Region (Niering and Lowe 1984, Caprio and Zwolinski 1992, McPherson 1992, 1997, Ffolliott 2002). However, basal sprouting of these tree species on the Cascabel Watersheds was surprisingly limited (relatively) after

Figure 8. Basal sprouting by trees on the Cascabel Watersheds, such as this Emory oak, was limited following the prescribed burning treatments and wildfire.

the prescribed burning treatments and wildfire, perhaps because of the low fire severities of the burns (fig. 8). Basal sprouting was observed on 37.4 percent of the surviving oak trees (three species combined) and on 11.0 percent of the surviving juniper trees (both species combined). Basal sprouting by the tree form of mesquite was inconsequential. Pinyon does not sprout.

Relationships between basal sprouting by trees after the burning events and the size of either the oak or juniper trees were inconsistent. While there were no differences in the presence or absence of basal sprouting by small and medium trees after the burns, basal sprouting by large trees was less frequently observed than on the small and medium trees. The large and likely older trees might have been less vigorous than the smaller trees before the burns, which may have limited their capabilities to sprout following the burns.

Relationships of basal sprouting by trees (all species combined) to the crown damage classes were insignificant, with the exception of basal sprouting of trees with greater than 2/3 of their crowns either killed or scorched by the burns. More trees suffering this level of crown damage sprouted than did not sprout. Apparently, many of these trees had not been root-killed by the burning events and, as a result, were capable of reproducing vegetatively by basal sprouting.

The extent that basal sprouting of the trees on the Cascabel Watersheds after the burning events will impact the future sustainability of the overstories is not known. Developing a more complete picture of effects of the burns on the post-fire basal sprouting of trees was not possible because information on pre-fire basal sprouting of the trees was not available. However, only limited basal sprouting before the burning events is possible. Caprio and Zwolinski (1992) found "frequent and vigorous" basal sprouting by Emory oak trees on burned sites following a wildfire of unknown severity in the Santa Catalina Mountains of southeastern Arizona, while basal sprouting by the trees on adjacent unburned sites was nil.

Spatial Distributions of Trees

Spatial distribution of trees in the oak savannas is generally more variable than in the more densely stocked oak woodlands at higher elevations (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). However, the spatial distribution of trees (all species and size classes combined) in the overstories on the Cascabel Watersheds was not impacted by the burning events (fig. 9). The pre-fire heterogeneous stocking of the trees on the watersheds was also unchanged by the

Figure 9. The heterogeneous stocking of tree overstories on the Cascabel Watersheds was not impacted by the burning events. This photo view was taken in July 2010 of a watershed burned during the warm season.

burns. Openings of varying sizes, shapes, and orientations that were interspersed within tree overstories of the oak savannas remained intact.

Conclusions

The prescribed burning treatments and the wildfire in the oak savannas on the Cascabel Watersheds were all low fire severities. It was not surprising, therefore, that the effects of these burning events on tree overstories of the watersheds were similar. Effects of these burns on initial tree survival, crown damage to the trees, and basal sprouting were mostly inconsequential in terms of management implications. Changes in tree composition, density, and annual growth rate in comparison to pre-fire conditions were also relatively minor.

It is unknown if the effects of fire on tree overstories in the oak savannas that are reported in this paper would be similar in magnitude with repeated prescribed burning treatments of low fire severity on the Cascabel Watersheds. It is also unknown what these effects might be if prescribed burning treatments of low fire severities were imposed on other sites in the oak ecosystems of the Southwestern Borderlands Region. A hotter fire might produce different results. However, ignitions of the warm-season prescribed burning of May 20, 2008, were approaching the threshold for initiating prescribed burning treatments in the Region. The results presented in this paper, therefore, should be considered case studies.

Management Implications

The information presented in this paper is useful to managers interested in re-introducing more historical fire regimes into the oak savannas of the Southwestern Borderlands Region. The overcrowding of tree overstories, concurrent decrease in herbage (forage) production, loss of critical wildlife habitats, and large accumulations of flammable fuels currently found on many sites could be alleviated (to some extent) by scheduling prescribed burning treatments at regular intervals. Managers might use results from the burning events on the Cascabel Watersheds as initial guidelines since there is relatively little information available on the effects of prescribed burning treatments on ecosystem resources in the oak savannas. However, these managers should also recognize that prescribed burning treatments of low fire severities on other sites in oak ecosystems of the Region might not produce results similar to those on the Cascabel Watersheds. Additional evaluations of prescribed burning treatments of varying severities and seasonal timing on ecosystem resources are needed to formulate appropriate management strategies to achieve the desired benefits. A change in protocols for implementing prescribed burning treatments might have to be considered in order to facilitate successful ignitions under less restrictive weather and fuel conditions and to achieve ecosystem improvement goals.

Evaluations of prescribed burning treatments of varying frequencies and timing should also include studies of the entire array of ecosystem resources available. In addition to tree overstories, these evaluations should include herbaceous plants, wildlife populations and habitats, soil resources and sediment production, and flows of water from upland watersheds. Such efforts are underway on the Cascabel Watersheds (Gottfried and others 2007). It is also necessary that management agencies, private organizations, and local stakeholders collaborate to obtain more natural fire regimes in the Southwestern Borderlands Region.

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