Fire Effects on Herbaceous Plants and Shrubs in the Oak Savannas of the Southwestern Borderlands

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Abstract

Much has been learned in recent years about the ecological, hydrologic, and environmental characteristics of the oak (encinal) woodlands of the Southwestern Borderlands. Comparable information for the lower-elevation oak savannas, including the impacts of fire on ecosystem resources, is also necessary to enhance the knowledge of the oak ecosystems in the region. Oak savannas are more open in stand structure than are the oak woodlands and, as a consequence, a higher level of herbaceous production might be expected in this ecosystem than in the oak woodlands. The effects of prescribed burning treatments and a wildfire on species compositions, production of grass and forb components, growth of shrubs, utilization of forage and browse plants by herbivores, and ecological diversity in a oak savanna are described in this paper.

Keywords: herbaceous plants, oak savannas, overstory-understory relationships, production, shrubs, southwestern United States, species compositions

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Cover: *Photograph by Larry Allen, Malpai Borderlands Group. A view of an area near the Cascabel Watersheds that was burned in the Whitmire Wildfire. The photograph was taken three months after the fire. The white instrument is a frequency transect frame used to sample plant species composition.*

Contents

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Introduction

Much has been learned in recent years about the ecological, hydrologic, and environmental characteristics of the oak (encinal) woodlands of the Southwestern Borderlands. Ecological and hydrologic relationships of these woodland communities have been studied by a number of investigators (DeBano and others 1995; Ffolliott 1999, 2002; Gottfried and others 2005, 2007a; McClaran and McPherson 1999; McPherson 1992, 1997; and others). However, comparable information for the lower-elevation oak savannas is necessary to enhance the knowledge of all of the oak ecosystems in the region. Oak savannas are situated in the transition (interface) between the higher-elevation oak woodlands and lower-elevation desert grasslands and shrub communities. While Niering and Lowe (1984), working in the Santa Catalina Mountains near Tucson, Arizona, described this band of vegetation as "open oak woodlands," the authors prefer the term "oak savannas" in differentiating this more open canopy ecosystem from oak woodlands.

Species compositions, the production of grass and forb components, growth of shrubs, utilization of forage and browse plants by herbivores, and ecological diversities before and after prescribed burning treatments and a wildfire are described in this paper. This information should be helpful in developing management strategies for reintroducing a more historically similar fire regime into the oak savannas to manage tree densities, control invasive plant species, increase productivity, and sustain ecosystem resources.

Cascabel Watersheds

Twelve watersheds on the eastern side of the Peloncillo Mountains in southwestern New Mexico were (collectively) the study areas for evaluating the effects of the burning events on the resources mentioned. These watersheds, ranging from about 20 to almost 60 acres in size, were established by the U.S. Forest Service, Rocky Mountain Research Station, to evaluate the impacts of prescribed burning treatments on ecological and hydrologic characteristics of the oak savannas in the region (Gottfried and others 2000, 2005, 2007b; Neary and Gottfried 2004). The aggregate area of the watersheds, called the Cascabel Watersheds, is 451 acres. They are representative of the oak savannas in the Malpai Borderlands in the eastern part of the Coronado National Forest on the western edge of the Animas Valley as shown in fig. 1. The Malpai Borderlands are found within the larger Southwestern Borderlands of the region.

The watersheds are at 5380 to 5590 ft in elevation. The nearest long-term precipitation station at the Cascabel Ranch headquarters indicates that annual precipitation in the vicinity of the watersheds averages 21.8 ± 1.2 inches, with more than one-half falling in the summer monsoonal season from late June through early September. However, a prolonged drought impacted the Southwestern Borderlands from the middle 1990s through the end of the study when the data summaries and interpretations presented in this paper were collected. The annual precipitation in this drought averaged 15.8 inches. The bedrock geology of the watersheds is Tertiary rhyolite overlain by Oligocene-Miocene conglomerates and sandstone. Soils are classified as Lithic Argustolls, Lithic Haplustrolls, or Lithic Ustorthents. These soils are generally less than 20 inches to bedrock. Streamflow originating in the oak savannas is mostly intermittent in nature, although large flows can follow high-intensity rainfall events (Gottfried and others 2006).

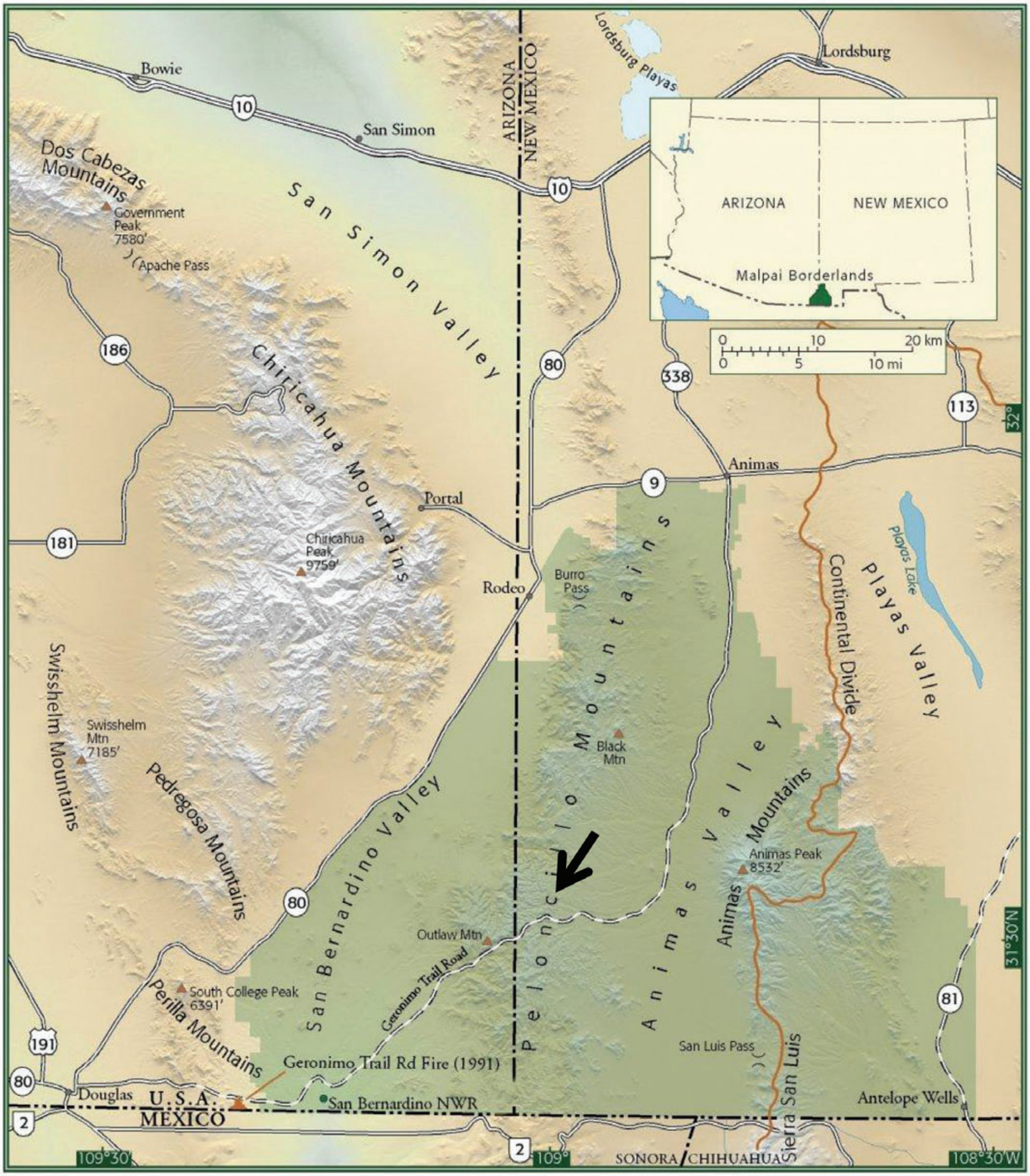

Figure 1—The Cascabel Watersheds (arrow) are located within the oak savannas of the Malpai Borderlands, an area of approximately 802,750 acres within the larger Southwestern Borderlands Region.

Further descriptions of the geological, edaphic, vegetative, and hydrologic characteristics of the watersheds are found in Ffolliott and others (2008b), Gottfried and others (2000, 2005, 2007b), Hendricks (1985), Neary and Gottfried (2004), Osterkamp (1999), Robertson and others (2002), Vincent (1998), Youberg and Ferguson (2001), and others.

Prescribed Burning Treatments and 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 ecosystem resources of the watersheds, including the herbaceous plants and shrubs. It was anticipated that these evaluations would be compared to those obtained on control (unburned) watersheds in determining these fire effects. Four of the watersheds (Watersheds C, H, K, and N) were burned by prescribed fire during the cool-season on March 4 and March 11 2008 (fig. 2). Three of the four watersheds (Watersheds A, E, and F) to be burned in the warm-season were ignited on May 20, 2008, but burning of the fourth watershed (Watershed I) was delayed because of the shifting weather conditions. However, wind gusts up to 60 mph on the morning of May 21, 2008, blew firebrands onto Watershed I and the four control watersheds (Watersheds B, J, M, and G). The resulting wildfire, designated the Whitmire Wildfire, spread beyond the watershed boundaries to burn nearly 4000 acres. Therefore, the original objective of the research on the Cascabel Watersheds was modified to evaluate the effects of cool-season and warm-season prescribed burning treatments and wildfire on the herbaceous plants and shrubs of the watersheds.

Average atmospheric conditions during the prescribed burning treatments and wildfire are presented in table 1. This information was obtained from a weather station located in the middle of the watersheds (Ffolliott and others 2011).

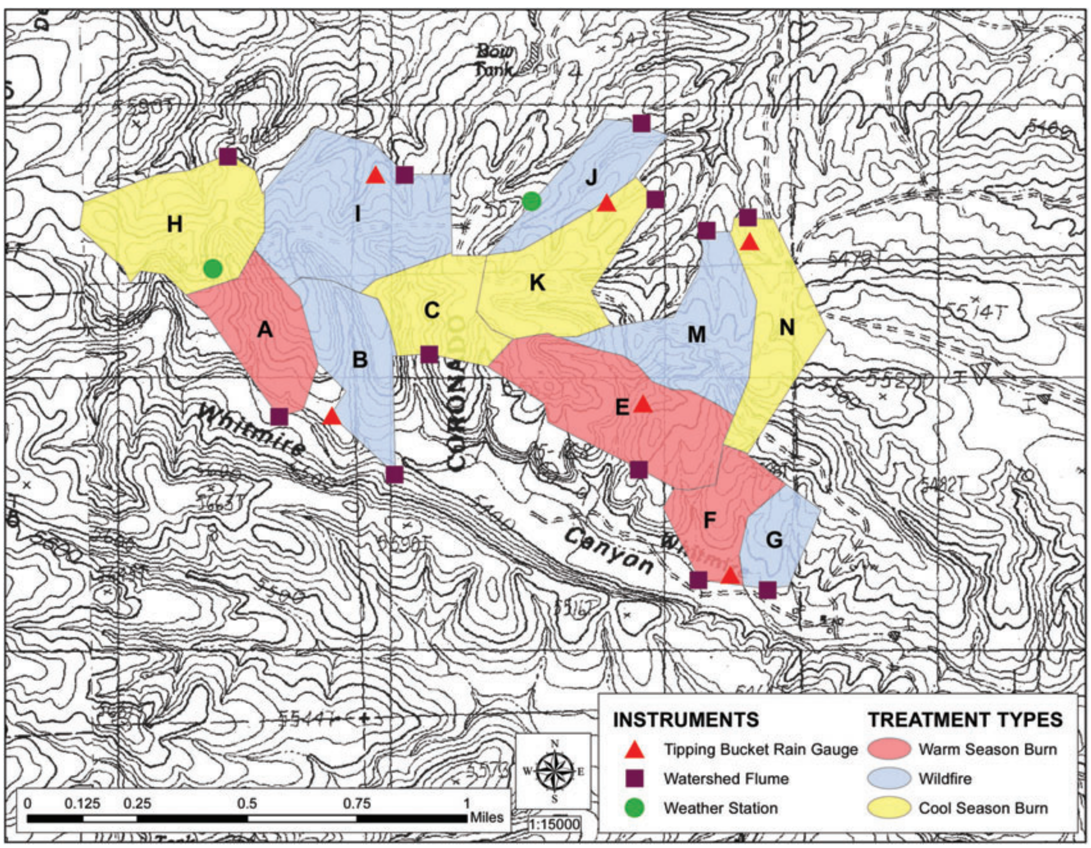

Figure 2—The original study design on the Cascabel Watersheds was to burn four watersheds by prescribed fire in the cool season, to burn four watersheds in the warm season, and to retain four watersheds as controls. However, the study design was changed following the Whitmire Wildfire, as shown in this figure. Watershed I was originally designated to be burned in the warm season but instead burned as a result of the wildfire.

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 this table was obtained from a weather station located in the middle of the watersheds.

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

Fire Severities

A system that relates fire severities 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 421 plots on the watersheds. The post-fire soil conditions are related to classes of severity ranging from low to medium to high in this system. Further details of this system are found in DeBano and others (1998), Neary and others (2005), and Wells and others (1979). Classifications of fire severity at the plots were then 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.

It was determined that 85 percent of the four watersheds experiencing the cool-season prescribed burn had been exposed to a low-severity fire; 5 percent had been exposed to a moderate-severity fire, and the remaining 10 percent were unburned (Stropki and others 2009). Spatial distributions of fire severities on the watersheds experiencing the warm-season prescribed burn and wildfire were similar to the distributions of fire severities for 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. These low fire severities were attributed largely to the discontinuous and generally limited accumulations of flammable fuels before the burns (Ffolliott and others 2008a) and the relatively high wind speeds

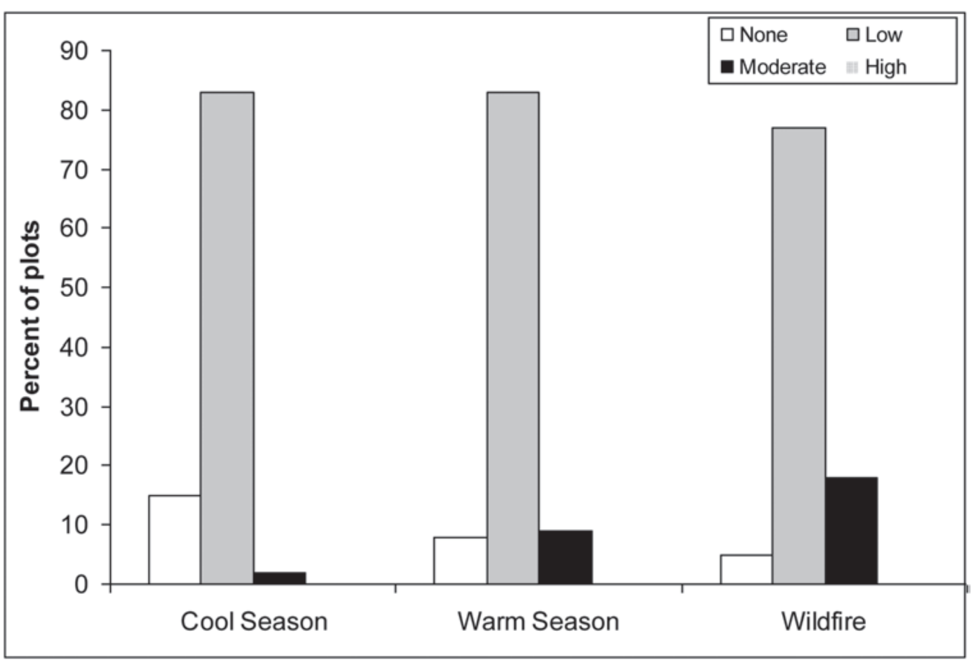

Figure 3—Fire severities of the cool-season and warm-season prescribed burning treatments and the Whitmire Wildfire on the Cascabel Watersheds based on the percent of plots sampled (from Stropki and others 2008). Fire severities shown in this figure are based on a classification system relating fire severities to the soil response to burning (Hungerford 1996). These values were extrapolated to a watershed basis.

during burning events (M. Harrington 2010, personal correspondence).

Wide-spread high-severity fire was not observed on the plots. However, there were scattered and localized sites on the watersheds where high fire severities occurred as a consequence of "heavy accumulations" of litter, duff, and other organic debris building up before the burning events occurred (Neary and others 2008).

Study Protocols

Sampling Basis

Each of the Cascabel Watersheds contains between 35 and 45 permanent plots that were established along transects located perpendicular to the main stream channels and situated from ridge to ridge to measure ecological resources and determine hydrologic functioning. The interval between the plots varied depending on the size and configuration (shape) of the watershed sampled. A total of 421 plots were established on the watersheds. Estimates of the production of herbaceous plants and growth of shrubs were obtained on 9.6 ft^2 plots centered over the previously established plots. Sampling was conducted in the spring and fall of each year.

Field Measurements

Estimates of the production of grasses and forbs and shrub growth were obtained by the weight-estimate procedure originally outlined by Pechanec and Pickford (1937) and later by Cook and Stubbendieck (1986). Samples of the herbaceous plants and shrubs were collected on 20 to 30 temporary 9.6 ft^2 plots located adjacent to a sub-sample of the primary plots. The collections were obtained at the same time that the estimates of herbage production and the growth of shrubs were made in order to develop the corrections factors necessary to convert the field estimates of green weights to actual (oven-dried) weights. The estimates of herbage production and shrub growth were then expressed in pounds per acre.

Species compositions and seasonal (spring and fall) estimates of the production (standing biomass) of the grass and forb components of herbaceous plants and seasonal growth of the shrubs were obtained before the prescribed burning treatments and wildfire from the spring of 2003 through the fall of 2007 (Ffolliott and others 2008b) and from the spring of 2008 through the fall of 2010 following the burns. The spring estimates reflect the production of early growing herbaceous plants and early growth of shrubs, while the fall estimates represent the production of late growing herbaceous plants and the late growth of shrubs (McPherson 1992, 1997). Temperature and antecedent soil water derived largely from late fall and winter precipitation events are the primary factors favorable to early growing plants. Late growing plant species are more responsive to the summer monsoonal rains.

Utilization of forage and browse plants by herbivores was determined ocularly (Cook and Stubbendieck 1986; Holechek and others 2004) at the same times that seasonal herbage production and shrub growth were estimated in the watersheds. No differentiation was made of the herbivores involved in utilizing the plants.

Analytical Methods

The data sets obtained on the Cascabel Watersheds before the early season and late season prescribed burning tests and wildfire were statistically similar for all pre-fire sampling dates and, therefore, pooled for analysis. The data sets on the watersheds experiencing the individual burning events were also statistically similar for all of the sampling dates. Furthermore, there were no statistical differences among the data sets for the burns and wildfire for the sampling dates. Therefore, the post-fire data sets also were pooled to evaluate the effects of the burning events on the herbaceous plants and shrubs.

The tests of significance in determining statistical differences in the data sets were evaluated at a 0.10 level of significance. However, because the grass and forb components were nested within the overall tests of all of the herbaceous plants, the individual tests of these two herbaceous components were evaluated separately at a 0.05 level of significance to maintain the overall 0.10 level of significance in accordance with a Bonferroni adjustment.

The number of herbaceous and shrub species present (species richness) and how equally abundant the species are (species evenness)—two commonly used measures of ecological diversity (Magurran 1988, 2004)—before and after the burning events were indicative of the effects of the burns on the ecological diversity of the species.

Results and Discussion

Species compositions of the herbaceous plants and shrubs on the Cascabel Watersheds were similar on the watersheds both before and after the prescribed burning treatments and wildfire. However, while the estimates of production obtained on the watersheds before the burns were statistically similar and, therefore, combined (Ffolliott and others 2008b), the effects of the burning events on the production of grasses and forbs and the growth of shrubs differed on the watersheds that experienced the three burning events. As a result, the watersheds were grouped into those experiencing prescribed burning in the cool season, those treated by prescribed burning in the warm season, and those exposed to the wildfire for analyses. Differences among the watersheds within each of these three groupings were insignificant.

Species Compositions

Species compositions of herbaceous plants and shrubs following the prescribed burning treatments and wildfire were largely similar to the compositions before the burning events (fig. 4). Perennial grasses after the burns included blue (*Bouteloua gracilis*), sideoats (*B. curtipendula*), slender (*B. repens*), and hairy (*B. hirsuta*) grama; common wolftail (*Lycurus phleoides*); bullgrass (*Muhlenbergia emersleyi*); and Texas bluestem (*Schizachyrium cirratum*). Species of lupine (*Lupinus* spp.), mariposa lily (*Calochortus* spp.), and verbena (*Verbena* spp.) were the primary plants in the relatively minor forb component of the herbaceous plants.

Beargrass or sacahuista (*Nolina microcarpa*), common sotol (*Dasylirion wheeleri*), fairyduster (*Calliandra eriophylla*), pointleaf manzanita (*Arctostaphylos pungens*), Mexican cliffrose (*Purshia mexicana*), and Fendler's ceanothus (*Ceanothus fendleri*) were scattered half-shrubs and shrubs. Palmer's agave (*Agave palmeri*) and banana yucca (*Yucca baccata*) were occasionally found on well-drained rocky slopes. Shrub-forms of Emory (*Quercus emoryi*), Arizona white (*Q. arizonica*), and Toumey (*Q. toumeyi*) oak and mesquite (*Prosopis glandulosa* var. *torreyana*) were present after the burns as they were before. Annual plants were largely absent on the watersheds.

Figure 4—Species compositions of the herbaceous plants and shrubs on the Cascabel Watersheds were not significantly changed by the prescribed burning treatments or wildfire. This is a view of the cool-season prescribed fire on Watershed K.

Precipitation Record

The production of herbaceous vegetation is correlated with the seasonal distribution of precipitation and available soil water in arid ecosystems (Mulroy and Rundel 1977). Data from the Cascabel J2 weather station, located in the center of the experimental area (fig. 2), provide information about precipitation during the study period (fig. 5). The totals sum the cool-season and warm-season records for the precipitation year and differ from the annual totals.

Average cool-season precipitation for the eight years with standard deviation was 6.0 ± 3.3 inches, while average warm-season precipitation was 10.9 ± 3.8 inches. The total average was 16.9 ± 4.4 inches. Approximately 64 percent of the moisture occurred in the warm season. Natural production of many important species coincides with the warm-season monsoon rains. The relative importance of the seasonal precipitation to early growing and late growing herbaceous plant production before and after the fire treatments is apparent in the subsequent figures. Although rigorous tests were not conducted, it does not appear that seasonal precipitation was different before and after treatments.

Production of Grasses

Averages and 90 percent confidence intervals for the production of early growing and late growing grasses before and after the prescribed burning treatments and wildfire are presented in fig. 6. The production of grasses in both the spring and fall was significantly greater following the burning events than before these burns, as illustrated by fig. 6. Depending on the event, there was a five- to seven-fold increase in the production of early growing grass species. Increases in the production of late growing grasses following the burns were significant but smaller in magnitude than the increases in early growing grasses. It must be remembered, however, that the effects of these burning events were estimated during a period of prolonged drought. It is also possible that the reported increases in the production of grass species will decline in magnitude if the drought continues.

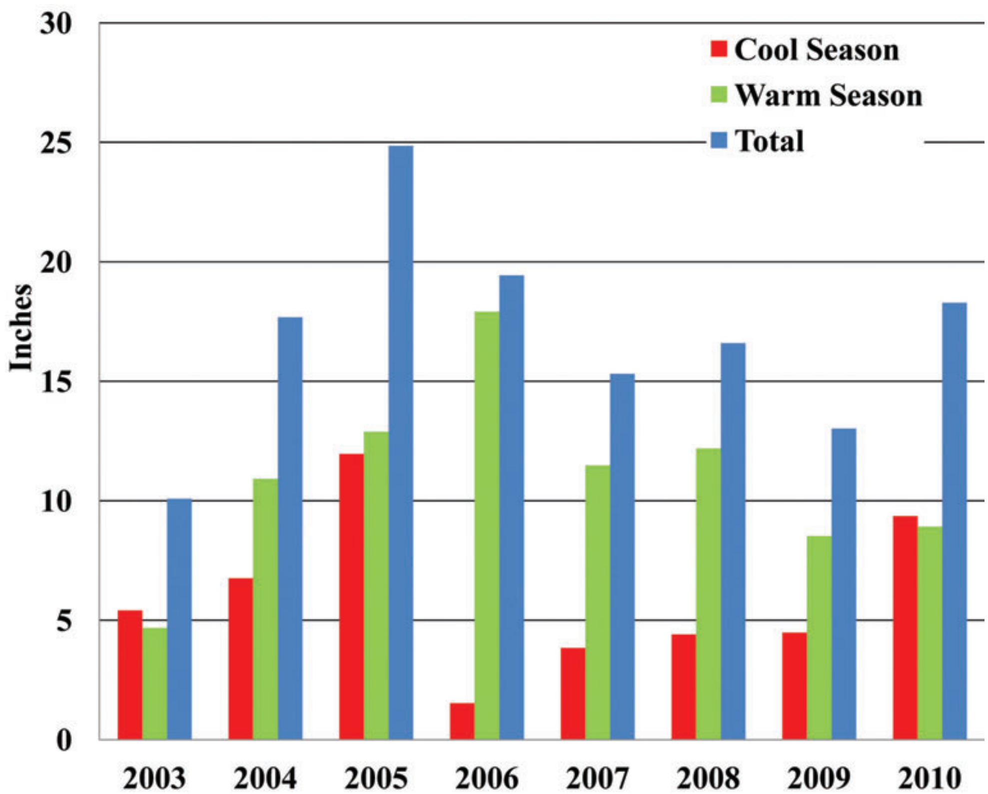

Figure 5. Precipitation records from the Cascabel J2 weather station. Cool-season precipitation includes monthly records from late fall of the previous year through April of the year of record. The cool-season precipitation for 2003 for example includes November and December 2002 through April 2003. The warm-season for 2003 includes May through October 2003.

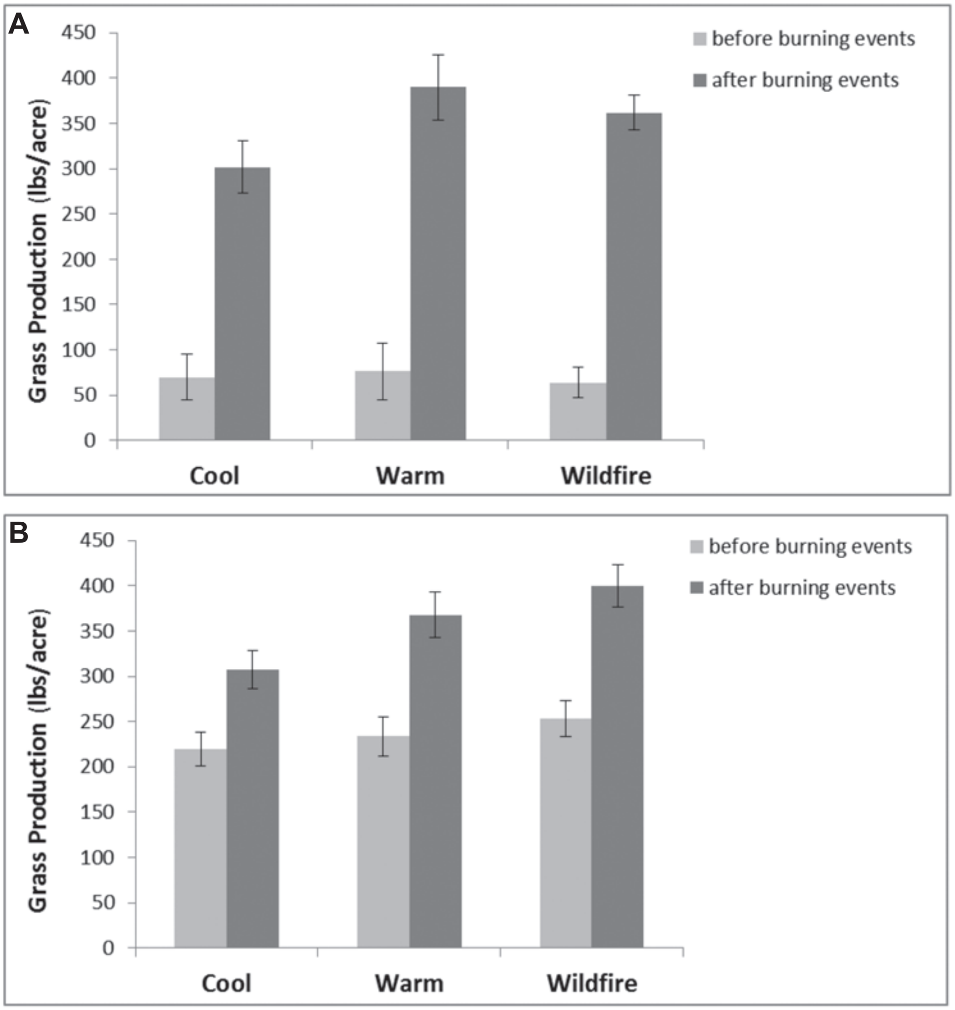

Figure 6—Averages and 90 percent confidence intervals for the production of early growing (A) and late growing (B) grasses on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire.

The greater production of grasses following the burning events was attributed to a combination of factors. One cause was likely the reduction of trees in the overstories. While only 20 percent of the trees were lost to burning (Ffolliott and others 2011), these trees competed with herbaceous plants for soil water. Therefore, the reduction of even this small number of trees was likely to make more of the limited soil water on the Cascabel Watersheds available for grass production. The consumption of portions of the litter and duff layers by the burns reduced interception of precipitation and could have also provided more soil moisture for the growth of the grasses. Still, another reason for the increase in grass production after the burning events could be that a pool of nutrients was formed where vegetation, litter, and duff were combusted by the burns. In general, one might anticipate a flush of available nutrients following fire (Bond and van Wilgen 1996; DeBano and others 1995; Whelan 1997).

Production of Forbs

The production of forbs was significantly less than the production of grasses before and after the prescribed burning treatments and wildfire. However, the effects of the burning events on forb production were inconsistent, as shown in fig. 7. Neither the production of early growing forbs nor the production of late growing forbs was altered by the cool-season burning treatment. However, the production of the early growing forbs increased following the warm-season prescribed burning treatment and the wildfire. These increases were attributed to the fact that the two burning events occurred at the same time and that both of the events resulted in low fire severities. There was no change in the production of late growing forbs after warm-season prescribed burn or the wildfire.

The reasons for the inconsistencies in the effects of the burning events on the production of forbs are unknown. However, varying combinations of the fewer trees and the release of available nutrients following the burns likely affected the growth of individual forb species in different ways and at different times throughout the growing season. Increased evaporation of soil water because of the loss of shade could have reduced soil water content in the summer and, as a consequence, affected the response of forbs to the burning events.

Production of Herbaceous Plants

Averages and 90 percent confidence intervals for the production of early and late growing herbaceous plants (grasses and forbs combined) before and after the prescribed burning treatments and wildfire are presented in fig. 8. The production of these plants paralleled the pattern of the seasonal production of grasses. That is, the production of herbaceous plants in both the spring and fall was greater following the burning events than before these burns. This finding was expected because the large proportion of the herbaceous plants on the Cascabel Watersheds was grass species.

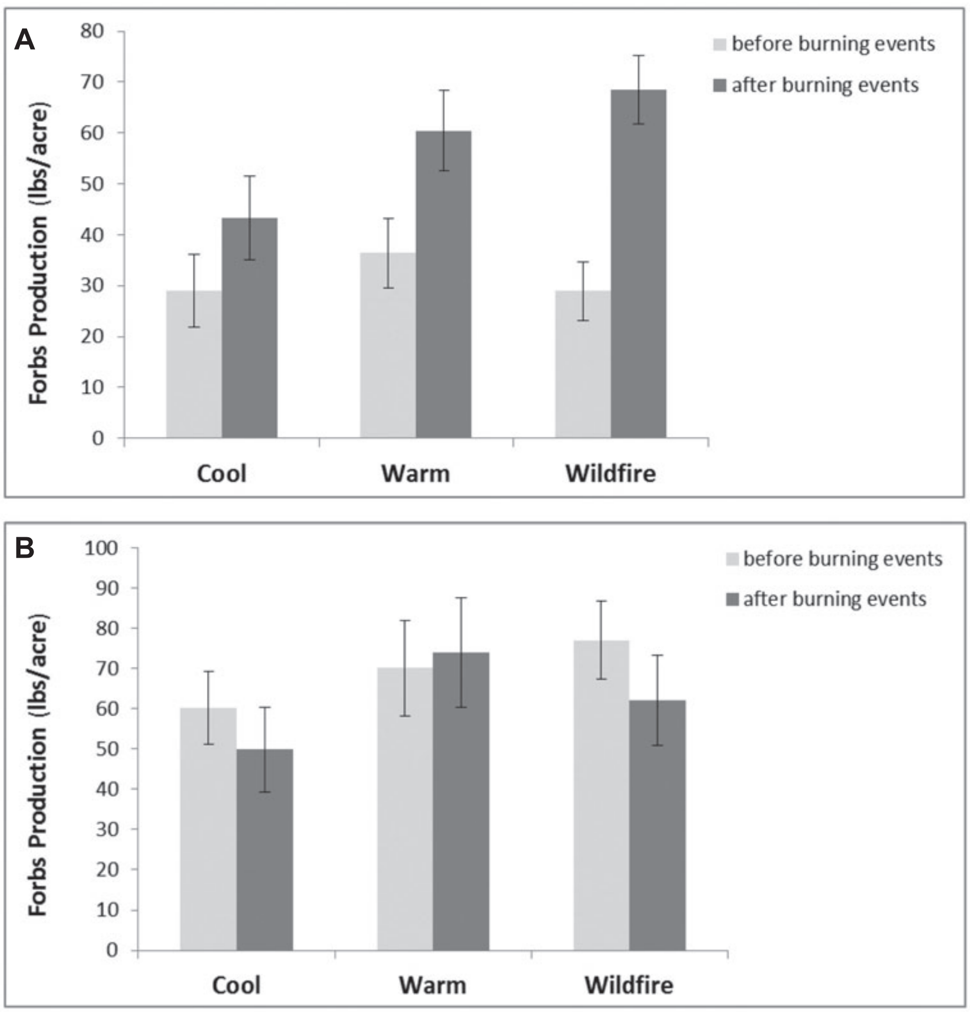

Figure 7—Averages and 90 percent confidence intervals for the production of early growing (A) and late growing (B) forbs on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire. Scales of the Y-axis are unique for each portion of the figure.

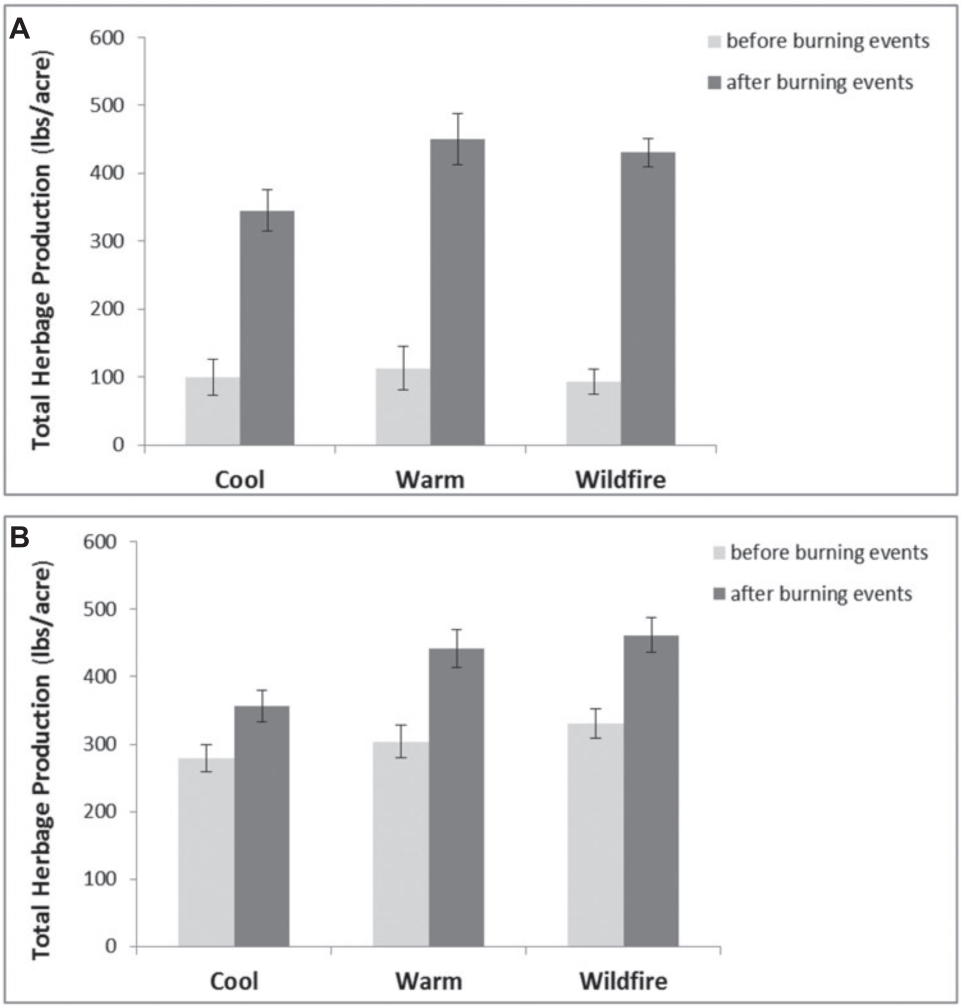

Figure 8—Averages and 90 percent confidence intervals for the production of early growing (A) and late growing (B) herbaceous plants on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire.

The reduction in trees; combustion of vegetation, litter, and duff; and a pool of nutrients were among the factors again assumed to have contributed to the estimated increases in herbaceous plants after the burning events. Thus, the reintroduction of fire into the Cascabel Watersheds achieved a beneficial increase in the production of herbaceous species, a primary ecosystem component.

Growth of Shrubs

Shrubs contributed little to the production of understory plants on the Cascabel Watersheds both before and after the prescribed burning treatments and wildfire. Furthermore, the growth of shrubs was not generally affected by these burning events, as shown in fig. 9. One exception was the late season growth of shrubs on the watersheds burned by the wildfire. The growth of shrubs, and particularly the growth of the basal sprouts of oak trees that dominated the shrub biomass, was significantly greater before than after the wildfire. This finding contrasts with the “frequent and vigorous” basal sprouting by oak trees on burned sites following a wildfire in the Santa Catalina Mountains of southeastern Arizona (Caprio and Zwolinski 1992). Basal sprouting by oak trees on adjacent unburned sites in the Santa Catalina Mountains was nil.

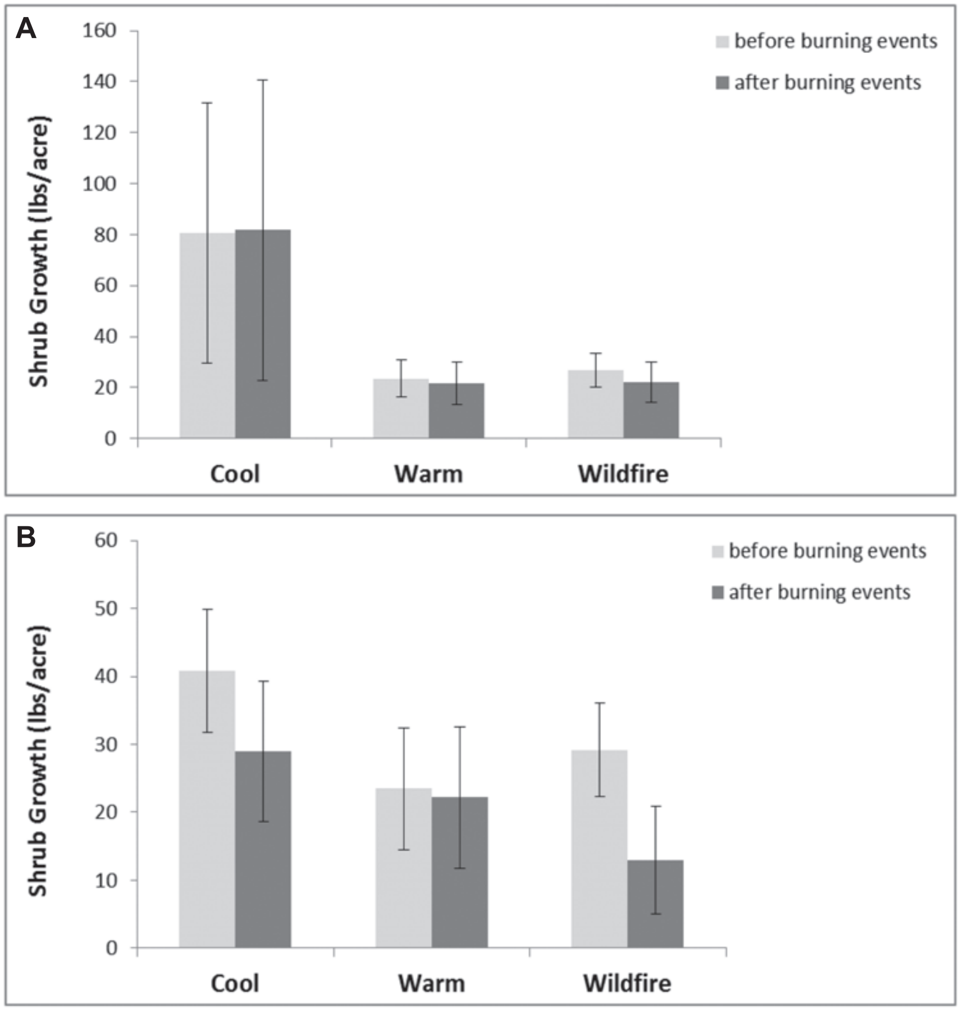

Figure 9—Averages and 90 percent confidence intervals for the early growth (A) and late growth (B) of shrubs on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire. Scales of the Y-axis are unique for each portion of the figure.

Utilization of Forage and Browse Plants

Utilization of forage and browse plants by herbivores was less than 5 percent both before (Ffolliott and others 2008b) and after the burning events. The local rancher removed the cattle from the Cascabel Watersheds in the summer of 2004 because of the prevailing drought conditions (Gottfried and others 2007b), and cattle were not allowed back onto the watersheds throughout the remainder of the study. It was speculated that the Coues white-tailed deer (*Odocoileus virginianus* var. *couesi*), an indigenous ungulate found on the watersheds, move to the higher elevations of the Peloncillo Mountains in the warmest months of the year to escape the high temperatures and lack of water (Ffolliott and others 2012). The low utilization of forage and browse plants by herbivores, therefore, was anticipated.

Tree Overstory-Understory Plant Relationship

Analyses of the frequently reported relationships of increasing production of understory plants with decreasing densities of a tree overstory (Ffolliott and Clary 1982; Bartlett and Betters 1983) indicated that there were no significant correlations between the production of herbaceous plants or the growth of shrubs and the range in densities of the tree overstories on the Cascabel Watersheds either before (Ffolliott and others 2008b) or after the burning events. A lack of correlation between the production of understory plants and the densities of tree overstories has also been found in the higher-elevation oak woodlands (Gottfried and Ffolliott 2002; Ffolliott and Gottfried 2005).

It is likely, therefore, that while the reduction in numbers of trees might have influenced the production of herbaceous plants, the densities of the tree overstories are not a significant factor in influencing the total production of understory plants. To some extent, however, precipitation is a factor influencing the production of herbaceous plants. An earlier study on the Cascabel Watersheds reported "high correlations" between the production of herbaceous plants and the precipitation amounts "favorable" to the seasonal production of these plants (Ffolliott and others 2008b). Depending on the plant component (grasses, forbs, or total herbage) and the season when its production was estimated, up to 64 percent of the variation in these estimates of production was attributed to the seasonal precipitation. Relationships between production of the herbaceous plants and air temperatures or relative humidity were insignificant.

In contrast to the situation on the Cascabel Watersheds, forage production beneath overstories of blue oak (*Quercus douglasii*) trees was significantly greater than the production of forage in the open grasslands on the San Joaquin Experimental Range in the foothills of the Sierra Nevada Mountains in central California (Frost and others 1991, 1997). Most of the forage production in this region occurs in March, April, and May when the soil moisture stored beneath the tree overstories is available for forage growth. However, soil moisture stored in the open grasslands at this time of the year is less because of the warm temperatures and high evapotranspiration rates.

Ecological Diversity

Diversity is a frequent theme of ecological studies because it is a measure of the "well being" of an ecosystem. Ecological diversity of the oak ecosystems in the Southwestern Borderlands Region is a reflection of the inherent structure and functioning, past and present land-use activities, and historical fire regimes (Bahre 1991, 1995; Bahre and Shelton 1996; Sayre 1999; Swetnam and Baisan 1996a, b). This ecological parameter embodies two fundamental indices no matter how it is measured (Magurran 1988, 2004). These indices are species richness (the number of species) and species evenness (how equally abundant the species are). High species evenness, that is, when the species inhabiting an area are virtually equal in their abundance, is equated with high diversity. These two indices were the basis for determining the effects of the prescribed burning treatments and wildfire on the ecological diversities of the understory plants on the Cascabel Watersheds.

The numbers of herbaceous and shrub species tallied on the Cascabel Watersheds before and after the burnings were essentially the same. Therefore, the ecological diversity of understory plants in terms of species richness was not affected by the burning events (fig. 10). However, the frequency of occurrences of these species was not measured either before or after the burns. As a consequence, a "direct measure" of species evenness was not possible. But, assuming that the herbaceous species included in the estimates of the production of herbaceous plants, and the shrub species included in the estimates of the growth of shrubs, can be a proxy for the frequencies of these species, the ecological diversity of understory plants by this measurement is also similar both before and after the burning events. It has been concluded, therefore, that the burns did not affect the general ecological diversity of understory plants on the watersheds.

Conclusions

Assuming that the findings presented in this paper reflect the more general situation in the oak savannas of the Southwestern Borderlands, it is suggested that burning events of low severity have little effect on species compositions. However, these burns can significantly increase the production of both early and late growing grasses in this ecotype. The effect of burning on the production of forb species is inconsistent, and the effect

Figure 10—Species richness of understory plants on the Cascabel Watersheds was not changed by the prescribed burning treatments or wildfire on the watersheds. View of an area burned by the Whitmire Fire in August 2008, about three months after the fire is illustrated by the photograph by Larry Allen, Malpai Borderlands Group.

of burning on the growth of shrubs is inconsequential. Ecological diversity appears to be little changed by such burns. It is unknown if the effects of burning on understory plants reported in this paper would be similar in magnitude following repeated prescribed burning events of low severities. It is also unknown how low-severity burns imposed on other sites in the oak savannas might affect the occurrence of herbaceous plants and shrubs. Furthermore, a hotter fire might produce different findings. Therefore, the results presented in this paper should be considered case studies.

Management Implications

The information in this paper should be useful to managers interested in reintroducing a more natural fire regime into the oak savannas. For example, managers can use the results obtained on the Cascabel Watersheds as initial guidelines on the effects of burning on herbaceous plants and shrubs in the oak savannas since information on these effects are limited. However, managers should also recognize the prescribed burning treatments of low severities on other sites in these ecosystems might not produce results that are similar to those obtained on the Cascabel Watersheds. Additional evaluations of treatments of varying burning severities and seasonal timing are needed to more completely formulate management strategies to achieve the desired benefits.

Evaluations of prescribed burning treatments of varying frequencies and timing should also include studies on the array of ecosystem resources and services available. Such efforts are underway on the Cascabel Watersheds (Gottfried and others 2007b). It is also important that management agencies, private organizations, and local stakeholders continue to collaborate in efforts to obtain more natural fire regimes and derive the resulting benefits.

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