

## CHARACTERISTICS AND BEHAVIOR OF A COOL-SEASON PRESCRIBED FIRE IN THE OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS

Karen A. Koestner,<sup>1</sup> Daniel G. Neary,<sup>1</sup> Gerald J. Gottfried,<sup>2</sup> and Ruben Morales<sup>3</sup>

Oak-savannas and woodlands comprise over 80,000 km<sup>2</sup> (31,000 mi<sup>2</sup>) in the mountains and high valleys of the southwestern United States and northern Mexico (Figure 1). Fire, which was once the most important natural disturbance in this system, has been excluded due to over-grazing and fire suppression practices. This has resulted in ecosystem changes and fuel accumulations. Prescribed fire is one management technique to restore natural processes within southwestern oak-savannas by reducing woody species density, increasing herbaceous plant production, and creating vegetative mosaics on the landscape. Seasonality of burn treatments and their effects on physical and ecological processes need to be determined prior to broad management application. The Cascabel Watershed Study is a collaborative interdisciplinary study to determine the effects of cool-season and warm-season prescribed burning on a southwestern oak-savanna ecosystem. Twelve small watersheds in the Peloncillo Mountains of southwestern New Mexico have been monitored for seven years to provide hydrologic data prior to prescribed burning treatment application (Figure 2). These watersheds are grouped in four replicated blocks, each consisting of a cool-season treatment, a warm-season treatment and a control watershed. This paper will discuss the characteristics and behavior of the cool-season burn treatment, summarizing burn intensity and severity estimates.

### SOUTHWESTERN OAK SAVANNA VEGETATION

Multiple species of oaks are found in the southwestern oak savannas, however Emory oak

<sup>1</sup>Rocky Mountain Research Station, U.S. Forest Service, Flagstaff, Arizona

<sup>2</sup>Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona

<sup>3</sup>Douglas Ranger District, Coronado National Forest, Douglas, Arizona

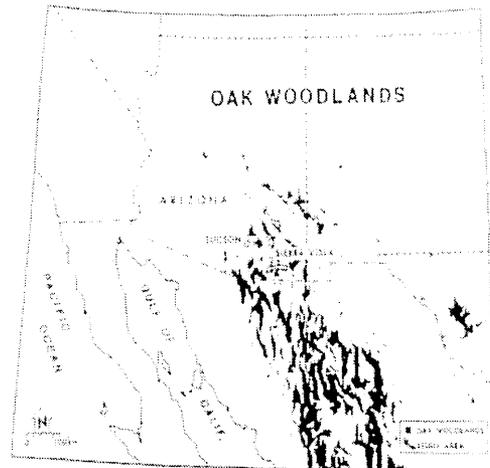


Figure 1. Extent of Southwestern oak woodlands and savannas. (Source: Brown and Lowe 1980.)

(*Quercus emoryi*), Arizona white oak (*Q. arizonica*), and Toumey oak (*Q. toumeyii*) are the most prevalent species in the Peloncillo Mountains (Brown 1982, Ffolliott and Gottfried 2005). These oaks are typically small, multi-stemmed, and irregularly formed with variable stand densities (Gottfried et al. 1995). The oak species native to this region are fire enduring-experiencing top kill / shoot mortality but sprouting following fire (Barton 1999). However, periodic fire is required to limit establishment and growth of woody species in savannas and allow for herbaceous competition (Van Auken 2000). Alligator juniper (*Juniperus deppeana*) is also a common overstory species in this region. Redberry juniper (*Juniperus coahuilensis*), pinyon (*Pinus cembroides*), and velvet mesquite (*Prosopis velutina*) are lesser components of the oak-savanna overstory (Ffolliott and Gottfried 2005).

The savanna or grassland component of this ecotype has multiple bunch grass species including blue (*Bouteloua gracilis*), sideoats (*B. curtipendula*), slender (*B. filiformis*), and hairy (*B. hirsuta*) grama, bull muhly (*Muhlenbergia emersleyi*), wolftail

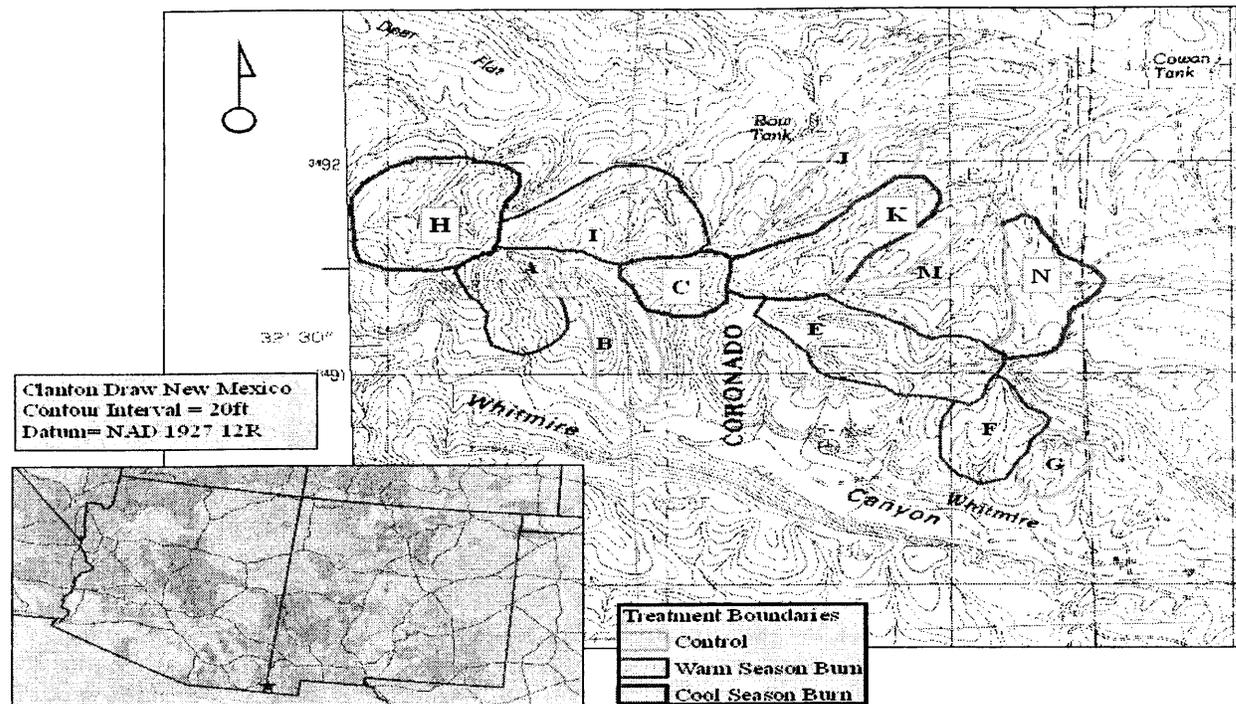


Figure 2. Cascabel watershed study area and treatment designations. Watersheds H, C, K, and N were burned in March 2008 for the cool-season treatment component of the Cascabel watershed study.

(*Lycurus pheoides*), and Texas bluestem (*Schizachrium cirratum*) (Brown 1982, Ffolliott and Gottfried 2005). Some forbs including Fendler ceanothus (*Ceanothus fendleri*) and Mexican cliffrose (*Pushia Mexicana*) can be found in southwestern oak savannas. Intermixed shrub species include Beargrass (*Nolina microcarpa*), fairy duster (*Calliandra eriophylla*), sotol (*Dasylirion wheeleri*), and manzanita (*Arctostaphylos spp.*). Yucca (*Yucca spp.*) and agave (*Agave spp.*) are also scattered throughout the oak-savanna ecotype.

Woody species (mostly oaks) have increased in both density and total cover on the landscape (Hester et al. 1997, Van Auken 2000). Native woody plant (oaks) encroachment has also decreased the cover of perennial grasses (Van Auken 2000, Ottmar et al. 2007). Woody encroachment is the result of both environmental conditions and management practices. Grasses inhibit woody species during early phases of growth, but are out-competed once the roots of woody plants are below the root zone of grasses, a situation that is maintained by fire exclusion (Van

Auken 2000, Webster et al. 2001).

#### FIRE IN THE BORDERLANDS

Fire has been a central component of the development of all southeastern Arizona ecosystems (Allen 1995). Prior to the 1890s wildfires were common in the Southwestern borderlands whenever sufficient fuel loads were present. These were both lightning and anthropogenic fires (Bahre 1991) generally occurring in drought years following a wet period when there was large increase in herbaceous growth (Allen 1995). Fire would typically burn in the dry lightning season from May to July prior to summer monsoons with low severity impacts (Gottfried et al. 2001). The presence and importance of fire on this landscape is further attested to by tree-ring fire scars at higher elevations, the rapid post-fire recovery and/or enhanced vegetation, historic records, and the high frequency of summer lightning ignitions (Bahre 1991).

Fire exclusion for the past century in this region has had considerable ecological effects (Kruse et al.

1996). The historic fire regime in savanna ecosystems is estimated as four to eight years prior to European settlement (Kaib et al. 1999). Several dominant species such as Emory oak and Arizona white oak are adapted to fire and will sprout after their tops have been killed off, though severe fire results in mortality (Ffolliott and Bennett 1996, Barton 1999). Fire exclusion has resulted in fuel accumulation and increased stand densities (Hester et al. 1997). These conditions increase the probability of stand-replacing high-severity wildfires (Gottfried et al. 2002).

Prescribed burning is a potential treatment technique to restore pre-European settlement conditions within the oak savannas (Gottfried et al. 2002). Restoring a more "natural" composition includes density reduction of woody species, increasing herbaceous plant production, and creating mosaics of vegetation on the landscape. Currently however, there is limited information concerning the impacts of prescribed fires on southwestern oak savannas (Barton 1999). The seasonality of fire is an important characteristic because it determines whether or not vegetation will burn during the dormant (cool) season in winter/spring or during the summer growing (warm) season. Brockway et al. (2002) documented grassland response to dormant or cool season fire with an increase grass cover, forb cover, and species richness. While growing or warm season fire reduced graminoids and forbs cover and increased litter cover. Variable removal of vegetation cover and exposure of soil between seasonal burn treatments may alter watershed functioning by increasing erosion, sedimentation and peak flows (Neary et al. 2005). Therefore, if prescribed fire is going to be adopted as a functional management technique in the southwestern border lands, the effects of prescribed fire on the now overstocked oak savannas, and the effects of fire season need to be determined.

#### **COOL SEASON BURN TREATMENT**

Watersheds N, H, K, and C were burned in March of 2008 fulfilling the cool-season treatment component of the Cascabel watershed study (Figure 2). The objective of this treatment was to blacken 50-75% of the watershed surface area with a

cool-season burn at varying severity across the designated watersheds. Up to 60-70% of shrubs within the oak-savannas were to be eliminated as well as the top kill of 25-40% of overstory species. The treatment prescription also called for the reduction of 1 hr (by 30-80%), 10 hr (by 10-40%), 100 hr (by 1-10%), and 1000 hr (by 1-20%) fuels in the watersheds. The environmental prescription for this burn required that temperatures fall between 50-105° F (day) and 30-70°F (night) with relative humidity ranging from 4 - 30%.

This was the first experimental burn treatment on the Cascabel watershed study to determine the impacts of cool vs. warm-season prescribed fire on Southwestern oak-savannas. The overall purpose of the burn is the reduction of hazardous fuels, while maintaining fire's natural role in the Peloncillo Mountains. Continued monitoring of post-fire response to determine the effects of cool and warm season prescribed burning on hydrologic and ecologic processes will be addressed in future studies.

#### **DETERMINING BURN INTENSITY AND SEVERITY**

Burn intensity is the heat produced per unit length of fireline during combustion of a given fuel (Pyne et al. 1996, Neary et al. 2005). Intensity was measured by two methods: infrared thermometer guns and temperature indicating paints. Infrared thermometers were used to take temperatures of different fuels during combustion. Table 1 summarizes the range of temperatures exhibited by various fuels. The ranges of values displayed in Table 1 (minimum to maximum burn temperatures by vegetation type) are extremely variable between fuel types with litter and light grass combusting at the lowest average intensities. *Yucca*, which burned at the highest intensity, had minimal cover on the landscape and was not typically combusted to the soil surface. Whereas bear grass, which burned at medium to high intensities was typically burned right to the soil surface. The range of burn intensities measured for each vegetation type are due to the time in the combustion process when the temperature was recorded, and the wind speed and direction at that time. The values provided are a

Table 1. Burn intensities of various vegetation types as measured with infrared thermometer guns during the cool-season burn treatment, March 2008.

FUEL	AVERAGE	MINIMUM	MAXIMUM	AVERAGE	MINIMUM	MAXIMUM
	TEMP - °C	TEMP - °C	TEMP - °C	TEMP - °F	TEMP - °F	TEMP - °F
LITTER	293.0	293.0	293.0	559.4	559.4	559.4
LIGHT GRASS	463.3	150.0	900.0	865.9	302.0	1652.0
AGAVE	481.5	382.0	581.0	898.7	719.6	1077.8
JUNIPER	586.7	216.0	858.0	1088.1	420.8	1576.4
YUCCA	620.7	225.0	997.0	1149.3	437.0	1826.6
HEAVEY GRASS	638.3	292.0	863.0	1181.0	557.6	1585.4
OAK	657.6	237.0	945.0	1215.7	458.6	1733.0
BEAR GRASS	658.6	164.0	887.0	1217.5	327.2	1628.6
MANZANITA	692.6	542.0	828.0	1278.6	1007.6	1522.4

general characterization of burn intensities of different vegetation types during a cool-season prescribed burn in Southwestern oak-savannas.

Ceramic tiles with temperature indicating paints ranging from 200° F to 2000° F (93° C - 1093° C) in intervals of 100° F (38° C) were placed under various fuel types. The full range of temperature indicating paints were on each tile (200° F to 2000° F) and three tiles were placed beneath each fuel class. When the paint reaches its indicating temperature it liquefies. The fuel types/location used were: light grass (LG), heavy grass (HG), bear grass (BG), oak (O), woody debris (WD), and the watershed channel (C). A full range of burn temperatures were indicated by the paints from <200° F (no liquification) beneath light grass, unconsumed fuels, and in the watershed channel to 2000° F beneath woody debris that was still smoldering the day after the burn. Interpreting the temperature indicating paints was often obstructed by ash. This was not a useful determinant of burn intensity due to the fact that the fire often missed the fuels under which the tiles were placed, and the

discrepancy in interpreting at which temperature the liquification occurred.

Fire severity is the effect that fire has on the environment—a characterization applied to multiple ecosystem components (Neary et al. 2005, Van Wagendonk 2006). For this initial estimate of cool-season burn severity on the Cascabel watersheds, the severity of the burn at the soil surface was considered. Soil burn severity was measured under the same vegetation classes as intensity, at the location where the tiles with temperature indicating paints were placed. This was done to provide a means to compare burn intensity and severity beneath various fuel classes. Using the soil burn severity index outline by DeBano et al. (2005) soils were classified as low, moderate or high severity post-burn. The descriptions of each characterization are: low severity burn: duff largely intact, light ground char, woody debris are partially consumed, mineral soil unchanged. moderate severity burn: litter consumed, duff charred or consumed, woody debris mostly consumed (except logs), gray - white ash present. high severity burn:

duff is completely consumed, top of mineral soil is reddish or orange, logs consumed or deeply charred

The cool-season burn was largely low severity. However, moderate severity was commonly exhibited beneath beargrass clumps, and moderate to high severity beneath consumed or smoldering woody-debris.

Another indicator of severity on post-burn soil properties is water repellency. Soil water repellency (WR) is a property that can be modified by the combustion of litter and organic matter, which can then impact the infiltration of water into the affected soil (DeBano et al. 2005). Determining the occurrence of WR is important as water-repellant soils can result in increases in runoff and erosion. WR was tested using Water-Drop Penetration Time (WDPT), which is the time it takes a drop of water to completely infiltrate into mineral soil. WDPT was extremely variable beneath all fuel types ranging from instantaneous to greater than 2 min at adjacent test locations at mineral soil. However, WDPT 1 cm below the soil surface ranged from instantaneous to 20 sec. Therefore, the impact of the cool-season burn treatment was minimal to non-existent on soil-water repellency across vegetation types.

### CONCLUSIONS

The results summarized in this paper represent initial intensity and severity estimates for a cool-season burn in Cascabel watersheds. The findings indicate that although combustion temperatures (intensity) are high and variable between fuel types, soil severity and soil-water repellency is generally low to moderate following a cool-season prescribed burn in oak savannas of the Southwest. High combustion temperatures do not necessarily result in a high severity burn. To minimize the impacts of prescribed fire, the residence time of a prescribed burn needs to be reduced.

Prescribed fire is a management tool that has potential to restore "natural" species compositions and densities. However, the physical and ecological effects of prescribed fire need to be determined to support environmental analyses of landscape level fire programs. Furthermore, the burn intensity and

severity data presented here provides managers an expected range of fire behavior and its effects by fuel type.

### REFERENCES

- Allen, L.S. 1995. Fire management in the sky islands. In: DeBano, L.F., Ffolliott, P.F., Ortega-Rubio, A., Gottfried, G.J., Hamre, R.H., Edminster, C.B., technical coordinators. Biodiversity and management of the Madrean Archipelago: the Sky Islands of southwestern United States and northwestern Mexico. U.S. Forest Service, General Technical Report RM-GTR-264, pp. 386-388.
- Bahre, C.J. 1991. A legacy of change: Historic human impacts on vegetation in the Arizona borderlands. University of Arizona Press, Tucson, Arizona, 231 p.
- Barton, A.M. 1999. Pines versus oaks: Effects of fire on the composition of Madrean forests in Arizona. *Forest Ecology and Management* 120: 143-156.
- Brockway, D.G., Gatewood, R.G., Paris, R.B. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: initial effects of prescribed burning during the dormant and growing seasons. *Journal of Environmental Management* 65: 135-152.
- Brown, D.E. 1982. Biotic communities of the American southwest-United States and Mexico. *Desert Plants* 4: 1-342.
- Brown D.E., and C.H. Lowe. 1980. Biotic communities of the Southwest. USDA Forest Service, General Technical Report RM-78. (Map)
- DeBano, L.F., Neary, D.G., Ffolliott, P.F. 2005. Soil physical properties. In: Neary, D.G., Ryan, K.C., DeBano, L.F., eds. 2005. Wildland fire in ecosystems: effects of fire on soil and water. U.S. Forest Service. General Technical Report RMRS-GTR-42-Vol.4, pp. 29-51.
- Ffolliott, P.F., Bennett, D.A. 1996. Peak Fire of 1988: Its effect on Madrean oak trees. In: Ffolliott, P.F., DeBano, L.F., Baker, M.B. Jr., Gottfried, G.J., Solis-Garza, G., Edminster, C.B., Neary, D.G., Allen, L.S., Hamre, R.H., tech. coordinators. Effects of fire on Madrean Province Ecosystems. U.S. Forest Service, General Technical Report RM-GTR-289, pp 235-237.

- Ffolliott, P.F., Gottfried, G.J. 2005. Vegetative characteristics of oak savannas in the Southwestern United States: A comparative analysis with oak woodlands in the region. In: Gottfried, G.J., Gebow, B.S., Eskew, L.G., Edminster, C.B., compilers. Connecting mountain islands and desert seas: biodiversity and management of the Madrean Archipelago II. U.S. Forest Service, Proceedings RMRS-P-36, pp. 399-402.
- Gottfried, G.J., Ffolliott, P.F., DeBano, L.F. 1995. Forests and woodlands of the Sky Islands: stand characteristics and silvicultural prescriptions. In: DeBano, L.F., Ffolliott, P.F., Ortega-Rubio, A., Gottfried, G.J., Hamre, R.H., Edminster, C.B., technical coordinators. Biodiversity and management of the Madrean Archipelago: the Sky Islands of southwestern United States and northwestern Mexico. U.S. Forest Service, General Technical Report RM-GTR-264, pp. 152-164.
- Gottfried, G.J., Neary, D.G., Bemis, R.J. 2001. Watershed characteristics of oak savannas in the southwestern borderlands. *Hydrology and Water Resources in Arizona and the Southwest* 30: 21-28.
- Gottfried, G.J., Neary D.G., Bemis R.J. 2002. Assessing the impacts of prescribed burning on soil and water resources of oak savannas in the southwestern United States. In *Assessing capabilities of soil and water resources in drylands: the role of information retrieval and dissemination. Proceedings of the International Arid Lands Consortium conference and workshop. Tucson, Arizona, pp.115-122.*
- Hester, J.W., Thurow, T.L., Taylor, C.A., Jr. 1997. Hydrologic characteristics of vegetation types as affected by prescribed burning. *Journal of Range Management* 50(2): 199-204.
- Kaib, M., Swetnam, T.W., Baisan, C.H. 1999. Fire history in canyon-oak forests, intervening desert grasslands, and higher elevation mixed conifer forests of the southwest borderlands. In: Gottfried, G.J., Eskew, L.G., Curtin, C.G., Edminster, C.B., compilers. *Toward integrated research, land management, and ecosystem protection in the Malpai Borderlands. U.S. Forest Service, Proceedings, RMRS-P-10, pp. 57-64.*
- Kruse, W.H., Gottfried, G.J., Bennett, D.A., Mata-Manqueros H. 1996. The role of fire in Madrean encinal oak and pinyon-juniper woodland development. In: Ffolliott, P.F., DeBano, L.F., Baker, M.B. Jr., Gottfried, G.J., Solis-Garza, G., Edminster, C.B., Neary, D.G., Allen, L.S., Hamre, R.H., Technical Coordinators. *Effects of fire on Madrean Province ecosystems. U.S. Forest Service, General Technical Report RM-GTR-289, pp. 99-106.*
- Neary, D.G., Ryan, K.C., DeBano, L.F., eds. 2005. *Wildland fire in ecosystems: effects of fire on soil and water. U.S. Forest Service General Technical Report, RMRS-GTR-42-Vol. 4.*
- Ottmar, Roger D.; Vihnanek, Robert E.; Wright, Clinton S.; Seymour, Geoffrey B. 2007. Stereo photo series for quantifying natural fuels: volume IX: Oak/juniper types in southern Arizona and New Mexico. U.S. Forest Service General Technical Report, PNW-GTR-714, 41 p.
- Pyne, S.J., Andrews, P.L., Laven, R.D. 1996. *Introduction to wildland fire. John Wiley & Sons Inc., New York.*
- Van Auken, O.W. 2000. Shrub invasions of North American semi-arid grasslands. *Annual Review of Ecological Systems* 31: 197-215.
- Van Wagtenonk, J.W. 2006. Chapter 3: Fire as a physical process. In: Sugihara et al. eds. 2006. *Fire in California's ecosystems. University of California Press; Berkeley, California, pp. 38-74.*
- Webster, G.L., Bahre, C.J., eds. 2001. *Changing plant life of la Frontera: Observations on vegetation in the United States/ Mexico borderlands. University of New Mexico Press, Albuquerque, New Mexico.*