Assessing the Impacts of Prescribed Burning on Soil and Water Resources of Oak Savannas in the Southwestern United States

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ABSTRACT

Oak (encinal) woodlands and savannas cover large areas in the southwestern United States and northern Mexico. However, there is relatively little hydrologic and soils data available to aid in the management of these lands. Fire was the most important natural disturbance prior to European settlement of the region. The decline of the native herbaceous vegetation, because of past over-grazing, and fire suppression activities have resulted in less frequent fires. Prescribed burning is seen as a technique to restore the natural processes within the savannas. However, there are questions about the effects of burning season and fire intensities on this ecosystem. Twelve watersheds on the east slope of the Peloncillo Mountains in southwestern New Mexico have been selected for a study on the impacts of cool season and warm season fires on the hydrology and ecology of oak woodlands and savannas. Two Parshall flumes and a sediment dam and channel cross-sections recently have been installed on each watershed. Weather stations and independent precipitation gauges have been established throughout the study area. Scientists from several organizations also will be studying the effects of burning on side-slope erosion, soil nutrient dynamics and microbiology, water chemistry, vegetation, mammals, and birds.

INTRODUCTION

Oak woodlands and savannas cover large areas in the mountains and high valleys of the southwestern United States and northern Mexico. While the woodlands and savannas provide a number of natural resources and amenities, there is relatively little information available to aid in their management. Public and private land managers are re-introducing fire into the oak ecosystems but are uncertain about the best prescriptions to restore and enhance ecosystem health. A watershed research study recently was initiated to provide scientific support for this effort (Gottfried et al. 2000b). The study, which involves scientists and managers from several agencies and organizations, will examine the hydrology and ecology of oak savannas and will evaluate the impacts of cool season and warm season fires on a number of ecosystem components. The study will be conducted on 12 watersheds that have been instrumented on the east slope of the Peloncillo Mountains of southwestern New Mexico, near the international border. Baseline data from this study will provide managers and scientists with increased knowledge of the biological and hydrologic characteristics and processes on small, oak-covered headwater watersheds in this region of the southwestern United States. Information collected and analyzed after the prescribed burning treatments will give managers a more complete understanding of the impacts of fire on this ecosystem. The objective of this paper is to review general information about the ecology and hydrology of oak woodlands and savannas and present preliminary information about a watershed experiment designed to determine the hydrology and the impacts of warm season or cool season prescribed burning prescriptions on this ecosystem.

Fire in the Borderlands

Fire was the most important natural disturbance in these ecosystems prior to European settlement, but they are less frequent now because of the impacts of past over-grazing on the native herbaceous vegetation and aggressive fire suppression activities. Some areas currently have fuel accumulations that could contribute to detrimental stand replacing wildfires. Prescribed burning is seen as a technique to restore the natural processes within the oak savannas, reduce densities of woody species, increase herbaceous plant production, and create mosaics of vegetation on the landscape. The Coronado National Forest currently is developing the Peloncillo Programmatic Fire Plan to reintroduce fire into the mountain range (Allen 1999). However, there are questions about the effects of burning season and fire intensities on this ecosystem. Fires normally occurred as a result of lightning during the late spring and early summer prior to the growing season. Many managers would like to duplicate nature, but others prefer cool season burning in the early spring or winter. The increase in woody fuels could result in large, high severity fires that destroy vegetation, causing declines in interception of precipitation by both vegetation and litter, and result in soil water repellency (DeBano et al. 1996). Such fires also would result in habitat degradations for several species including threatened, endangered, or sensitive wildlife species. However, there is concern that cool season burning would leave sites bare of vegetation for a longer period, which could result in increased erosion and possibly a shift in plant composition to favor woody species at the expense of herbaceous species.

OAK WOODLANDS AND SAVANNAS

The oak woodlands and savanna, also referred to as the encinal or Madrean evergreen formation, are concentrated in the Sierra Madre Occidental of Mexico and extend northward into southeastern Arizona, southern New Mexico, and Texas. These woodlands cover approximately 80,000 km^2, although a precise delineation of this community is difficult because of differences in classification criteria (Ffolliott 1992). These lands provide a number of natural resources and amenities. They supply tree and other vegetative products, such as firewood, fence posts, acorns, and beargrass (Nolina microcarpa) for local consumption, and are important for livestock grazing and wildlife habitats, especially for a number of threatened, endangered, or sensitive species. The watersheds are important to protect soil stability, water quality, and sustained stream flows. Recreational activities are increasing as the population of the region grows and represent a large income producer for local communities.

Annual precipitation in the oak woodlands generally exceeds 406 mm, with a range of from 305 to 1,016 mm (Gottfried et al.1995). More than half of the precipitation falls in the May through August growing season while the late spring and autumn are dry. The proportion of annual precipitation attributed to summer convectional rains decreases from southeastern Arizona to the northwest. Woodlands generally occur between 1,219 and 2,225 m in elevation. A large variety of oaks are found in the encinal woodlands. Emory oak (Quercus emoryi) is common in the mountains of the Southwestern Borderlands and can be associated with Arizona white oak (Q. arizonica), gray oak (Q. grisae), and Mexican blue oak (Q. oblongifolia). These oaks are generally small, often multiple-stemmed, irregularly formed trees. Redberry juniper (Juniperus coahuilensis), alligator juniper (J. deppeana), and border pinyon (Pinus discolor) are intermixed with the oaks on many sites and Chihuahua pine (P. leiophylla var. chihuahuana) is often found along major drainages. Encinal stand densities are variable and have been related to soil properties; elevation and other topographic characteristics; and fire and human land use histories (Gottfried et al. 1995).

WOODLAND AND SAVANNA HYDROLOGY

There is little information about the hydrology of the encinal woodlands and savannas (Lopes and Ffolliott 1992). Much of the hydrological research in the region has been conducted in the Chihuahuan Desert vegetation at Walnut Gulch, near Tombstone, Arizona (Osterkamp 1999). One of the main gaps concerns streamflow and surface runoff characteristics of the oak woodlands. Surface runoff is the result of both rainfall and snowmelt events; however, high intensity summer rains produce most of the surface runoff and can accelerate erosion and sedimentation. Encinal watersheds also are important because they often contain channels that transmit water from the higher elevation conifer forests. Many of the problems on these watersheds can be linked to past overgrazing of livestock. Periodic high severity, stand-replacing wildfires impact the hydrology of Madrean Province ecosystems because of the loss of vegetative and soil cover. Soil repellency may result in increased overland and stream flows and erosion (DeBano et al. 1996). Good encinal watershed condition is necessary so that accelerated erosion and sedimentation do not impair water quality. This condition is best accomplished by maintaining healthy, well-stocked stands of trees and herbaceous vegetation (Lopes and Ffolliott 1992, Baker et al. 1995). Watershed management objectives are to minimize the adverse effects of current land use activities on soil and water resources, increase water yields, and rehabilitate degraded watersheds. However, it is unlikely that management practices will increase streamflow from the oak woodlands because of the high evapotranspiration demands (Baker et al. 1995).

THE PELONCILLO EXPERIMENTAL WATERSHEDS

Twelve watersheds were selected on the east side of the Peloncillo Mountains of southwestern New Mexico to evaluate the impacts of cool season and warm season prescribed burning on oak savanna ecosystems common to the region (Gottfried et al. 2000b). The baseline data from this study also will increase the knowledge about the hydrology of small oak watersheds in this region of the southwestern United States that can be used for land management activities over a large area. The study currently involves several organizations including the USDA Forest Service, Rocky Mountain Research Station and Coronado National Forest, USDA Natural Resources Conservation Service, Animas Foundation, the Arid Lands Project, the Malpai Borderlands Group, and the University of Arizona. Much of the ecological and management information for the Peloncillo Mountains and the Southwestern Borderlands Region has been collected through the efforts of these organizations and their associates (Gottfried et al. 1999, 2000a).

The Watersheds

The watersheds selected for the experiment are located north of Whitmire Canyon approximately 50 km south of Animas, New Mexico. The research area is primarily within the Coronado National Forest but includes some private ranch land. The watersheds are representative of many oak savanna and open woodland sites in the Southwest based on elevation, annual and seasonal precipitation, and amount of oak cover. The annual precipitation and elevations are near the center of the reported ranges for the type (Gottfried et al. 1995). Elevations range from about 1,640 to 1,705 m. An east-west ridge between Whitmire and Walnut Creeks is the main topographic divide, and six watersheds are on the north side of the ridge and six on the south side. The watersheds range in size from 8 to 34 ha. Important watershed characteristics are presented in Table 1. Annual precipitation averaged 597 mm during a 19-year period (1981-1999) at the Cascabel Ranch headquarters at 1,634 m on the eastern edge of the experimental area; 54% occurred during the July to October rain season. The wettest year was 1991 when 813 mm were measured and the driest year was 1989 when 356 mm of precipitation fell.

Geology, Geomorphology, Soils, and Vegetation

A geology and geomorphologic survey was conducted in the study area (Youberg and Ferguson 2001) to determine if there were differences among watersheds that would compromise the treatment effects or the hydrologic analysis. The Peloncillo Mountains are part of the Basin and Range Physiographic Province. The main creeks in the study area drain into the middle sub-basin of the southern Animas Valley that drains to the north into the Gila River. Streams on the north side of the east-west ridge tend to be longer and have a lower gradient than those on the south side (Table 1). This difference has been related to the relative sizes of Whitmire and Walnut Creeks, lithologic changes, and relative location of the creeks to the crest. Whitmire is a major drainage in the area, and has a larger watershed, carries more streamflow, and has experienced more down cutting than Walnut Creek.

The bedrock geology is described as a rhyolite lava flow overlain by volcaniclastic sedimentary rocks. The Tertiary rhyolite is part of an extensive lava field that was formed about 25 to 27 Ma during the Oligocene. Rhyolites dominate or are important components of the three most western watersheds. Oligocene-Miocene conglomerates and sandstone overlie the rhyolite on the other watersheds. There are no faults or other geological factors that would result in erroneous runoff measurements due to surface water flowing between experimental watersheds or circumventing the flumes. The potential for increased erosion is probably small.

USDA Forest Service soil scientists and ecologists conducted a Terrestrial Ecosystem Survey on the experimental area to describe the relationships that exist among its soil, climate, and vegetation (Robertson et al. 2002). The information will be used to establish soil and vegetation plots to further characterize pretreatment conditions and to evaluate post-treatment effects. The mix of vegetation types varies by soil and climate, with the more western watersheds, which are at a higher elevation, containing more juniper and oaks than the lower elevation eastern watersheds. Grama (Bouteloua spp.) foothills or piedmont grasslands are common to all watersheds. Five TES map units were identified within the experimental area. The major soil subgroups characterized by the five map units included two units with Lithic Argiustolls; a unit with Lithic Ustorthents; and two with Lithic Haplustolls. Differences between similar map units are found at the family level of soil taxonomy and in the vegetation types (Robertson et al. 2002).

Experimental Design

The six watersheds on each side of the ridge were divided into two groups of three contiguous watersheds. Each set will have a spring and a summer burning treatment and an untreated control treatment that will be assigned randomly. Streamflow, erosion, and precipitation data will be collected for at least three years prior to the prescribed burning treatments. A paired-watershed approach will be employed. Streamflow data from individual storms will be the primary response parameter in the analysis of treatment effects. Pre- and post-treatment regressions will be developed among treated and control watersheds and evaluated by covariance techniques. Summer rains are convective and often inconsistent. The pretreatment period may be extended to more than three years if insufficient calibration data are collected (< 30 storms). The final treatment assignments will be reassessed for pretreatment homogeneity after the analysis of the pretreatment data. Variations in watershed size might affect responses; the final assignments within each aspect could be altered once the pretreatment analyses are completed.

Hydrologic Design

Prefabricated Parshall flumes were selected for the experiment, partially because they can be transported across rough terrain and assembled on site. The problem was to design installations that were not so small that they would be unable to measure uncommon, but significant, peak stream flows, and not too large that the majority of more common low flows would not be measured accurately. Climatic and hydrological records for the area are limited, which increases the difficulty of basic hydrological analyses needed for the design of streamflow measurement structures. The relationship between precipitation and streamflow rates is of particular importance. Osterkamp (1999) determined runoff and sedimentation relationships for the Upper Animas Creek Basin, but the results could not be confidently transferred to the small headwater watersheds. An initial approach was to make field measurements that could be used to calculate discharge using the Chezy-Manning Equation (Linsley et al. 1958), but high water marks were not obvious after the relatively dry period. The U.S. Geological Survey (USGS) and USDA Natural Resources Conservation Service (NRCS) equations and procedures became the primary tools for selecting the proper flumes for the 12 watersheds. Flume specifications were based on the 5-year recurrence interval (USGS5 and NRCS5 in Table 1), although other intervals also were calculated.

Discharge equations developed by the USGS for the southwestern United States (Thomas et al. 1994) were one method used to estimate peak flows. The USGS divided the southwestern region into a number of hydrological units and developed regression equations that relate peak discharge to watershed area and, occasionally, elevation for several recurrence intervals (Table 1). The NRCS procedure for simulating a unit hydrograph for streams where rainfall and streamflow data are unavailable (USDA Soil Conservation Service 1984) is based on a curve number (CN) for hydrologic soil groups based on runoff potential, infiltration rates, water transmission rates, and hydrologic conditions, which are based on amount of ground cover. A CN of 84, out of 100, was assumed for the Peloncillo watersheds, indicating soils with high runoff potential and shallow depths over nearly impervious material and ground cover of between 30 and 70%, to calculate NRCS5. The time of concentration (T_c) is calculated using flow length, watershed slope, and the curve number. Isopluvial maps for the region estimated the 5-year, 24-hour precipitation as 61 mm.

The Installations

The decision based on these analyses was to install Parshall flumes with a capacity of 1,628 L/s (liters per second) on eight of the watersheds. Four of the watersheds are on the south side of the ridge (A, B, C, and E) and four are on the north side of the ridge (H, I, K, and M). Smaller flumes with a capacity of 1,209 L/s were installed on the remaining four watersheds. Since we were interested in low flows as well as peak flows, a flume with a capacity of 122 L/s was installed on each watershed. The small flumes can measure flows as low as 2.6 L/s. All of the flumes currently are installed and instrumented and two recording weather stations have been established within the experimental area to relate precipitation to streamflows. The flumes contain electronic stage recorders. The recorders and weather stations are downloaded to laptop computers in the field on a regular schedule. Weather data are available through the web page of Rocky Mountain Research Station in Flagstaff, Arizona (www.rmrs.nau.edu/weather/stations).

A sediment dam was constructed in each watershed and permanent channel cross-section stations have been established. Scientists are monitoring the vegetation, fuel loading, and small and large mammal and bird populations on the watersheds to establish baselines for post-burning evaluations. Additional efforts are being planned to study the effects of treatments on soil chemistry and microbiology.

CONCLUSIONS

Scientists and land managers are attempting to learn more about the oak ecosystems of the southwestern United States and Mexico so that sound land stewardship can be maintained and enhanced. Watersheds are considered a primary landscape unit for many management activities. The reintroduction of fire into the woodlands and savannas is a primary management objective because its declining role over the past 100 years often has resulted in detrimental changes to the land, including overly dense stands of woody species. However, fire used injudiciously can have negative ecological consequences. Research on hydrology and sedimentation dynamics and the related biological studies will be important components in evaluating the impacts of spring and summer prescribed fires in the oak savannas of the southeastern Peloncillo Mountains. Results from the Peloncillo watershed study should be applicable to similar oak woodlands and savannas in the southwestern United States and northern Mexico.

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Table 1. Watershed Characteristics and Five-Year Peak Discharge (L/s) Recurrence Estimates for the Peloncillo Mountains Experimental Watersheds, New Mexico.

WS	Area ha	Av. Elev. meters	Av. Slope percent	Channel Length meters	Channel Slope percent	Aspect degrees	Tc hours	USGS5 L/s	NRCS5 L/s
A	13.8	1692	22.8	380	5.6	160	0.130	1133	1416
B	15.0	1687	28.4	591	7.0	180	0.174	1189	1388
C	13.4	1686	17.5	243	2.5	180	0.148	1133	1303
E	24.3	1677	19.8	655	5.1	175	0.219	1529	2039
F	12.5	1665	16.2	429	6.4	180	0.168	1076	1161
G	8.1	1664	17.4	226	6.7	180	0.126	878	850
H	22.3	1695	18.7	550	5.0	45	0.220	1444	1869
I	33.6	1686	16.6	769	3.8	50	0.275	1812	2577
J2	9.3	1673	20.7	602	5.6	45	0.212	934	793
K	15.4	1677	16.2	688	4.4	60	0.238	1218	1246
M	18.2	1669	17.1	664	4.1	20	0.245	1331	1472
N	10.9	1672	9.0	421	3.6	360	0.283	1019	821

Tc is the time of concentration; the time it for runoff to travel from the hydraulically most distant point of the watershed to its outlet takes.