Soil Erosion and Deposition Before and After Fire in Oak Savannas

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Abstract—*Effects of low severity prescribed burning treatments and a wildfire on soil erosion and deposition in the oak savannas in the Southwestern Borderlands are reported. Measurements in the spring and fall, respectively, characterize soil movements following winter rains and high-intensity summer rainstorms. Annual values are also presented. Relationships between soil erosion and deposition and precipitation amounts, physiographic characteristics, and vegetation were analyzed to determine possible cause-and-effect implications. The information should be useful in developing strategies for re-introducing more natural fire regimes into the oak savannas.*

Introduction

Low severity wildfires were common in the Southwest Borderlands before Euro-American settlement. However, the severities and frequencies of the fires in the region have been altered since the early 1900s largely because of fire suppression policies of management agencies and livestock grazing at this time removed significant portions of the fire-carrying herbaceous fuels (Fulé and Covington 1995). These practices and policies have resulted in increased densities of tree overstories on many sites making them more susceptible to wildfires, insects, and diseases. Unwanted woody plants have often invaded productive rangelands. As a consequence of these conditions, management agencies and their collaborators are exploring the possibility of re-introducing a "more natural" fire regime into the ecosystems of the region including the oak savannas situated between the higher-elevation and more dense oak woodlands and lower-elevation grassland-shrub communities.

Estimates of average soil erosion and deposition before and after cool- and warm-season prescribed burning treatments and a wildfire in the oak savannas are the focus of this paper. Preliminary estimates have been reported earlier (Ffolliott and others 2005). The information presented in this paper and the earlier publication should be useful in accessing the possible effects of re-introducing a more natural fire regime on soil movement in the oak savannas of the Southwestern Borderlands region.

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Cascabel Watersheds

Twelve watersheds, ranging from 20 to almost 60 ac in size, located in the Peloncillo Mountains of southwestern New Mexico were the study site. The total area of these watersheds, called the Cascabel Watersheds, is 451.3 ac. They are situated between 5,380 and 5,590 ft in elevation. The nearest long-term precipitation station indicates that annual precipitation averages 21.8 ± 1.2 in., with nearly one-half falling in summer rainstorms. Streamflow originating on the watersheds is intermittent. High flows can be generated by high-intensity summer rainstorms (Gottfried and others 2006). Most of the surface soils are very gravelly or very cobbly sandy loams or sandy clay loams (Robertson and others 2002). Additional vegetative, geologic, physiologic, and hydrologic characteristics of the watersheds are described elsewhere (Ffolliott and others 2008, Neary and Gottfried 2004, Youberg and Ferguson 2001, and others) and, therefore, are not presented.

Prescribed Fire Treatments and Wildfire

The original objective of the research program on the Cascabel Watersheds was to compare the effects of cool-season (November through April) and warm-season (May through October) prescribed burning treatments on ecosystem resources and hydrologic functioning of the watersheds with similar evaluations on unburned watersheds to assess the impacts of the burning treatments. Following the calibration period, four of the watersheds were burned during the cool-season in early March 2008. Three of the four watersheds to be burned in the warm-season were burned on May 20, 2008, with burning of the fourth watershed scheduled for a later date. However, wind gusts of up to 60 mph blew burning embers onto the remaining watershed to be burned and the four control watersheds in the morning of May 21, 2008. The resulting Whitmire Wildfire crossed the watershed boundaries and spread out to burn nearly 4,000 ac. The current research program, therefore, is evaluating the effects of the prescribed burning treatments and the wildfire on the features originally sampled, including soil erosion and deposition.

Fire Severities

A system relating fire severity to the soil-resource response to burning (Hungerford 1996) was used to classify the severities of the prescribed burning treatments and wildfire on the watersheds. Classifications at the sample plots on the watersheds (see below) were then extrapolated to a watershed-basis to determine the proportion of the watersheds that were unburned or had burned at low, moderate, and high severities. It was determined that all of the watersheds had burned at low severities (Stropki and others 2009).

Study Protocols

Sampling Basis

Between 35 and 45 sample plots that had been established along transects perpendicular to the main stream systems on each of the Cascabel Watersheds were the basis for obtaining the measurements of soil erosion and deposition. Intervals between these plots varied depending on the size and configuration of the watershed. A total of 421 plots were located on the 12 watersheds. These plots have also been used in other studies of ecosystem resources on the watersheds (Gottfried and others 2007).

Measurements of Soil Erosion and Deposition

Three capped pins were placed around every third plot on the watersheds to measure soil erosion and deposition. Measurements of soil loss beneath a cap (soil erosion) or soil accumulation above a cap (deposition) were made in the spring and fall to characterize soil movements following periods of winter rains and summer rainstorms, respectively. Occasionally, there was no change in the soil surface beneath the cap in which case either the magnitudes of soil erosion and deposition between the successive measurements equaled each other or (what is less likely) neither erosion nor deposition occurred. The capped pins were re-set to be flush with the soil surface after each measurement to facilitate subsequent measurements. Measurements obtained at a plot were averaged to estimate soil movements at the plot and the plot measurements on a watershed were then averaged to describe soil erosion and deposition on a watershed-basis. A bulk density value of 70.5 lbs/ft^3 was used to convert the measurements of soil erosion and deposition to corresponding measures in tons per acre on a watershed-basis.

Initial measurements were made in the fall of 2004 with pre-fire measurements continuing in the spring and fall until the burning events occurred. Post-fire measurements were initiated in the spring of 2008 shortly following the cool-season burns with these measurements then made in the fall of 2008 and the spring and fall of 2009 and 2010.

Analysis

Measurements of soil erosion and deposition were analyzed separately because they are separate processes of soil movement. Results of the Shapiro-Wilk test of normality indicated that the frequency distributions for soil erosion and deposition were non-normal. Transformations failed to normalize the distributions. Therefore, occurrences of statistical differences in the measurements were determined by the non-parametric Mann-Whitney test of significance (Zar 1999). This test was applied because the estimates of the respective processes were independent of each other. Plots with no measurable change in soil movement were excluded from the analyses. Differences were evaluated at the 0.10 level of significance.

Results and Discussion

Measurements of soil erosion and deposition are summarized by bar graphs (see below) showing the magnitudes of the respective processes before and after the burning events. Inferences relating to differences in the magnitudes of the two processes are not necessarily valid, however, because the frequency distributions of the data used in developing the bar graphs were non-normal. Significant differences in the measurements of soil erosion and deposition were determined through interpretations of the Mann-Whitney test.

Pre-Fire

There were no statistically significant differences in either soil erosion or deposition among the individual watersheds throughout the pre-fire period. Therefore, the respective data sets were pooled for analysis.

Soil erosion—Soil erosion measurements obtained in the spring following the winter rains were compared to the fall measurements after the summer rainstorms to determine whether seasonal or annual differences occurred. Spring measurements were statistically similar to the fall measurements with an average of 14.6 t/ac. Annual soil erosion averaged 14.2 t/ac. Differences in soil erosion within the seasons and years of measurement were insignificant.

Soil deposition—Soil deposition after the winter rains was also compared to the measurements taken following the summer rainstorms to determine if seasonal differences occurred before the burning events. It was found that the deposition of soil in the spring differed from the depositions in the fall, 4.6 and 7.8 t/ac, respectively, with annual soil deposition averaging 6.3 t/ac. Differences in soil deposition within the seasons and years of measurement were inconsistent and, therefore, considered insignificant.

There were no consistent relationships in the magnitudes of soil erosion or deposition and rainfall patterns or the physiographic characteristics or vegetation surrounding the sample plots.

Post-Fire

Comparisons of the post-fire data sets indicated that there were no significant differences in soil erosion or depositions on the respective watersheds experiencing the prescribed burning treatments or wildfire. Therefore, the data sets were pooled for comparison with pre-fire values.

Soil erosion—Soil erosion following the prescribed burning treatments and wildfire was greater (19.1 t/ac) than measurements of pre-fire soil erosion following winter rains but lower after the summer rainstorms (10.5 t/ac) in relation to pre-fire measurements (fig. 1). There was no significant difference in annual soil erosion as a consequence of the burning events. The seasonal measurements of soil erosion appeared to "balance" each other on an annual basis.

That the annual post-fire erosion of soil after the burning events was within the range of the pre-fire value was likely a result of similar erosive forces generated by rain drops impacting on the soil surface throughout the pre- and post-fire periods. Furthermore, the absence of widespread water repellent soils after the burns (Stropki and others 2009), and, as a consequence, the likelihood of a little change in the overland flows of water necessary to dislodge soil particles from a site occurred. There also was little evidence of increased rill formations on the hillslopes of the watersheds following the three burning events.

Soil deposition—Post-fire deposition of soil following the winter rains was statistically similar to the pre-fire deposition (fig. 2). However, the deposition measured after high-intensity summer rainfalls was significantly greater (11.7 t/ac) following the burning events for a reason unknown to the authors. Soil deposition on an annual basis was also greater following the burning events (9.4 t/ac) because of the difference in the fall measurements.

Similar to the pre-fire findings, soil erosion and deposition following the prescribed burning treatments and wildfire were not related to the rainfall events, physiographic characteristics, or vegetation.

Summary

The information presented in this and the earlier paper on soil movement on the Cascabel Watersheds (Ffolliott and others 2005) should be useful to people interested in knowing the effects of re-introducing a more natural fire regime into the oak savannas of the Southwestern Borderlands. However, knowledge of the effects of prescribed burning treatments of higher fire severities, in other seasons, and on the array of ecosystem resources and factors affecting the hydrologic functioning of watersheds in the oak savannas is necessary before attempting to introduce more natural fire regimes through prescribed burning treatments.

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References

Ffolliott, P. F.; Gottfried, G. J.; Stropki, C. L. 2008. Vegetative characteristics and relationships of the Southwestern Borderlands. Res. Pap. RMRS-RP-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 p.

Ffolliott, P. F.; Stropki, C. L.; Gottfried, G. J.; Neary, D. G. 2005. Initial estimate of soil erosion on the Cascabel Watersheds in the oak savannas of the Malpai Borderlands region. Hydrology and Water Resources in Arizona and the Southwest. 35:51-52.

Fulé, P. Z.; Covington, W. W. 1995. Changes in fire regimes and forest structures of unharvested Petran and Madrean pine forests. In: DeBano, L. F.; Ffolliott, P. F.; Ortega-Rubio, A.; [and others], tech. coords. Biodiversity and management of the Madrean Archipelago: The Sky Islands of southwestern United States and northwestern Mexico. Gen. Tech. Rep. RM-GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 408-415.

Gottfried, G. J.; Neary, D. G.; Ffolliott, P. F. 2007. An ecosystem approach to determining the effects of prescribed fire on Southwestern Borderlands oak savannas: a baseline study. In: Masters, R. E.; Galley, K. E. M., eds. Fire in grassland and shrubland ecosystems: proceedings of the 23rd Tall Timbers Fire Ecology Conference. Tallahassee, FL: Timbers Research Station: 140-146.

Gottfried, G. J.; Neary, D. G.; Ffolliott, P. F.; Decker, D. D. 2006. Impacts of a high-intensity summer rainstorm on two oak savannas watersheds in the Southwestern Borderlands. Hydrology and Water Resources in Arizona and the Southwest. 36:67-73.

Hungerford, R. D. 1996. Soils: Fire in ecosystem notes: unit II-I. Marana, AZ: National Advanced Resources Technology Center.

Neary, D. G.; Gottfried, G. J. 2004. Geomorphology of small watersheds in an oak encinal in the Peloncillo Mountains. Hydrology and Water Resources in Arizona and the Southwest. 34:65-71.

Robertson, G.; Damrel, D.; Hurja, J.; Leahy, S. 2002. Terrestrial ecosystem survey of the Peloncillo watershed study area. Draft Rep. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.

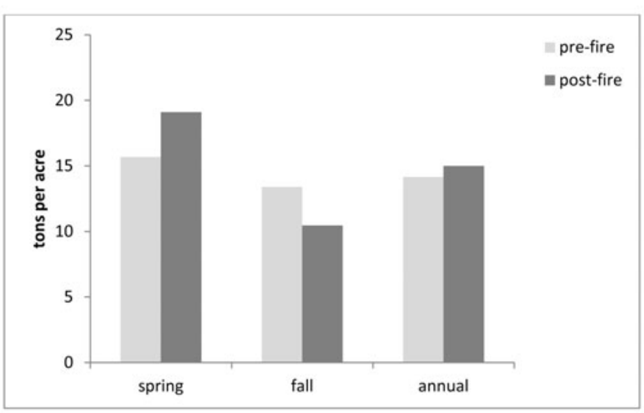

Figure 1—Seasonal and annual soil erosion on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire. Averages for the respective study periods are shown in the figure.

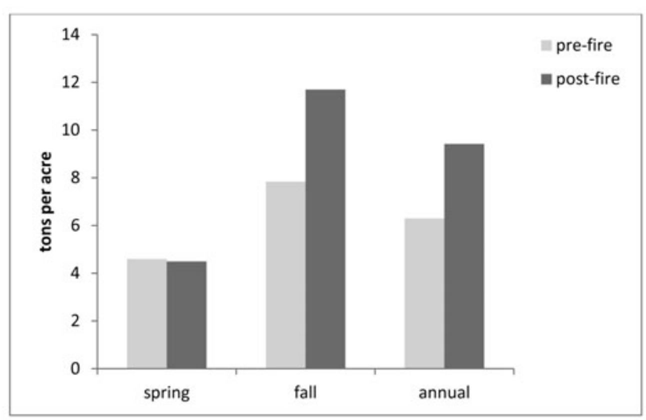

Figure 2—Seasonal and annual deposition of soil on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire. Averages for the respective study periods are presented in the figure.

Stropki, C. L.; Ffolliott, P. F.; Gottfried, G. J. 2009. Water repellent soils following prescribed burning treatments and a wildfire in the oak savannas of the Malpai Borderlands region. Hydrology and Water Resources in Arizona and the Southwest. 39:5-8.

Youberg, A.; Ferguson, C. A.. 2001. Geology and geomorphology of 12 small watersheds in the Peloncillo Mountains, central portion of the Malpai Borderlands project area, Hidalgo County, New Mexico. Open-File Rep. 01-05. Phoenix, AZ: Arizona Geological Survey. 22 p.

Zar, J. H. 1999. Biostatistical analysis. Upper Saddle River, NJ: Prentice Hall. 663 p.

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