Postfire Hillslope Erosion in Southern California Chaparral: A Case Study of Prescribed Fire as a Sediment Management Tool[1]

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Abstract

Land managers in southern California have speculated that prescribed burning could reduce the soil erosion generated by catastrophic wildfires. A unique opportunity to test this notion arose when a wildfire swept over an ongoing field experiment measuring hillslope erosion from a prior prescribed burn. Results indicate that fire severity can affect erosion response, that postfire hillslope erosion levels can return to normal within 3 years, and that prescribed fire can reduce the erosion produced by future wildfires. On the basis of these results, an economic analysis for a hypothetical watershed suggests that prescribed fire can be a viable sediment management tool.

Introduction

Chaparral is the thick blanket of fire-prone brush that covers the lower and middle elevation foothills throughout much of California. This evergreen shrub-dominated plant community with a sparse herbaceous understory covers about 11 percent of the State (Barbour and Major 1988). Chaparral ecosystems appear to be adapted to both summer droughts, associated with the strongly seasonal Mediterranean-type climate, and periodic burning (Axelrod 1989, Zedler and Zammit 1989). Indeed, fire may be necessary for ecosystem perpetuation, as it stimulates the regeneration of many chaparral shrub species (Barro and Conard 1991).

Chaparral typically burns in stand-replacing crown fires that exhibit spectacular fire behavior and have a return interval of 20 to 100 years (Conard and Weise 1998). In heavily populated southern California, where human development has encroached on chaparral brushfields at the urban/wildland interface, fire in chaparral threatens nearby residential communities. Moreover, catastrophic wildfires alter the surface soil conditions, rendering the postburn landscape susceptible to massive erosion, flooding, and downstream sedimentation with the onset of heavy winter rainstorms (Rice 1974, Wells 1981). Consequently, the economic impacts of wildfire and accelerated erosion in chaparral are tremendous.

One method to mitigate the impacts of catastrophic wildfires is through a program of prescribed burning. Selectively burning strategic corridors and buffer zones can reduce hazardous fuel conditions adjacent to urban areas (Green 1981). Prescribed burning of larger land units can also create a mosaic of vegetation age classes on the landscape that will reduce the fire severity in the event of a destructive wildfire and aid suppression efforts in effective fire control (Conard and Weise 1998, Riggan and others 1994). Thus, both the amount of damage and the cost of suppression could be reduced by using prescribed fire as a vegetation management tool.

It has further been suggested that prescribed fire could be used as a sediment management tool. Burning a smaller area under more moderate conditions that generates less site disturbance than a wildfire should reduce the loss of soil and

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nutrients (Green 1981). Because the potential for extensive damage and expensive cleanup costs associated with accelerated erosion in fire-prone chaparral ecosystems is enormous, any reduction in the volume of generated debris would result in cost savings.

Unfortunately, the utility of prescribed fire as a sediment management tool in chaparral has not been adequately demonstrated in the field. Pase and Lindenmuth (1971) reported that a prescribed fire generated only 10 percent of the sediment produced by a wildfire in a comparable area in central Arizona. In southern California, watersheds burned under a moderate intensity prescription yielded only 35 percent as much water and sediment as watersheds burned under a high intensity prescription intended to simulate a wildfire (Riggan and others 1994). Although both these studies suggest that the erosion response after a prescribed fire is lower than that after a natural burn, neither was able to address the impact of prescribed burning on future wildfires.

A long-standing controversy in the management of chaparral ecosystems involves the seeding of introduced grass species as a postfire emergency rehabilitation measure for erosion control (Barro and Conard 1987). Managers are under conflicting pressures to seed burned hillslopes to protect life and property and not to seed to protect native plant communities and endangered species. Much of the controversy has stemmed from the lack of objective data, derived from rigorous field-testing, that managers need to make informed decisions.

To address the question of grass seeding as a viable postfire rehabilitation technique, the USDA Forest Service, in partnership with the California Department of Forestry and Fire Protection, initiated burning and seeding field experiments in 1988. The purpose of this project was to investigate postfire hillslope erosion and vegetation development, and the effect of annual ryegrass for emergency watershed protection, on chaparral sites (Beyers and others 1998b, Wohlgemuth and other 1998). This paper discusses the result of our study on postfire erosion at one of the field sites in southern California that may illuminate the use of prescribed burning as a sediment management tool.

Study Area

The Belmar study area is located in the Peña Canyon watershed on the southern slopes of the Santa Monica Mountains, above the costal community of Malibu, California (fig. 1). Although the Belmar area constitutes an unreplicated case study, it represents much of the central and western Transverse Ranges of southern California in geology, soils, climate, and vegetation, where the problems of fire and accelerated postfire erosion are particularly acute. The characteristics of the Belmar study area are:

Distance from the coast	2 km
Elevation	450 m
Mean aspect	south
Mean slope angle	27°
Parent rock type	sedimentary, primarily sandstone
Soil series	Millsholm
Soil texture	sandy loam
Mean annual precipitation	467 mm

The Belmar site was established in January 1988 and was burned the next June by the Los Angeles County Fire Department. This prescribed fire burned with moderate fire severity-based on the depth of soil char, the diameter of the remaining plant stems, and the degree of consumption of ground litter and foliage (Wohlgemuth and others 1998). However, because of a sharp rise in relative humidity during the prescribed fire operation, it only burned about half

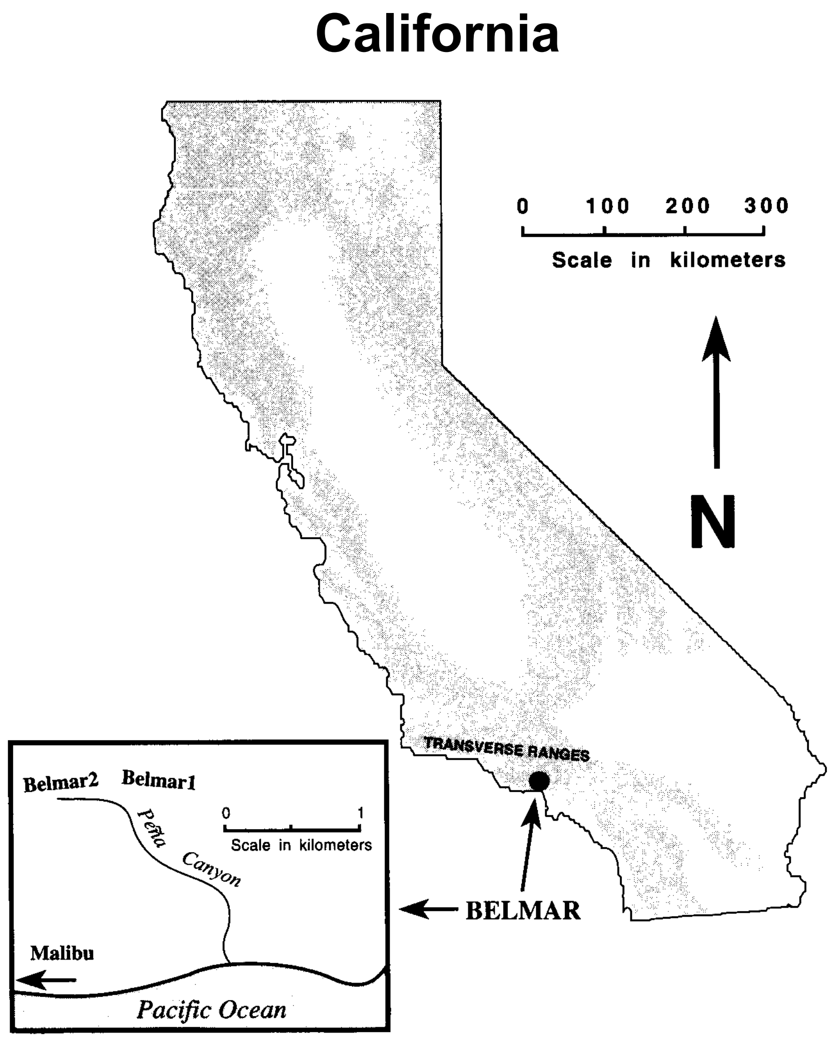

Figure 1

Study area in the coastal southern California mountains.

the site. The unburned portion was eventually abandoned, but the erosion measurement equipment was never removed. The entire Peña Canyon watershed was subsequently burned in the wind-driven Old Topanga Fire of November 1993. The wildfire burned under more severe weather conditions than did the original prescribed burn. Consequently, the prescribed burn section of the Belmar site re-burned with moderate to high fire severity, while the previously unburned vegetation was completely consumed with very high fire severity (Wohlgemuth and others 1998).

Methods

We initially established 70 erosion plots over a 60 ha (150 ac) area in mature mixed chaparral at the Belmar site. Each erosion plot consisted of a segmented sheet metal sediment collector trap with a 1.5 m aperture parallel to the slope contour and an approach apron flush with the mineral soil surface (Wells and Wohlgemuth 1987). These unbordered erosion plots were situated at midslope positions, with the potential contributing area extending to the hillslope crest. Ten of the plots were established outside the firelines to serve as unburned controls. After the prescribed fire, partially burned and unburned erosion plots within the firelines were discarded, and the remaining plots comprise the Belmar1 site *(fig. 1).* After the wildfire, many of the abandoned erosion plots and the previously unburned controls were reactivated as burn plots, constituting the Belmar2 site *(fig. 1).* After both fires, some new erosion plots were established to increase the sample size to 39 and 36 for the Belmar1 and Belmar2 sites, respectively.

Sediment was gathered periodically from the collector traps and taken to the laboratory, where it was dried and weighed. The preburn erosion record consisted of a single collection from January to June 1988, comprised predominantly of wet season sediment movement. Postfire erosion was measured with decreasing frequency for 5 years after each fire. The erosion data were aggregated into wet season (roughly November to March) and dry season (April to October) collection periods, based on the precipitation patterns from a local rain gauge (Wohlgemuth and others 1998).

Most of the erosion plots that became the Belmar2 site were abandoned after the 1988 prescribed burn, and measurements at the Belmar1 site were terminated after 5 years of postburn monitoring in the spring of 1993. Thus, gaps exist in the erosion record of both sites before they were reactivated after the fall 1993 wildfire. Although the magnitudes of the missing data points were small, to compare the erosion response for both Belmar sites over the entire 10-year life of the project, we relied on estimation procedures to fill in these gaps. The missing erosion values for the unburned Belmar2 site were estimated from the relationship between the prefire erosion measurements and those from the unburned controls. The missing values for both sites for the dry season 1993 were estimated by multiplying the median 1992 dry season erosion rate (amount divided by duration) by the duration of the 1993 season.

Because of unequal sample sizes, non-normally distributed data, and our desire to avoid numerical transformations in analyzing the data, central tendency and dispersion were characterized as the medians and semi-interquartile ranges of the distributions. Subsequent statistical analysis used the non-parametric Wilcoxon rank sum statistic (Dixon and Massey 1969) to compare the postfire erosion responses of the various fire scenarios.

Results and Discussion

Wildfires at the wildland /urban interface are seldom beneficial. At the mouth of Pena Canyon during hydrologic year 1994, minor property damage occurred associated with accelerated postfire flooding and erosion (Franklin, pers. comm.). However, the serendipity of an incomplete prescribed burn followed by a wildfire over a site instrumented to measure hillslope erosion afforded us a unique opportunity to evaluate the utility of prescribed fire as a sediment management tool. Specifically, we were able to quantify the postfire erosion response from three distinct fire cases for essentially identical site characteristics: a moderate severity prescribed burn, a moderate to high severity short-interval re-burn, and a very high severity wildfire.

General Post fire Erosion Response

The magnitude and duration of the postfire erosion response of the prescribed burn and the re-burn appear similar *(table 1),* despite the differences in fire severity. Results of the statistical analyses confirm that the two cases were comparable in the immediate postburn environment (the first two years postfire), but show that the prescribed burn produced significantly more ($p=0.03$) erosion over the 5-year study period than did the re-burn. In contrast, the erosion response of the wildfire was 10 times greater than the other two cases during the first two postfire wet seasons *(table 1)* and was significantly greater ($p<0.01$) than the prescribed fire or the re-burn over the 5-year study period. This is consistent with previous observations (Pase and Lindenmuth 1971) and reflects the greater degree of site alteration (foliage and litter consumption, surface soil structure disruption, degree of soil non-wettability) associated with very high severity fires. Because of the initial postfire erosion spike after the wildfire, the abrupt return to normal erosion levels may seem to be quite remarkable. However, our research has shown that burned hillslopes are very resilient, typically recovering to prefire erosion rates in 2 to 4 years (Wohlgemuth and others 1998).

Table 1-*Postfire erosion by season and year postfire at the Belmar study area.*

Year postfire		Belmar bum sites		
		Prescribed burn	Re-burn	Wildfire
		--------Kilograms--------		
Year 1	Dry season	[1]0.35 ± 0.46	(2)	(2)
	Wet season	6.99 ± 2.84	5.40+7.70	97.62 ± 38.55
Year 2	Dry season	3.91 ± 2.82	0.67 ± 0.74	0.70 ± 0.72
	Wet season	2.02 ± 2.25	0.63 ± 0.47	23.34 ± 27.70
Year 3	Dry season	1.69 ± 5.48	1.04 ± 1.34	1.13 ± 0.74
	Wet season	0.51 ± 0.56	0.39 ± 0.71	0.21+019
Year 4	Dry season	1.76 ± 4.70	0.50 ± 0.80	0.33 ± 0.55
	Wet season	0.64 ± 0.92	0.22 ± 0.12	0.26 ± 0.11
Year 5	Dry season	0.46 ± 0.57	0.17 ± 0.27	0.15 ± 0.48
	Wet season	0.36 ± 0.46	0.25 ± 0.21	0.24+0.50

[1] Median and semi-interquartile range.

[2] As the rainy season commenced shortly after the wildfire, there was no appreciable Year 1 postfire dry season.

Controlling Factors

Factors governing postfire erosion response in southern California are precipitation, vegetation regrowth, and perhaps the depletion of hillslope sediment supply. Generally, postfire soil erosion is more pronounced in wet years than during sub-normal rainfall years, while a greater cover of herbaceous vegetation regrowth has a better ability to retard soil movement (Beyers and others 1998a, Wohlgemuth and others [In press]). We have also speculated (Wohlgemuth and others 1998) that most of the supply of loose, easily erodible soil may be removed in an initial postfire flush, exposing more compacted soil material at the surface during subsequent years.

In addition to the moderate fire severity, the modest erosion response after the Belmarl prescribed burn was probably a result of the prevailing drought conditions *(fig. 2)* that may have also depressed vegetation regrowth. Erosion levels remained low relative to the estimated erosion for the unburned Belmar2 site with the return of wetter weather in 1992-93 *(fig. 2)*. These levels may be the result of differences in vegetation (thick herbaceous ground cover on Belmarl versus chaparral with a negligible understory on Belmar2) but may also reflect hillslope sediment depletion.

The Belmarl re-burn and the Belmar2 wildfire sites burned simultaneously and experienced identical postfire weather patterns: a low rainfall year, followed by a very wet year, followed by 2 years of nearly normal precipitation *(fig. 2)*. The

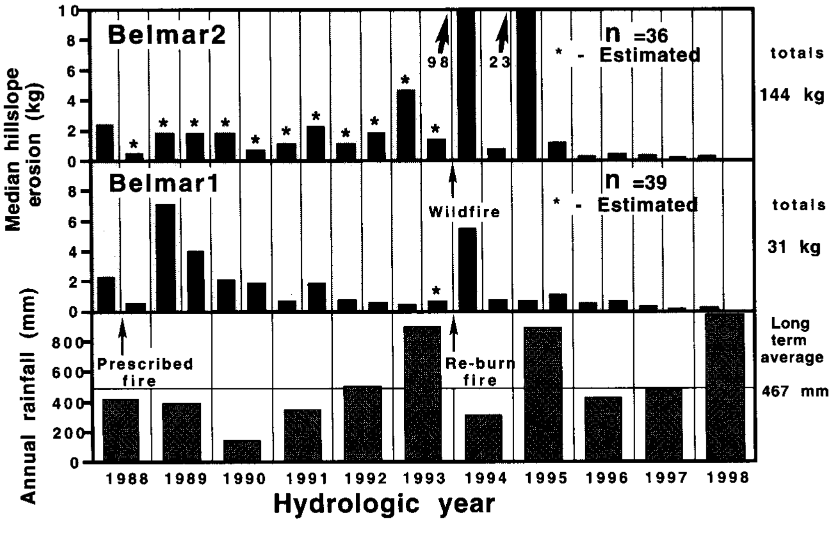

Figure 2

Hillslope erosion and annual rainfall at the Belmar sites by hydrologic year (October 1 to September 30). The shaded background columns are wet season erosion; the unshaded columns are dry season erosion. Column widths are standardized and do not represent the actual season durations.

re-burn site produced only moderate erosion initially and very minor erosion during the subsequent years. This probably reflects the patterns of vegetation regrowth, as the herbaceous cover was two to three times greater after the Belmar1 re-burn than after either the Belmar1 prescribed fire or the Belmar2 wildfire (Beyers and others 1998a). Presumably, the seed bank from the herbaceous plant community after the prescribed fire at the Belmar1 site sprouted vigorously after the re-burn, and the additional cover afforded greater site protection against postfire erosion, even in a very wet year. This would explain the results of our statistical analyses and the lower levels of erosion after the Belmar1 re-burn than after the prescribed burn. Alternatively, the lower level of erosion in the higher rainfall years after the short-interval re-burn may reflect a depletion of hillslope sediment supply.

In contrast, after the wildfire, the Belmar2 site generated substantial sediment movement for both the low and high rainfall years, then abruptly ceased *(fig.* 2). The amount of herbaceous cover after the wildfire was nearly identical to the amount after the Belmar1 prescribed burn (Beyers and others 1998a) in a low rainfall year. This finding strongly suggests fire intensity is a major factor in governing the magnitude of postfire erosion. Despite the relatively rapid recovery period, soil erosion from the wildfire was greater than from the other two fire cases combined. Over a 10-year period for identical site characteristics and rainfall patterns, the Belmar1 prescribed fire and short-interval re-burn together produced only 22 percent of the soil erosion from the Belmar2 wildfire and estimated preburn record *(fig.* 2).

Economic Analysis

By using the postfire erosion response relationships from the Belmar study area, an economic analysis can be developed for a hypothetical southern California watershed comparing the cost of sediment management resulting from prescribed burning to that from wildfire. We assumed a hypothetical intermediate-sized watershed of 400 ha (1,000 ac). From map analysis, we calculated a drainage density (total length of stream channels per unit area) of about 9 km / km^2 for comparably-sized watersheds in southern California.[4] This yields a total length of channels of 36 km or 36,000 m for our 4 km^2 hypothetical watershed and a total hillslope /channel interface of 72,000 m (as a channel has two banks). Wohlgemuth (1996) reported that the amount of sediment moving down a southern California hillside is comparable to that delivered from the hillslope to the channel. Thus, the total amount of sediment reaching the channel is the product of the interface length times the erosion level.

For the 10-year period at the Belmar1 site that included the prescribed fire and the re-burn, the cumulative median erosion was 31 kg per 1.5 m of slope contour *(fig. 2)*. For our hypothetical watershed, this yields 1.488 million kg of sediment. By using the standard density of 1.0 g CM $^{-3}$ for loose, unconsolidated sediment, this produces 1488 m^3 of eroded material. If a conservative channel delivery coefficient of 0.5 is used to route the sediment down the stream network, this means that 744 m^3 of material would be delivered to the watershed mouth-for example, a debris basin protecting some downstream residential community or a water supply reservoir. Finally, if it costs about \$15 M^{-3} to clean out a debris basin (Bolander, pers. comm.), the total cost of sediment management under this scenario would be about \$11,000.

For the 10-year period at the Belmar2 site that included the wildfire, the cumulative mean erosion was 144 kg per 1.5 m of slope contour *(fig. 2)*. By using the same procedures, our hypothetical watershed would deliver 3,456 m^3 of sediment to the debris basin, generating a total cleanup cost of about \$52,000. Thus, over a 10-year period, prescribed fire could save \$41,000 on the cost of sediment management. If the cost of prescribed burning is about \$250 ha $^{-1}$ (Faser, pers. comm.), then the savings in sediment management would be about 40

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[4] Unpublished data on file, Pacific Southwest Research Station, Riverside, Calif.

percent of the cost of burning the hypothetical watershed. Admittedly, the savings in sediment management resulting from prescribed burning is small compared to the estimated savings of \$2,500 ha $^{-1}$ in suppression costs in the event of a wildfire (Faser, pers. comm.). However, the savings in sediment management is itself a considerable sum that needs to be included in any cost-benefit analysis, and suggests that prescribed fire is an economically viable sediment management tool.

Conclusions

Fire and accelerated postfire erosion in southern California chaparral are inevitable. It has long been suggested that prescribed fire could be used as a sediment management tool to mitigate the potentially disastrous erosion effects of catastrophic wildfires, but little objective data have been available to confirm this notion. After a fortuitous wildfire burned over the area of a former prescribed burn and a previously unburned companion site, we were able to compare the erosion response of three fire scenarios for essentially identical site characteristics. Data from the Belmar area indicate that fire severity affected erosion response, as the wildfire case generated 10 times as much sediment as the prescribed burn in the first postfire winter with similar amounts of rainfall and vegetation regrowth. Postfire erosion recovered to normal levels in as little as 2 years, although it is unclear to what degree these measured responses reflect vegetation regrowth or the depletion of the supply of loose surface soil. Prescribed fire reduced the hillslope erosion of a future wildfire in the Belmar area, with the prescribed fire plus the re-burn cases together producing only 22 percent of the sediment generated by the wildfire. By using the erosion responses from the Belmar area, an economic analysis for a hypothetical watershed indicated that prescribed burning can result in considerable savings in sediment management costs in the event of a wildfire. Undoubtedly, the specific erosion and cost values would be different at other study sites with different fire characteristics and rainfall patterns, but it is likely that the general trends would be similar. Although more examples are needed to fully explain the effects of prescribed burning on the erosion response of future wildfires, this case study suggests that prescribed fire can be an effective and economically viable sediment management tool.

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