Effects of Fire and Grass Seeding on Soil Erosion in Southern California Chaparral

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Introduction

Chaparral in California is a shrub-dominated plant community that covers about eleven percent of the state (Barbour and Major 1988). Chaparral appears to be adapted to both summer droughts, associated with the strongly seasonal Mediterranean climate, and periodic burning (Axelrod 1989, Zedler and Zammit 1989). Indeed, fire may be necessary for ecosystem perpetuation by stimulating the regeneration of many chaparral plant species (Burro and Conard 1991). However, catastrophic wildfires may render the postburn landscape susceptible to massive soil erosion, flooding, and downstream sedimentation with the onset of heavy winter rainstorms. Many of these brushfields occur at the urban/wildland interface, where burgeoning population centers in the lowland valleys have encroached on adjacent foothills and steep mountain fronts. Consequently, the societal impacts of wildfire and accelerated erosion in chaparral are tremendous.

The general patterns of posture soil erosion on chaparral hillslopes in southern California have been well documented (Rice 1974, Wells 1981, Wells 1986, Wells et al. 1986, Wells 1987). Fires remove the protective vegetation and organic litter cover from hillsides, and can destabilize surface soils on steep slopes. During and immediately after a fire, surface erosion increases by raveling or gravity sliding, as organic barriers to sediment movement have been incinerated and soil structure disrupted. With the beginning of the rainy season, soil erosion again increases, as the denuded hillsides are exposed to raindrop impact and surface runoff. Moreover, the production of afire-induced, near-surface water repellent soil layer (DeBano 1981) alters hillslope hydrology by restricting soil water infiltration. This can generate extensive overland flow capable of eroding considerable quantities of soil material. . Erosion generally remains elevated for several years after a fire, decreasing over time as the area revegetates, and watershed erosion rates return to prefire levels within 5 to 10 years (Rowe et al. 1949).

The potential for extensive damage and expensive cleanup costs associated with accelerated erosion, flooding, and sedimentation in fire-prone chaparral ecosystems is enormous. Land managers and fire protection agencies have undertaken a variety of postfire emergency rehabilitation measures to protect downstream life and property. While many possible options for erosion control are available, including expensive engineering structures (USDA Forest Service 1992), conventional wisdom holds that it is most cost-effective and realistic to attempt to reduce erosion at the source--i.e. the hillslopes (Rice et al. 1965).

As an onsite erosion mitigation measure, land managers have typically employed grass seeding as an emergency rehabilitation technique. Seeding treatments seek to rapidly establish a dense ground cover on burned hillslopes that will hold the soil in place until the area revegetates. By 1950 annual ryegrass (Lolium multiflorum) had become the species of choice for postfire seeding in chaparral ecosystems: it germinates quickly; produces an extensive root system; is inexpensive and readily available; and can be easily applied to large areas from the air (Burro and Conard 1987).

The utility of grass seeding as a watershed protection practice remains uncertain, however, as there has been generally little monitoring of treatment effectiveness. Many projects have been evaluated qualitatively or subjectively, perhaps with a photo series to document the degree of postfire ground cover. Rigorous quantification of hillslope erosion has been lacking (Burro and Conard 1987). The few studies that have measured surface erosion and compared postfire treatment effects suffered from inadequate sample sizes (Blankenbaker and Ryan 1985), or were confounded by factors such as severe animal disturbance on small plots (Taskey et al. 1989) or extremely low precipitation in the first postfire winter (Rice et al. 1965).

A fundamental difficulty of working in chaparral ecosystems is the huge spatial and temporal variability in hillslope erosion response (Wells 1981, Wohlgemuth 1986). To overcome this variability, field experiments should be widely replicated over both space and time; to the maximum that logistics and budgets will allow. Otherwise, the results of an individual site from a single year may reflect specific local site characteristics and/or postfire weather patterns, rather than general erosion responses or hillslope treatment effects. This paper presents the results of burning and seeding field studies to quantify both postfire hillslope erosion response and the effect of annual ryegrass for emergency watershed protection in southern California chaparral ecosystems.

Methods

Study sites were established within four upland regions across coastal central and southern California that reflect a variety of topographic and substrate conditions-the Peninsular Ranges, the central Transverse Ranges, the western Transverse Ranges, and the southern Coast Ranges (see Figure 1 and Table 1). All sites were located in areas that were targeted for burning by federal, state, or county agencies as part of fuel hazard reduction programs. The four study sites burned in three different years: Belmar in 1988, Bedford and Vierra in 1990, and Buckhorn in 1994. In addition, the Belmar site and a previously unburned companion site (Belmar2) burned in a wildfire in 1993, yielding results from five different fires (Beyers et al. in press, Wohlgemuth et al. in press).

We established 70 erosion plots in mature, mixed chaparral at each site. Each erosion plot consisted of a set of five sheet metal sediment traps with a 30 cm aperture parallel to the slope contour and an approach apron flush with the mineral soil surface (Wells and Wohlgemuth 1987). These unbordered plots were situated at midslope positions, with the potential contributing area extending to the hillslope crest. We measured both wet season (roughly November to March) and dry season (April to October) hillslope erosion for one to four years prior to burning. At each site, ten plots were established outside the firelines to serve as unburned controls. The rest were burned in prescribed fires intended to mimic wildfire conditions. Fire severity, based on the degree of consumption, was evaluated for each site and is arrayed in Table 1. Partially burned plots were discarded, and half of the remainder were randomly selected for seeding with annual ryegrass. Seed was applied in the late fall with hand-spreaders at a rate of 9 kg/ha, comparable to aerial seeding operations (Burro and Conard 1987). Postfire erosion was measured with decreasing frequency for up to five years at each site and erosion data were aggregated into wet and dry season collection periods, based on the precipitation patterns from local raingages.

Only about half of the original Belmar site burned in the prescribed fire in 1988. The remaining unburned plots were abandoned (except the original controls). Eroded soil was collected for five postfire winter seasons, as called for in the study plan, and the site was terminated, but the collector traps were not removed. Both sites were reactivated after the 1993 wildfire. The gaps in the erosion record for both sites were estimated from the relationship between the prefire values and those from the unburned controls. The wildfire burned under much more severe weather conditions than did the original prescribed burn. Consequently, the Belmar reburn site burned with higher fire intensity than it did in the prescribed burn, while the previously unburned vegetation on the Belmar2 site was completely consumed.

Because of unequal sample sizes, non-normally distributed data, and our desire to avoid numerical transformations, central tendency and dispersion were characterized as the medians and semi-interquartile ranges of the distributions (Table 2). In addition, differences in seeding treatment at a site were evaluated using a twosample randomization technique (Manly 1991), with each p-value being estimated from 1000 randomizations (Table 2).

This study is unique in several respects. First, by physically capturing soil and sediment in collector traps, we were able to measure hillslope erosion directly, rather than relying on ocular estimates or indirect techniques such as erosion pins (Haigh 1977) or erosion bridges (Ranger and Frank 1978). Second, by using a large sample size, we were able to overcome the large spatial variability inherent in hillslope erosion that has undermined previous studies, as noted above. Third, by using prescribed burns to simulate wildfires, sites were established prior to burning, enabling us to measure prefire erosion levels and the complete postfire erosion record for the exact same location, rather than using uncalibrated controls. Fourth, by establishing sites over a large geographic area and in different years, we were able to quantify erosion response over a wide variety of meteorologic, topographic, and substrate conditions.

Table 1. Comparative site characteristics of the study areas.

Site Location	Bedford Santa Ana Mountains	Vlerra Santa Lucia Mountains	Buckhorn Santa Ynez Mountains	Belmar Santa Monica Mountains	Belmar2 Santa Monica Mountains
Distance from the Coast (km)	37	15	21	2	2
Elevation (m)	670	425	1035	450	450
Mean Aspect	NE	S	SSW	S	SSE
Mean Slope Angle (degrees) 33	27	32	1	28	26
Parent Rock Type	Metamorphic	Volcanic	Sedimentary	(Sedimentary	Sedentary
Soil Texture	Sandy Loam	Rocky Loam	Rocky Loam	Sandy Loam	Sandy Loam
Mean Prefire Vegetation Cover (percent)	33	31	27	45	38
Mean Annual Precipitation (mm)	440	595	690	465	465
Fire Severity (degree of consumption)*	High	Moderate/ High	High	Low/Mod.[1] Mod./High[2]	High
Month of Burn	July	October	March	June[1] November[2]	November

[1] Prescribed Burn
[2] Wildfire

* Fire severity criteria:
Low - leaf litter charred but soil unaffected; unburned foliage greater than 50 percent.

Moderate - leaf litter mostly consumed; charring to soil depths of 1 cm; unburned foliage greater than 25 percent.

High - leaf litter completely consumed; charring to soil depths of 2.5 cm; foliage completely consumed.

Table 2. Annual rainfall (millimeters) and ratios of postfire erosion to calculated unburned baseline erosion for the study sites. Erosion values and composite summaries are the medians and the semi-interquartile ranges of their respective distributions. The p-values are the results of the randomization tests comparing seeded and unseeded plots on a site.

Site	Bedford	Vierra	Buckhorn	Belmar	Belmar2	All
Year 1 Postfire						
Rainfall	476	624	511	389	308	476 ∂ 61
Dry erosion						
Unseeded	2.05 ∂ 2.70	3.44 ∂ 7.71	2.03 ∂1.23	6.08 ∂ 23.78	(b)	2.75 ∂ 1.36
Seeded	1.84 ∂ 1.09	1.34 ∂ 2.02	2.06 ∂ 1.41	5.42 ∂ 6.34	(b)	1.95 ∂ 1.07
p-value	(a)	(a)	(a)	(a)		
Wet erosion						
Unseeded	13.15 ∂ 11.30	30.71 ∂ 23.58	0.13 ∂ 0.05	5.97 ∂ 2.51	37.19 ∂ 12.71	13.15 ∂ 12.37
Seeded	12.46 ∂ 6.44	19.50 ∂ 15.96	0.30 ∂ 0.14	4.56 ∂ 1.60	39.58 ∂ 12.36	12.46 ∂ 7.47
p-value	0.182	0.076	0.459	0.415	0.273	
Year 2 Postfire						
Rainfall	514	639	1105	135	885	639 ∂ 185
Dry erosion						
Unseeded	1.99 ∂ 1.20	1.98 ∂ 1.76	0.13 ∂ 0.09	5.96 ∂ 4.63	0.31 ∂ 0.15	1.98 ∂ 0.84
Seeded	1.46 ∂ 0.44	1.12 ∂ 1.31	0.13 ∂ 0.08	3.00 ∂ 2.41	0.34 ∂ 0.35	1.12 ∂ 0.56
p-value	0.081	0.122	0.147	0.295	0.127	
Wet erosion						
Unseeded	3.34 ∂ 1.73	8.32 ∂ 8.72	0.10 ∂ 0.07	2.72 ∂ 2.09	2.00 ∂ 1.28	2.72 ∂ 0.67
Seeded	2.07 ∂ 0.76	8.43 ∂ 5.36	0.13 ∂ 0.07	0.67 ∂ 0.72	2.52 ∂ 3.13	2.07 ∂ 0.92
p-value	0.079	0.220	0.004	y0.466	0.242	
Year 3 Postfire						
Rainfall	931	846	457	336	419	457 t 213
Dry erosion						
Unseeded	0.62 ∂ 0.61	0.71 ∂ 0.44	0.68 ∂ 1.86	9.76 ∂ 20.21	0.88 ∂ 0.54	0.71 ∂ 0.10
Seeded	0.25 ∂ 0.16	0.33 ∂ 0.23	0.26 ∂ 0.27	4.31 ∂ 16.66	0.84 ∂ 0.61	0.33 ∂ 0.29
p-value	0.002	0.074	0.008	0.443	0.136	
Wet erosion						
Unseeded	0.53 ∂ 0.37	1.17 ∂ 2.46	0.17 ∂ 0.22	1.15 ∂ 0.66	0.03 ∂ 0.03	0.53 ∂ 0.49
Seeded	0.11 ∂ 0.11	0.29 ∂ 1.09	0.10 ∂ 0.14	0.30 ∂ 0.68	0.05 ∂ 0.04	0.11 ∂ 0.09
p-value	0.081	0.035	0.016	0.281	0.255	
Year 4 Postfire						
Rainfall	325	347	(c)	490	464	406 ∂ 70
Dry erosion						
Unseeded	0.21 ∂ 0.30	0.34 ∂ 0.27	(c)	3.21 ∂ 5.26	0.34 ± 1.81	0.84 ∂ 1.00
Seeded	0.10 ∂ 0.06	0.17 ∂ 0.09	(c)	0.79 ∂ 3.04	0.83 ∂ 1.12	0.48 ∂ 0.34
p-value	0.001	0.003		0.353	0.095	
Wet erosion						
Unseeded	0.30 ∂ 0.68	0.39 ∂ 0.36	(c)	0.92 ∂ 1.18	0.08 ∂ 0.03	0.35 ∂ 0.23
Seeded	0.10 ∂ 0.07	0.17 ∂ 0.19	(c)	0.63 ∂ 1.77	0.14 ∂ 0.06	0.16 ∂ 0.14
p-value	0.001	0.001		0.163	0.308	
Year 5 Postfire						
Rainfall	732	1072	(c)	893	(c)	893 ∂ 170
Dry erosion						
Unseeded	0.18 ± 0,15	0.30 ∂ 0.20	(c)	0.46 ∂ 0.62	(c)	0.30 ∂ 0.14
Seeded	0.16 ∂ 0.13	0.24 ∂ 0.20	(c)	0.67 ∂ 1.07	(c)	0.24 ∂ 0.25
p-value	0.258	0.025		0.070		
Wet erosion						
Unseeded	0.37 ∂ 0.48	0.08 ∂ 0.06	(c)	0.08 ∂ 0.14	(c)	0.08 ∂ 0.15
Seeded	0.11 ∂ 0.23	0.08 ∂ 0.07	(c)	0.12 ∂ 0.15	(c)	0.11 ∂ 0.02
p-value	0.004	0.074		0.297		

(a) Not yet seeded (b) Not available (c) Not yet collected

Fifth, one of our sites burned in a wildfire five years after the original prescribed fire, enabling us to quantify the effects on hillslope erosion of a recent reburn. This project, employing identical methodologies over a wide variety of sites and conditions, reprints the most comprehensive hillslope erosion and seeding study to date in chaparral ecosystems.

Results and Discussion

Erosion data from the control plots were used in conjunction with the prefire data from the burned plots to calculate an unburned baseline level of soil erosion for each site location (Beyers et al. in press). This baseline is an estimate of the amount of erosion over time that would have been produced by a site if it had not been burned. The baseline erosion level varies over time, generally increasing in response to greater rainfall, but the magnitude of the fluctuations is very small compared to the change in erosion level following fire: Postfire erosion was compared to the calculated baseline erosion as a ratio to quantify the effects of both the fire and the grass seeding on hillslope surface sediment movement (Table 2). Figure 2 illustrates a generalized pattern of erosion response, based on data from our study sites.

Surface erosion increased dramatically after the fire at most sites and resulted in hillslope erosion up to 40 times greater than prefire levels, consistent with previous observations (Rice 1974, Wells 1981). Variability in erosion response was high, with the values of the semi-interquartile range often exceeding those for the median (Table 2). Accelerated erosion in the form of dry ravel starts during and immediately after the fire, and continues prior to any rainfall. A second pulse of accelerated erosion is generated with the onset of winter rains and associated overland flow. Generally, soil erosion in the first postfire winter is snore pronounced in wet years (or years with very high intensity rains) than during normal or sub-normal rainfall years. In the case of drought years, dry season erosion can actually exceed surface transport during the wet season.

Accelerated postfire surface erosion eventually recovers to prefire levels as the site revegetates. On our sites, erosion levels returned to normal within 2 to 4 years, after which the measured soil erosion values actually dropped below the calculated baseline (see Table 2 and Figure 2). This is similar to the pattern observed by Wells (1981), and results from the increase in vegetation cover associated with the initial herbaceous regrowth and possibly the depletion of hillslope sediment supply (discussed below).

Seeding with ryegrass to reduce soil erosion produced mixed results. On two of the sites (Belmar and Belmar2), there was no treatment difference in erosion rates. On the other sites (Bedford, Buckhorn, and Vierra), significantly more ($p < 0.05$) postfire hillslope erosion was generated on the unseeded plots than the seeded plots for several of the seasonal collection periods (Table 2). However, this difference was not achieved until erosion was at, or below, the baseline level (see Figure 2). Thus, seeding had no effect in the critical first year following the fire.

The wildfire at the Belmar sites provided a valuable opportunity to compare several postfire soil erosion responses for essentially identical site characteristics and rainfall patterns (see Figure 3). Following the prescribed fire, the Belmar site experienced a three-fold increase in soil erosion and a gradual recovery to baseline over the next two years. This modest response was due in part to the prevailing drought conditions, but also reflects the moderate fire severity. Erosion levels remained low relative to baseline and the unburned Belmar2 site with the return of wetter weather in 1992-93. This is a function of the thick ground cover (>75 percent) of herbaceous vegetation growing at the burn site--and its ability to retard soil movement--compared to the relatively open stands (cover values of ~40 percent) of chaparral (Wohlgemuth et al. in press). However, this may also indicate that the supply of loose, easily-erodible soil had been depleted, leaving a more compacted mass exposed at the surface.

Despite the higher fire severity during the wildfire, the Belmar site again experienced a moderate increase in soil erosion in a low rainfall year, slightly lower than after the prescribed burn (see Figure 3). The site recovered after the first postfire winter, however, and soil erosion has remained below baseline since that time, notwithstanding a very wet year. Low rainfall during the first postfire winter would depress the vegetation regrowth, yet high rainfall during the following winter produced very minor erosion. This suggests that depletion of loose surface soil may be an important factor in explaining the observed erosion response.

After the wildfire, the Belmar2 site exhibited a substantial increase in soil erosion, even in a low rainfall year (see Figure 3). Accelerated erosion persisted during the following high rainfall year, then abruptly ceased. Despite the two-year recovery period, soil erosion from the wildfire on the Belmar2 site was greater than the two burns on the Belmar site combined. Over a 10-year period for identical site characteristics and rainfall patterns, the Belmar prescribed fire and recent reburn together produced only 40 percent of the soil erosion from the Belmar2 wildfire and estimated preburn record (see Figure 3); perhaps suggesting that prescribed fire could be used as a sediment management tool.

Conclusions

In southern California chaparral-covered uplands, soil erosion is inevitable. Fire can increase the naturally high hillslope erosion by one to two orders of magnitude. Some of the postfire soil erosion occurs in the dry season on these steep hillsides, and dry season erosion can exceed wet season erosion during drought years. Accelerated erosion by dry ravel immediately following the fire is superseded by the processes of rainsplash and overland flow with the onset of winter rains. Hillslope recovery to preburn erosion levels is rapid, occurring within 2-4 years after the fire, after which soil erosion may actually fall below baseline values. It is unclear to what degree these measured erosion responses reflect the relative importance of the fire characteristics, the vegetation regrowth, or the depletion of the supply of loose surface soil. Grass seeding as a postfire emergency rehabilitation measure does little to reduce erosion until the amounts have already dropped to baseline levels. Thus, it is unrealistic to expect that seeding can ever be more than a partial solution to the management problems associated with accelerated postfire erosion.

Each of these study locations was unique in terms of the combination of site characteristics, fire characteristics, and postfire rainfall that governed vegetation regrowth, soil erosion response, and seeding treatment effectiveness. Although we have been able to make some initial comparisons and note general trends, more study sites with better replication will be necessary before postfire soil erosion patterns are fully explained.

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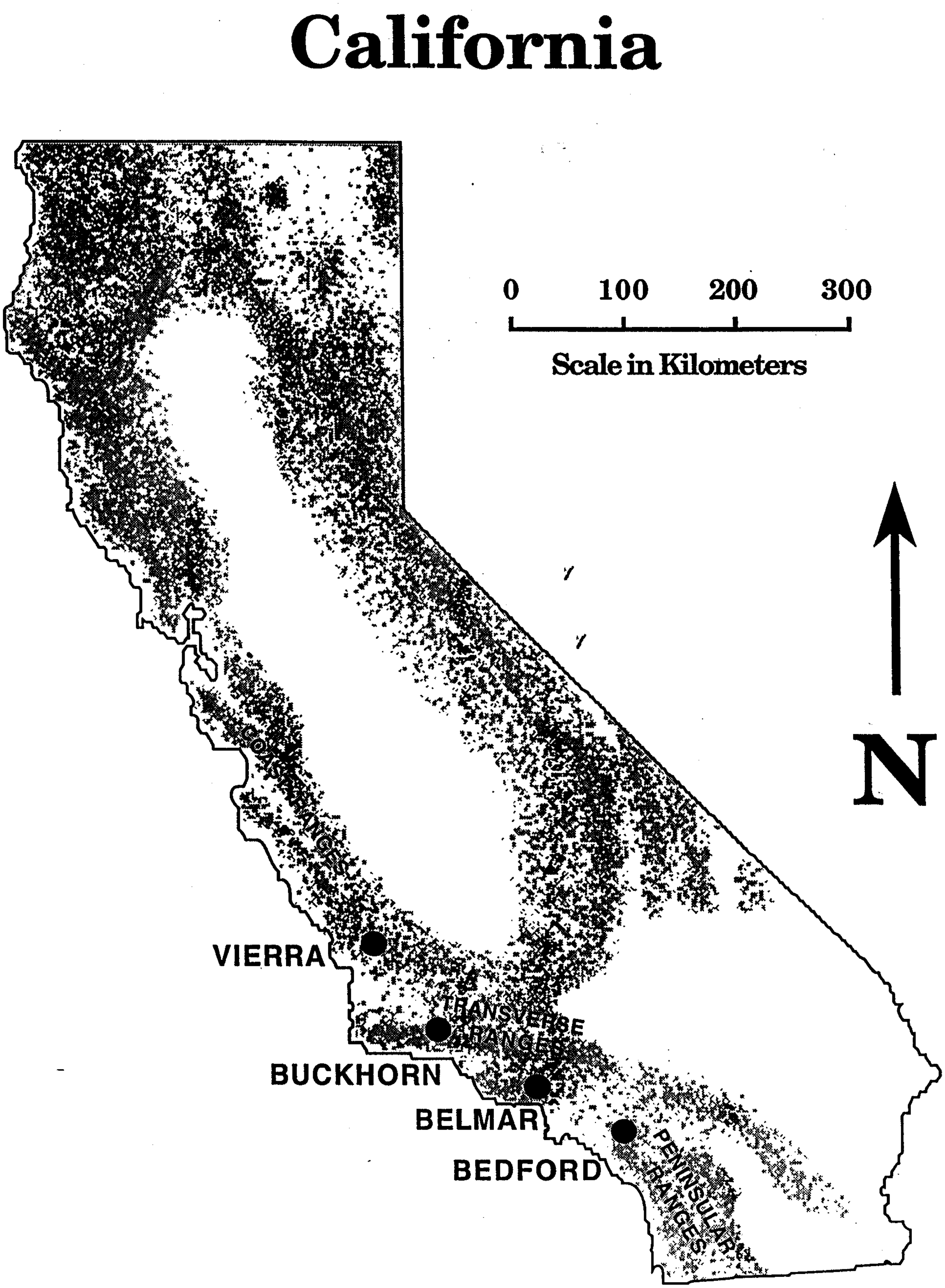

Figure 1. Location map showing the study sites in the coastal central and southern California mountains.

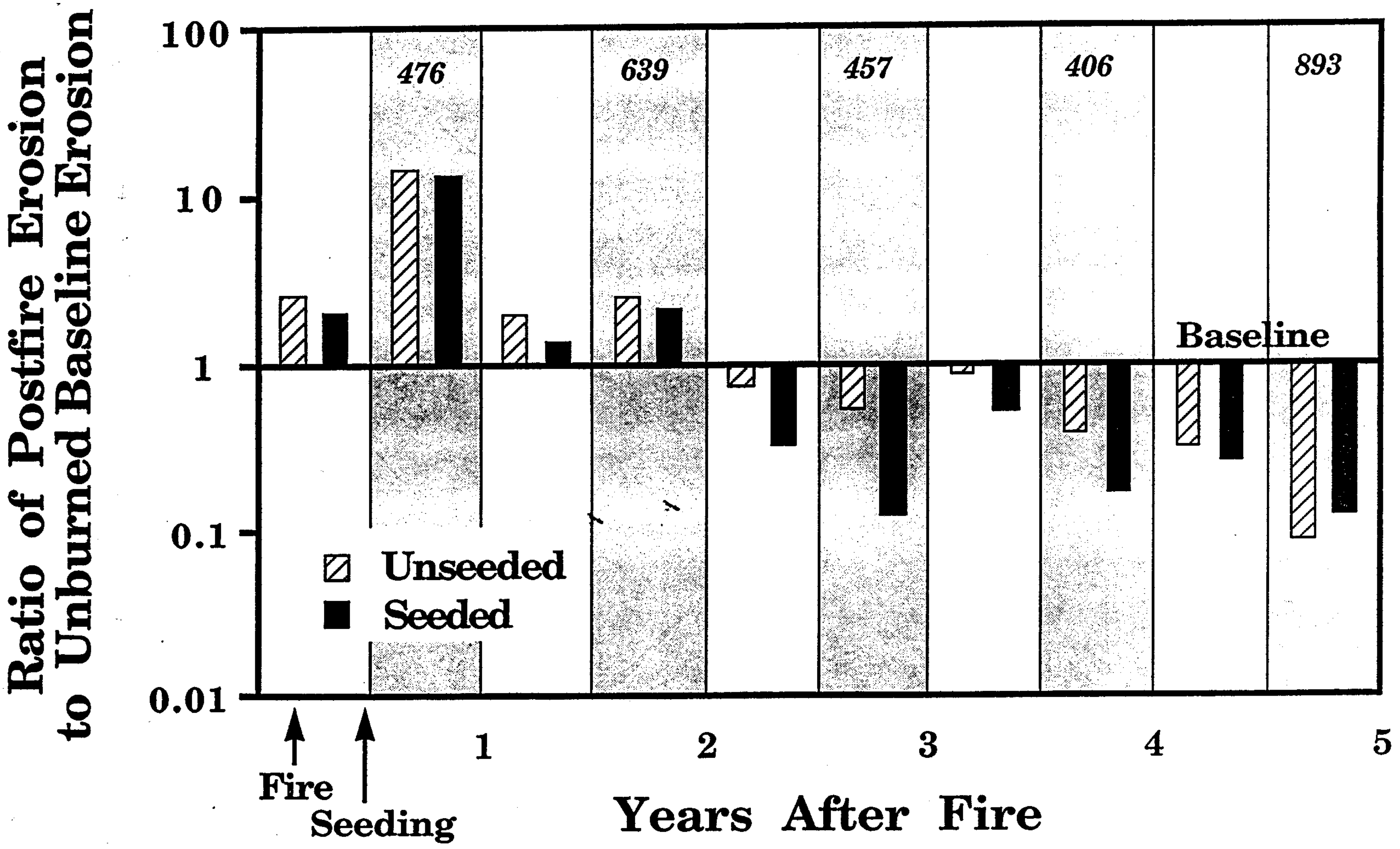

Figure 2. Generalized pattern of postfire hillslope erosion and the influence of ryegrass seeding in southern California chaparral. Histogram heights are the median values of all five burn sites from Table 2 (note logarithmic scale). The baseline is the calculated unburned erosion level (see text). The shaded columns are wet season erosion; the unshaded columns are dry season erosion. Column widths are standardized and do not represent actual season durations. Numbers in italics are the median annual rainfall values for all sites in millimeters.

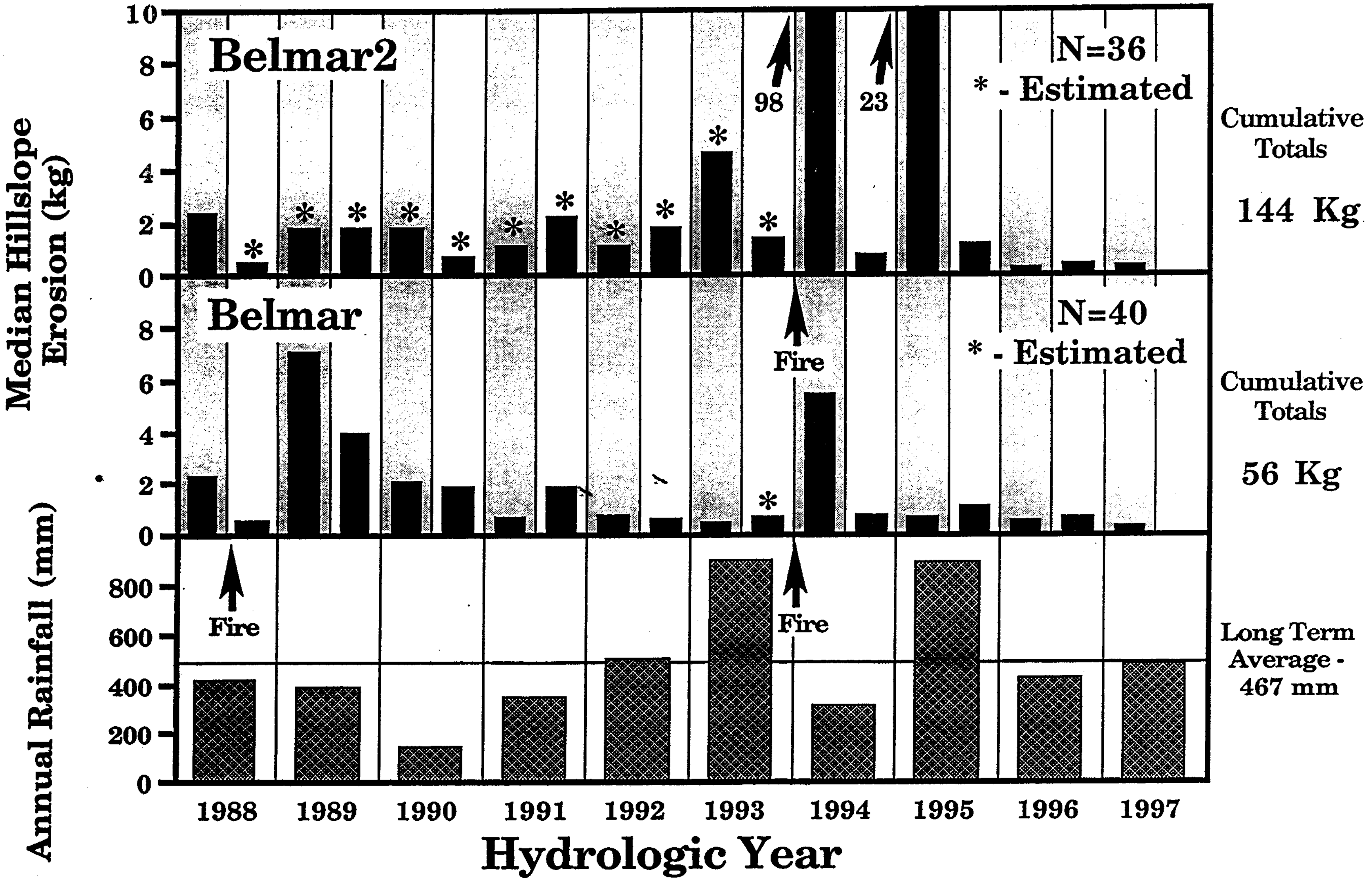

Figure 3. Hillslope erosion and annual rainfall at the Belmar study sites by hydrologic year. The shaded columns are wet season erosion; the unshaded columns are dry season erosion. Column widths are standardized and do not represent the actual season durations. As there was no seeding treatment effect, both seeded and unseeded plots are combined on each site.