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Postfire Vegetation Recovery in the Santa Monica Mountains Under Two Alternative Management Programs

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Abstract.—In the autumn of 1993, two large wildfires were ignited within a week of each other at opposite ends of the Santa Monica Mountains. This study compared postfire plant recovery on the Green Meadow burn, which was managed passively by relying solely on natural regeneration, with recovery on the Old Topanga burn, which was actively managed by aerial seeding of mostly non-native annual grasses and forbs. Establishment of both exotic and native seeded species was very poor and largely insignificant, relative to the natural regeneration. Comparing recovery on the Old Topanga burn and Green Meadow burn, there was no significant difference in plant cover on the two burns. Aerial seeding did contribute to a significantly greater number of non-native species on the Old Topanga burn, but it is unknown whether or not seeding contributed to the reduced species richness observed on the Old Topanga sites.

Over a period of less than 10 days in autumn 1993, the southern California landscape exploded in massive wildfires that burned more than 80,000 ha (Anonymous 1993a). These fires were particularly important because they touched off a storm of controversy that had far reaching political ramifications. Much of the controversy stemmed from the fact that many fires burned simultaneously on lands under the jurisdiction of different agencies which advocated different postfire management practices.

One situation, exploited by the media, was the coincidence of massive wildfires in both the western and eastern ends of the Santa Monica Mountains. The Green Meadow Fire burned over 16,000 ha of state and national park land at the western end of the range, including much of Pt. Mugu State Park. Days later the Old Topanga Fire burned nearly 7000 ha of Los Angeles County and other smaller holdings at the eastern end, between Malibu and Old Topanga Canyon Rd. Almost within days of the Old Topanga Fire, the County of Los Angeles announced that, as an erosion control measure, they would seed lands under their jurisdiction, at a cost of $440,000 (Anonymous 1993b; Keeley et al. 1995). In marked contrast, both the state and national parks announced that seeding was neither necessary nor desirable and, not only would they not seed their lands burned by the Green Meadow Fire, they requested that the County of Los Angeles take care to avoid seeding the small pockets of park land within the Old Topanga Fire. Although the Los Angeles County Forestry Division announced that native species would be utilized, only 3% of the seed mix comprised native species, specifically *Bromus carinatus* (Table 1).

The purpose of this study was to monitor postfire recovery on sites that received aerial seeding within the perimeter of the Old Topanga Fire and on sites not seeded within the perimeter of the Green Meadow Fire. I am testing the hypothesis that

Table 1. Seedling prescription used to aerial seed the Los Angeles County and City of Malibu lands burned by the Old Topanga Fire. Seeding was done in late November 1993. Data were provided by the Santa Monica Mountains National Recreation Area, 18 August 1994. *Bromus carinatus* is a native species, others are not native to California (Hickman 1993).

	Percentage			
	By mass	Numerically@		
Trifolium hirtum (rose clover)	49	22	Seeding density	= 5.4 kg/ha (4.8 lbs/ac)
Vulpia myuros (zorro fescue)	26	56	Area seeded	= 5041 ha (12,456 ac)
Bromus carinatus (California brome)	13	3	Seed cost	= $393,500
Bromus hordeaceous (blando brome)	12	19	Total cost*	= $87/ha ($35/ac)

@ Based on average number of seeds per kg (from Ransom Seed Lab, unpublished data).
* Total cost includes application costs.

aerial seeding of burned slopes increases postfire plant cover over sites recovering naturally.

Study Sites

The primary criteria for site selection were accessibility and lack of other disturbances. Since site characteristics such as slope aspect, inclination, rock cover, soil nutrients, prefire vegetation age and fire intensity can affect vegetative recovery, sites comparable in these respects were selected from both seeded and non-seeded areas. Sites within the Old Topanga Fire were selected from within seeded areas indicated on a map provided by the Los Angeles County Fire Department, Division of Forestry. Ten sites were selected across the extent of the Old Topanga Fire; three at the northern end off Old Topanga Canyon Rd., three near the eastern end in Tuna Canyon, two near the western end in Puerco Canyon, one at the mouth of Carbon Canyon and one in the center of the burn off Schueren Rd.

For the area burned by the Green Meadow Fire and not aerially seeded, ten sites were selected within Pt. Mugu State Park (five in upper Big Sycamore Canyon, five in lower Big Sycamore Canyon), and two additional sites near Circle X Ranch were included.

In the first growing season after the fire, rainfall was slightly below average. Precipitation during the four months of November, December, January, and February, which was between the time of the fire and the first sampling period, was 79% of the long term average for the nearest climatological station at Oxnard (NOAA, Climatological data for California, 1993–1994). The following three months (March, April and May), between the first and second sampling periods, was 90% of the average.

Methods

Each site was 1000 m^2, subdivided into ten plots of 100 m^2 each, in which prefire and postfire shrub composition was determined, and within each of the ten plots, two 1 m^2 subplots were selected and total herb and shrub density was recorded. Also, in each of the 1 m^2 subplots, aerial diameter and height were recorded for three individuals of every species, selected to represent the range of

Table 2. Site characteristics for 22 sites in the Old Topanga and Green Meadow fires.

Site	Distance from coast (km)	Elevation (m)	Aspect (°)	Inclination (°)	Insolation (KC/cm^2)
Old Topanga Fire					
Carbon Cyn	1	60	SSW	28	313
Old Topanga 1	8	475	S	27	316
Old Topanga 2	8	425	W	26	262
Old Topanga 3	8	450	E	12	269
Puerco Cyn 1	1	120	E	28	262
Puerco Cyn 2	1	120	NW	23	219
Schueren Rd	4	600	SSW	19	309
Tuna Cyn 1	2	450	NNW	35	153
Tuna Cyn 2	1	350	E	28	262
Tuna Cyn 3	1	365	NNE	21	202
Green Meadow Fire					
L. Sycamore Cyn 1	2	110	S	21	312
L. Sycamore Cyn 2	2	120	NW	18	232
L. Sycamore Cyn 3	2	160	N	32	176
L. Sycamore Cyn 4	1	75	WNW	30	227
L. Sycamore Cyn 5	4	100	S	20	312
U. Sycamore Cyn 1	10	260	N	27	176
U. Sycamore Cyn 2	10	250	S	31	317
U. Sycamore Cyn 3	9	210	WNW	28	234
U. Sycamore Cyn 4	8	170	NNW	21	202
U. Sycamore Cyn 5	4	130	ESE	22	285
Circle X 1	6	730	NNW	24	184
Circle X 2	6	700	S	21	312

sizes in the subplot. Coverage was estimated by calculating the average aerial cover for the three samples of each species (assuming the canopy approximated a circle) and multiplying by the plot density for that species. Vegetation was sampled in late winter (last week of February) and again in late spring (second week of June) of 1994.

Slope aspect was measured with a compass, inclination with a clinometer. Elevation and distance from the coast were taken from topographic maps. Prefire stand age was determined from polished wood samples cut from shrub skeletons collected at each site. Total annual solar insolation was calculated from tables based on slope aspect, inclination and latitude.

Two estimates of fire intensity were made from measurements of shrub skeletal remains. Since these were not direct measures of fire intensity they were labeled "Fire Severity Indices". Index #1 was based on the diameter of the smallest twig remaining on the shrub skeleton in or nearest to each 1 m^2 subplot. The justification for using this as a surrogate measure for fire intensity is based on a study by Moreno and Oechel (1989) which related known fire intensity to diameter of the smallest twig remaining on shrub skeletons of *Adenostoma fasciculatum.* Since our study dealt with species in addition to *Adenostoma fasciculatum,* we assigned an index, between 1 and 10, to different diameter shrub skeleton twigs based on two assumptions: (1) smaller twigs reflected lower fire intensities and (2) for a

Table 3. Vegetation type, age, fire severity indices and rock cover for the 22 sites in the Old Topanga and Green Meadow fires.

Site	Pre-burn vegetation type	Pre-burn age (yrs)	Average fire severity index 1	Average fire severity index 2	Mean rock cover (%)
Old Topanga Fire					
Carbon Cyn	Coastal Sage	25	4.1	5.6	19
Old Topanga 1	Chaparral	31	4.9	7.2	11
Old Topanga 2	Chaparral	48	4.9	6.3	9
Old Topanga 3	Chaparral	55	4.3	7.2	10
Puerco Cyn 1	Coastal Sage	22	3.3	2.0	1
Puerco Cyn 2	Coastal Sage	21	2.5	4.5	5
Schueren Rd	Chaparral	25	7.5	4.9	18
Tuna Cyn 1	Coastal Sage	36	4.2	4.9	15
Tuna Cyn 2	Chaparral	24	4.8	4.9	5
Tuna Cyn 3	Chaparral	24	7.2	4.9	6
Green Meadow Fire					
L. Sycamore Cyn 1	Coastal Sage	19	4.4	6.7	21
L. Sycamore Cyn 2	Coastal Sage	20	4.5	5.5	4
L. Sycamore Cyn 3	Chaparral	21	3.0	5.5	14
L. Sycamore Cyn 4	Coastal Sage	3	1.2	4.0	3
L. Sycamore Cyn 5	Chaparral	17	6.4	7.8	30
U. Sycamore Cyn 1	Chaparral	26	9.2	4.9	5
U. Sycamore Cyn 2	Coastal Sage	26	6.2	4.9	28
U. Sycamore Cyn 3	Chaparral	6	2.1	4.9	9
U. Sycamore Cyn 4	Chaparral	31	3.9	4.9	14
U. Sycamore Cyn 5	Coastal Sage	20	3.9	4.9	24
Circle X 1	Chaparral	48	3.8	4.9	6
Circle X 2	Chaparral	35	4.5	4.9	8

given twig diameter, coastal sage shrubs would have generated a lower fire intensity than chaparral shrubs. Fire Severity Index #2 was based on the height above ground level of shrub skeleton. Within each of the ten 100 m^2 plots, five skeletons of each woody species were measured. As with Index #1, indices from 1 to 10 were assigned to different heights based on two assumptions: (1) shrub skeletons burned to ground level reflected higher fire intensities than skeletons still standing, i.e., shorter skeletons reflected a higher fire intensity than taller skeletons, and (2) for a given skeleton height, coastal sage shrubs would have generated a lower fire intensity than chaparral shrubs. Although it is expected that stand age would affect this index, insufficient understanding of this relationship precluded using age in this index.

At each site, rock cover (as a percentage of ground surface covered) was visually estimated in each 1 m^2 subplot. Soil nutrient analyses were performed by the soil testing lab in the USDA Forest Service, Riverside Fire Lab on three samples collected in early spring from each site.

Pairwise comparisons were made with either a one-tailed or two-tailed t-test, as appropriate. Correlations were with the Pearson product moment correlation coefficient.

Table 4. Average soil characteristics for the 22 sites in the Old Topanga and Green Meadow fires (N = 3).

	Soil characteristics					
Site	pH	Sand (%)	Clay (%)	P (%)	N (%)	C (%)
Old Topanga Fire						
Carbon Cyn	6.3	59	10	0.05	0.30	4.9
Old Topanga 1	6.6	56	18	0.06	0.16	2.2
Old Topanga 2	6.8	33	28	0.05	0.16	2.5
Old Topanga 3	6.3	62	16	0.04	0.15	2.3
Puerco Cyn 1	6.6	47	34	0.07	0.26	2.8
Puerco Cyn 2	6.5	38	39	0.06	0.29	3.5
Schueren Rd	6.5	61	13	0.06	0.32	4.4
Tuna Cyn 1	6.5	68	11	0.05	0.33	5.2
Tuna Cyn 2	6.5	67	12	0.05	0.33	5.0
Tuna Cyn 3	6.4	54	19	0.04	0.30	4.4
Green Meadow Fire						
L. Sycamore Cyn 1	6.5	59	15	0.09	0.29	3.5
L. Sycamore Cyn 2	6.4	58	13	0.08	0.32	3.9
L. Sycamore Cyn 3	6.8	64	14	0.03	0.15	2.5
L. Sycamore Cyn 4	7.0	53	25	0.04	0.21	2.7
L. Sycamore Cyn 5	6.8	57	16	0.05	0.42	7.8
U. Sycamore Cyn 1	7.1	56	12	0.04	0.38	6.4
U. Sycamore Cyn 2	6.6	58	16	0.07	0.18	2.7
U. Sycamore Cyn 3	6.3	49	19	0.06	0.49	8.1
U. Sycamore Cyn 4	6.1	60	15	0.06	0.37	5.3
U. Sycamore Cyn 5	6.2	58	15	0.05	0.27	3.0
Circle X 1	6.8	54	20	0.06	0.43	7.3
Circle X 2	6.6	58	14	0.08	0.48	6.6

Results and Discussion

Site Characteristics

A summary of the site characteristics is given in Tables 2, 3, & 4. The 10 sites aerially seeded within the perimeter of the Old Topanga Fire were generally similar to the 12 sites not seeded within the perimeter of the Green Meadow Fire. Both seeded and non-seeded sites included ones near the coast and ones 8–10 km further inland; sites near sea-level and above 600 m; sites on all major slope aspects and sites with a similar range of inclines.

In each burn, approximately half of the sites were in coastal sage scrub and half in chaparral. Prefire stand ages were mostly between 20–30 yrs but the range was from 3 to 55 yrs; mean was 31 yrs for the Old Topanga Fire and 27 yrs for the Green Meadow Fire. Based on the two measures of fire severity, apparently there were sites in each burn that were more intensely burned than others. Other characteristics such as rock cover and soil characteristics were generally similar between sites in the two burns (Tables 3 and 4). Using a 2-tailed t-test, there was no significant difference ($P > 0.05$) between Old Topanga sites and Green Meadow sites for the site characteristics specified in Tables 2–4.

Thus, site characteristics between seeded and non-seeded sites were broadly similar.

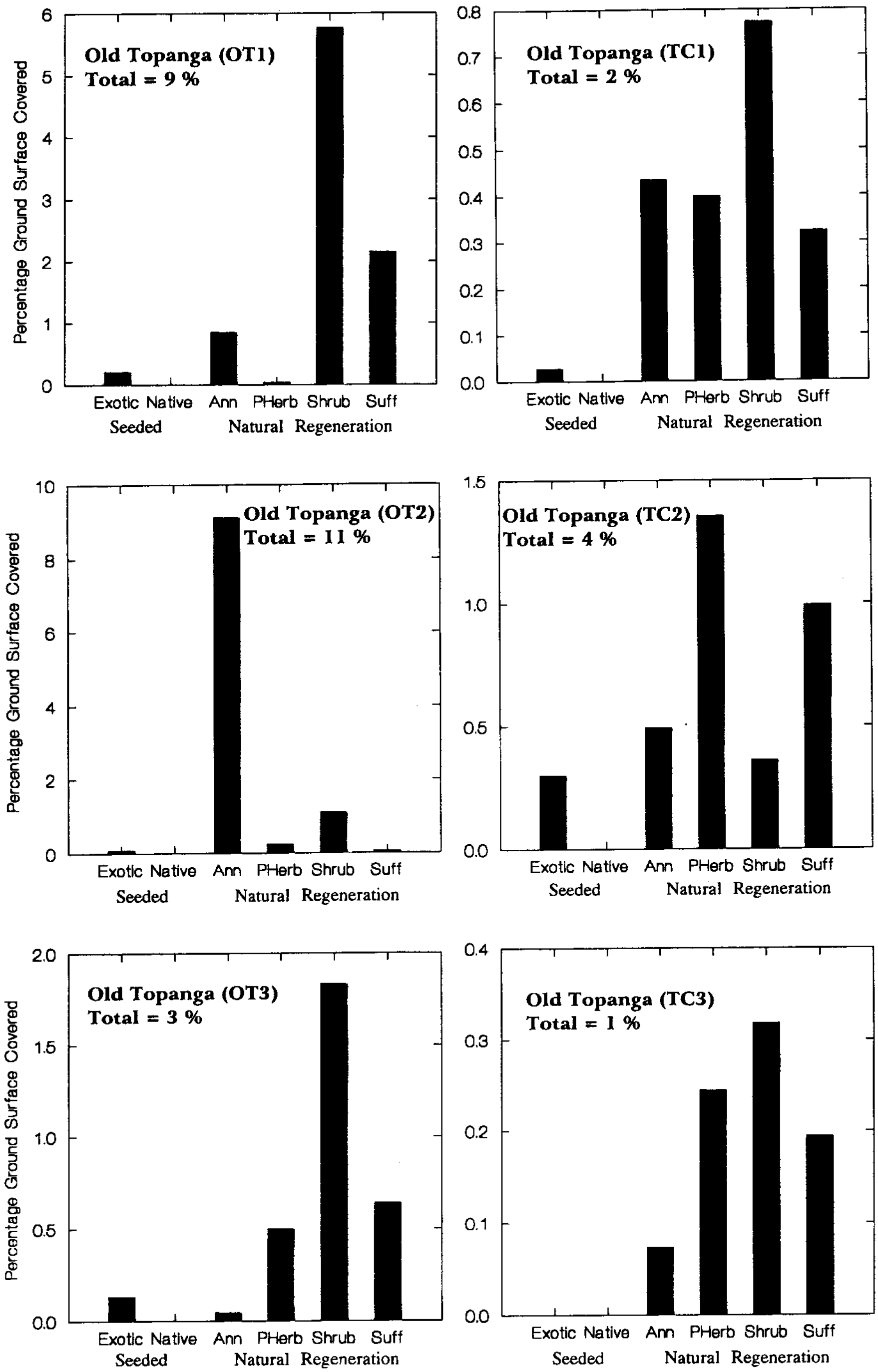


Fig. 1. Percentage ground surface covered for seeded species (non-native exotic species and native species) and for natural regeneration (annuals, herbaceous perennials, shrubs and suffrutescents; suffrutescents are species that become woody only near the base) as of 1 March 1994 for each of the 10 seeded sites in the Old Topanga burn.

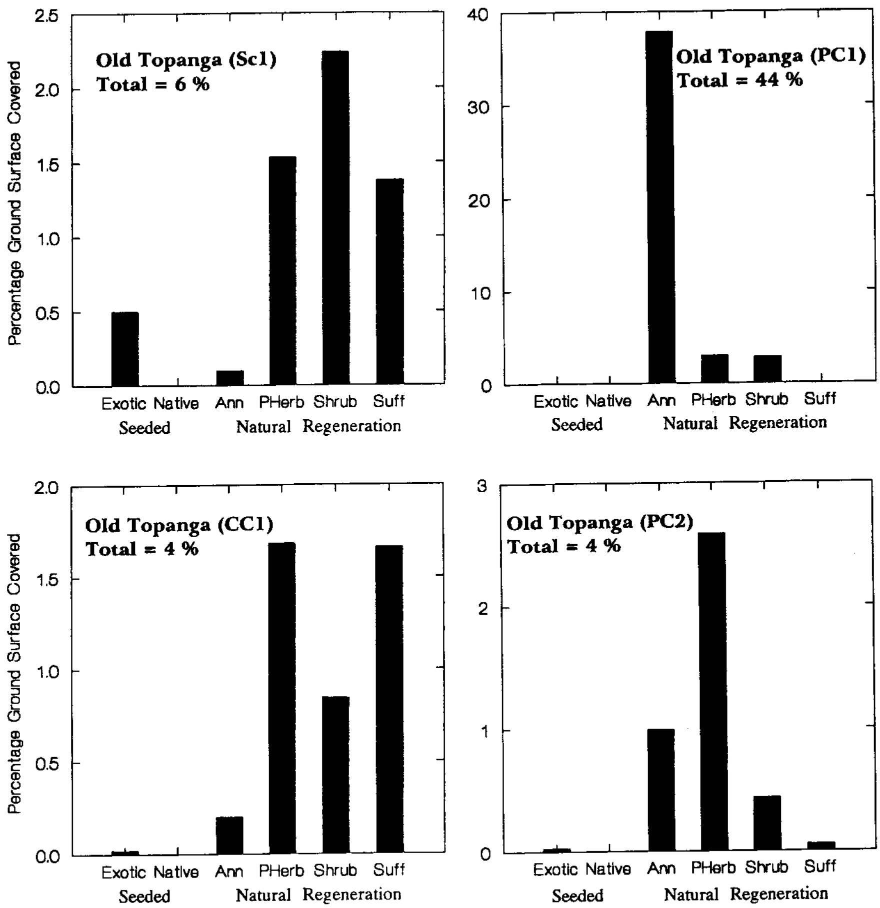


Fig. 1. Continued.

Winter Vegetation Recovery on Seeded Sites in the Old Topanga Burn

Vegetation recovery by the end of the winter storm season, approximately three months after the aerial seeding, is presented by site in Figure 1. Total cover ranged from 1% to 44% ground surface covered, however, cover contributed by seeded species ranged from 0–0.5%. Lack of establishment of seeded species is not due to our sites being missed by the aerial seeding effort as evidenced by the presence of the seeded species *Trifolium hirtum* and *Vulpia myuros* on all 10 Old Topanga sites, but not on any of the 12 sites from the Green Meadow burn. These two species represented the bulk of the seed mixture dropped on the Old Topanga burn (Table 1).

Close to 90 percent of the seed mixture used for aerial seeding comprised three species, *Trifolium hirtum, Vulpia myuros,* and *Bromus hordeaceous,* which are widespread annual grasses in southern California, although of European origin (Hickman 1993). The fact that these are not native to California is at odds with reports in the Los Angeles Times (Anonymous 1993b), which noted that the chief of the Los Angeles County Fire Department's Forestry Division had stated, "We

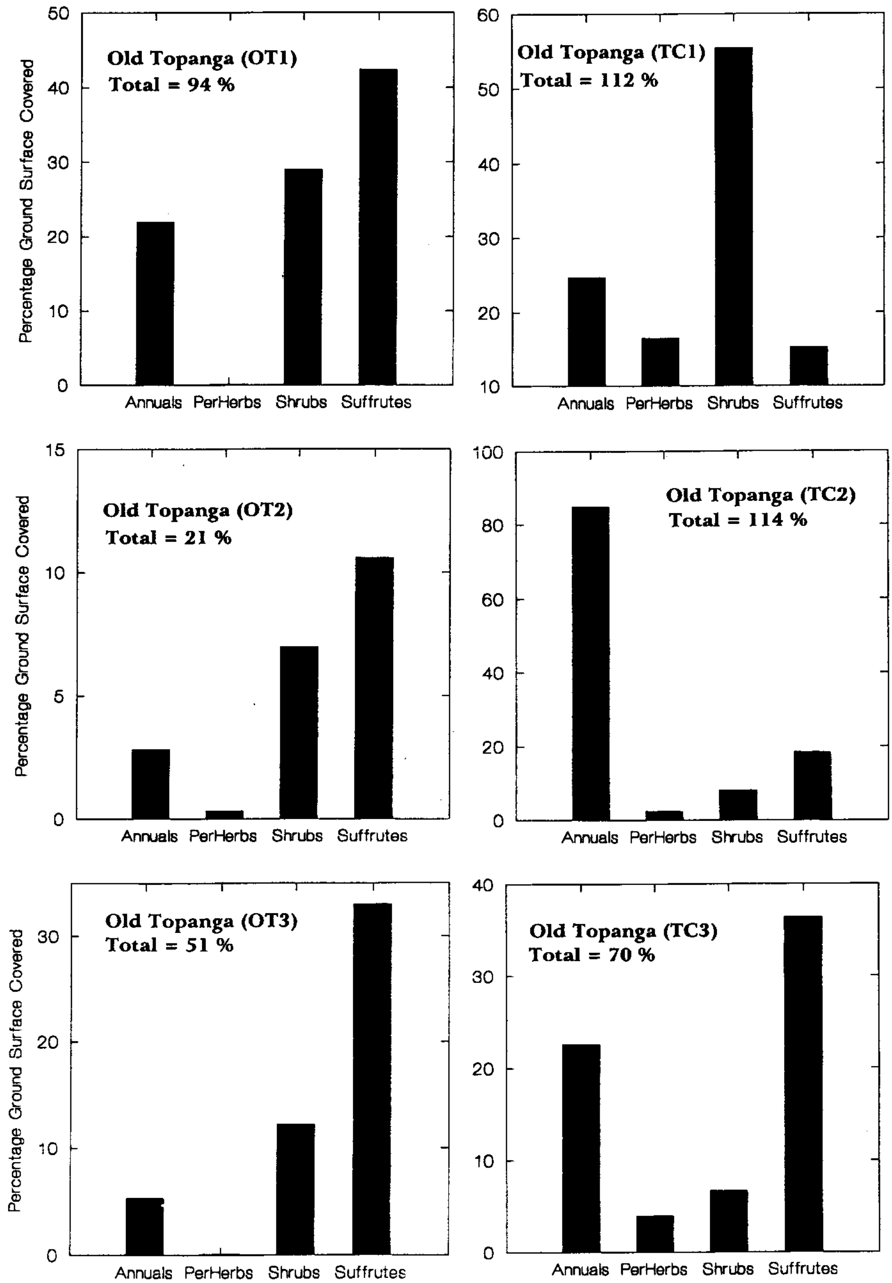


Fig. 2. Peak vegetative recovery recorded at the end of spring 1994 on the 10 Old Topanga burn sites.

can sow rye grass and make a lot of people unhappy, or we can sow native grasses and not upset a lot of people. We're trying to be sensitive to the environmentalist concerns." However, only one minor component of the seed mix (*Bromus carinatus*) is native to California. A few isolated individuals of *Bromus car-*

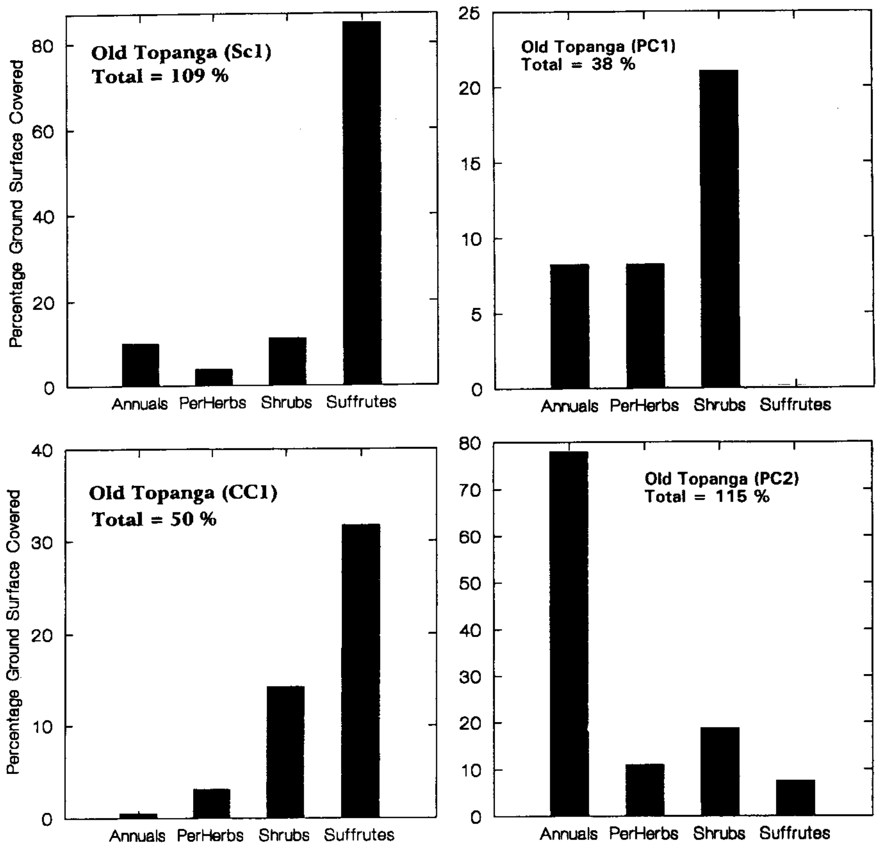


Fig. 2. Continued.

inatus were recorded from four of the Old Topanga sites and none were recorded from the Green Meadow sites. Poor establishment of this native species is likely due to two factors. (1) This species represented only a minor proportion of the seed mix (Table 1), and (2) this species is not typically found on burned sites in this region; no published postfire studies in the Santa Monica Mountains have reported *Bromus carinatus* (e.g., Radtke 1981; O'Leary 1984; Keeley and Keeley 1984; O'Leary and Westman 1988; Conard et al. 1995). Further, while some native bunchgrasses such as *Nasella lepida* are common on burned sites, their presence is due to resprouts, with seedling regeneration occurring in subsequent years on most sites (Keeley, unpublished data), suggesting that in general our native grasses may be poor choices for seed mixtures.

Very likely a contributing factor to low establishment of seeded species was the below average rainfall, which, during the months prior to sampling, was 21% below average (see Study Sites Section). Nonetheless, there was sufficient rainfall to support establishment of significant native cover on most sites (Fig. 1).

In summary, the natural regeneration far exceeded that attempted through aerial seeding; by two orders of magnitude on most sites. These sites were monitored throughout the spring growing season, and although total cover increased (see

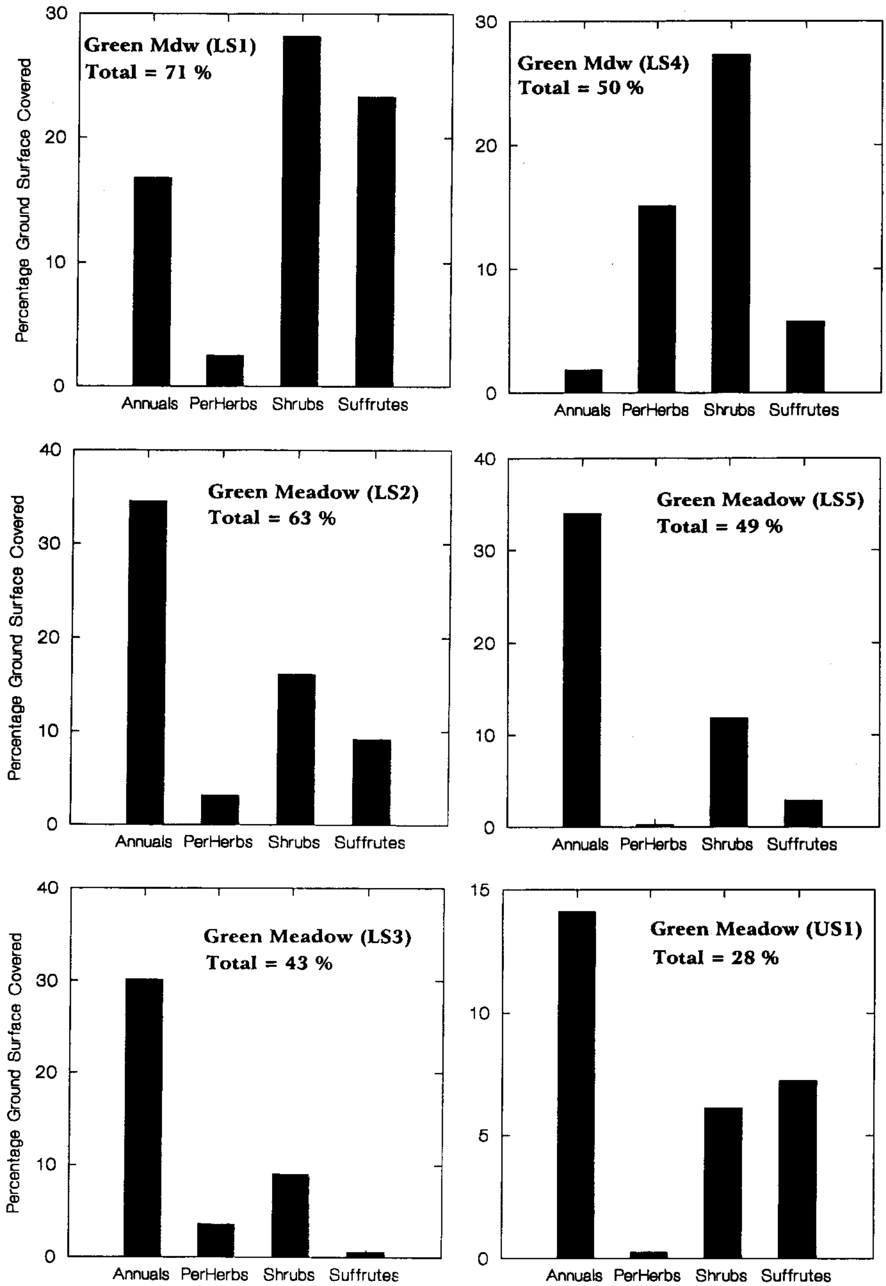


Fig. 3. Peak vegetative recovery recorded at the end of spring 1994 on the 12 Green Meadow burn sites.

below), there was little change in the relative importance of seeded species. The very poor coverage produced by seeded species during the winter months is noteworthy because further increases in coverage later in the spring are unlikely to have any significant effect on erosion and flooding. Because seeded species never

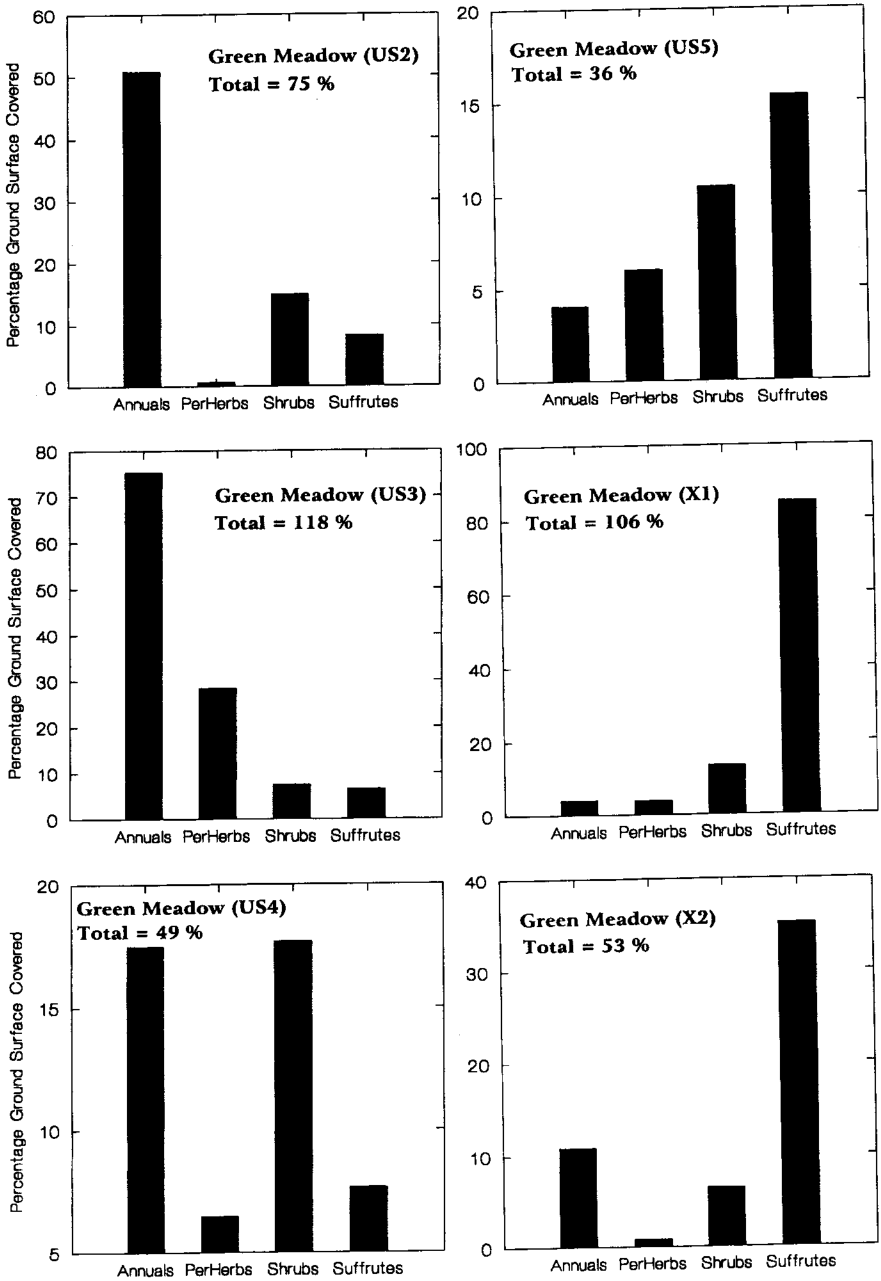


Fig. 3. Continued.

represented more than a minor fraction of the total plant cover, the $440,000 spent on aerial seeding was clearly not a good investment on this burn.

What is the prognosis for seeding in future years? It seems unlikely that the below average rainfall was a major limitation to the early establishment of cover on these burned sites. This is supported by the fact that although all sites showed substantial increases in cover between the first and second sampling period (see below), precipitation was also below average during that period (see Study Sites Section). Even if we assume the poor establishment of seeded species was tied to below average rainfall, such years are hardly abnormal in southern California. Indeed, below average years are commonplace as the year to year variation in precipitation is extraordinarily large, with many months exhibiting a coefficient of variation in excess of 200% (Keeley and Keeley 1988).

Peak Vegetation Recovery on Seeded Sites and Unseeded Sites

Vegetative cover at the end of spring in late May to early June 1994, is presented for the 10 seeded sites in the Old Topanga burn (Fig. 2). The seeded species *Trifolium hirtum, Vulpia myuros* and *Bromus hordeaceous* were widespread, but on 7 of the 10 sites peak cover did not exceed 1% ground surface cover. Maximum cover by these species was 8% ground surface cover on the Puerco Canyon Site 2, however, natural regeneration was more than an order of magnitude greater (Fig. 2).

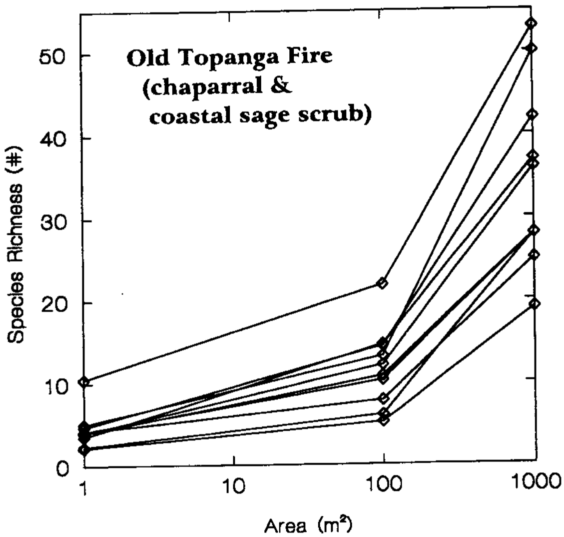
Comparing these seeded sites with the 12 unseeded sites in the Green Meadow burn (Fig. 3), shows little difference in pattern of postfire recovery. In both burns, peak cover ranged from about 25% to over 100% ground surface covered (>100% arises when plant canopies overlap). Using a 1-tailed t-test to test the hypothesis that seeded sites had greater vegetative cover showed no significant difference ($P > 0.05$) between seeded and non-seeded sites for the following vegetation parameters: (1) percentage ground surface covered, (2) annual cover, (3) herbaceous perennial cover, (4) shrub cover, and (5) suffrutescent cover.

There were, however, a few vegetation parameters that were significantly different between seeded sites in the Old Topanga burn and the non-seeded sites in the Green Meadow burn. The number of non-native exotic species was significantly greater on the Old Topanga burn sites (7.1/site vs 3.4/site for the Green Meadow burn sites, $P < 0.001$). Since two of the non-native seeded species, *Trifolium hirtum* and *Vulpia myuros,* were present on all of the Old Topanga sites and absent from the Green Meadow sites, the postfire management practice of aerial seeding likely accounts for differences in number of non-native species on these two burns.

Species richness was also significantly greater on the Green Meadow burn sites at the 100 m^2 scale (15.4/plot vs 11.6/plot for the Old Topanga burn sites, $P < 0.05$) and at the 1 m^2 scale (6.8/subplot vs 4.4/subplot for the Old Topanga burn sites, $P < 0.01$). In light of the rather poor establishment of seeded species on the Old Topanga burn sites, it seems unlikely that the presence of seeded species accounts for reduced species richness on the Old Topanga sites. Different histories of land use could play a role in these patterns. The greater population density in the eastern portion of the Santa Monica Mountains may play a role; e.g., leading to increased establishment of non-native species which could have contributed to loss of native biodiversity. Of course regional floristic differences can not be ruled out.

Patterns of Postfire Recovery on all Sites

Patterns of species richness vs scale were remarkably similar between all sites from both burns (Fig. 4). One noteworthy feature of these biodiversity patterns



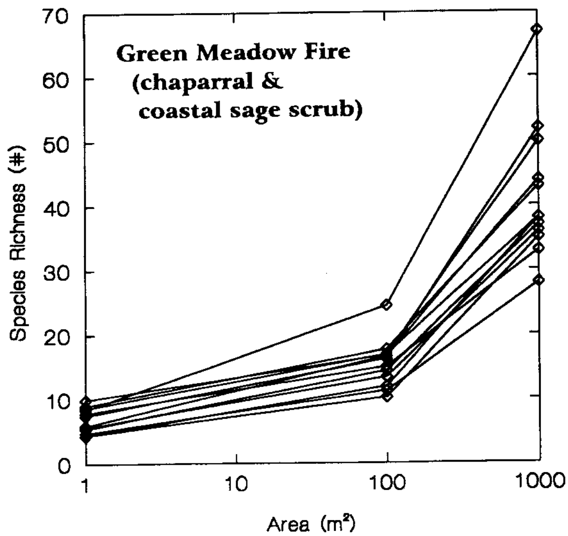


Fig. 4. Plant species richness at 1 m^2, 100 m^2, and 1000 m^2 for chaparral and coastal sage scrub sites in the Old Topanga burn and the Green Meadow burn.

is that they are unlike other Mediterranean climate ecosystems, which show a linear relationship on a semi-log scale (e.g., Bond 1983; Specht 1988). Relative to Australian heath and South African fynbos, these coastal sage scrub and chaparral sites have similar species richness at the scale of 1 m^2 and 1000 m^2 but are depauperate at 100 m^2.

Considering all sites collectively, species richness at each of the three scales was tested for their correlation with the site characteristics listed in Tables 2, 3, & 4. At all scales, the only site factor significantly correlated with species richness was total annual solar insolation (Fig. 5). Thus, richness is greatest on the cooler, moister, north-facing slopes than on the hotter south-facing slopes.

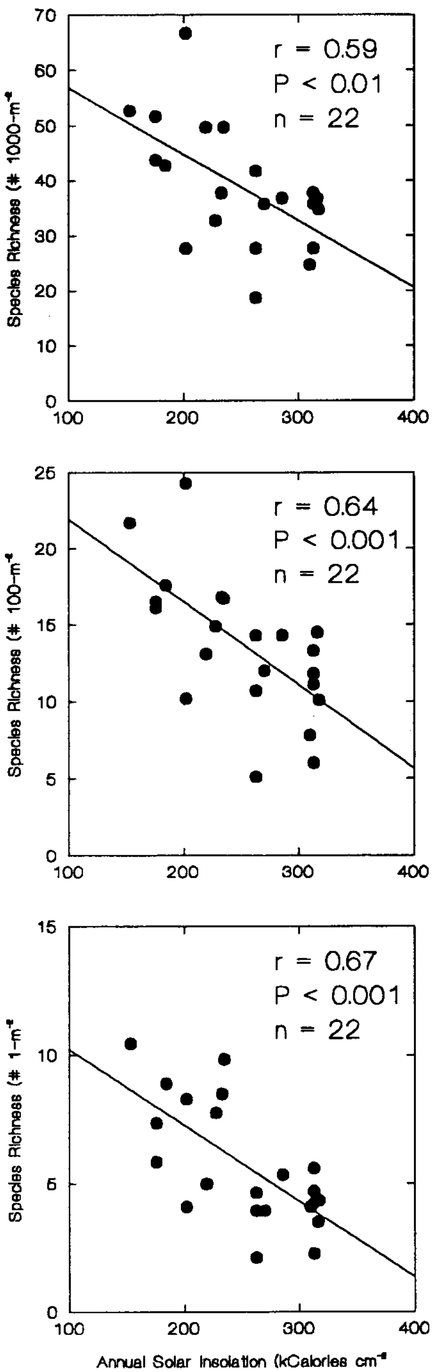


Fig. 5. Correlation between annual solar insolation (calculated from slope aspect, inclination and latitude) and species richness at 1 m^2, 100 m^2, and 1000 m^2 for all sites combined.

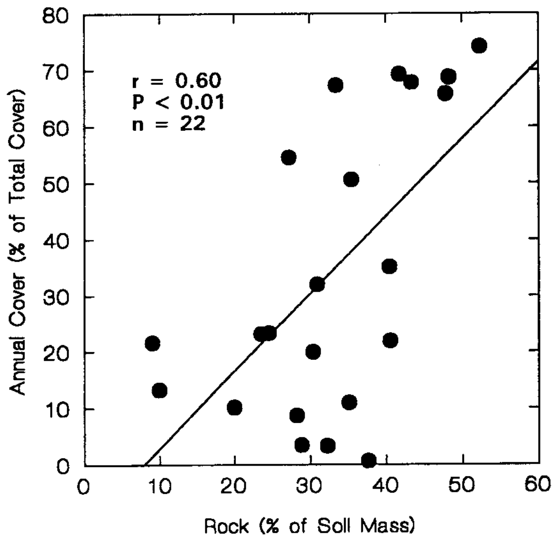


Fig. 6. Correlation between percentage (by weight) of rocks in soil and proportion of total cover by annual species, for all sites combined.

Several other vegetation characteristics were significantly correlated with site factors. The proportion of total cover derived from annuals was significantly correlated with the percentage, by mass, of rocks in the soil (Fig. 6). Thus, across all sites, annuals are more common on rocky sites. The proportion of herbaceous perennials comprising the postfire plant cover was negatively correlated with the fire severity index 1 (Fig. 7). Since uniformly, herbaceous perennials almost always are present on recent burns as resprouts from underground vegetative parts

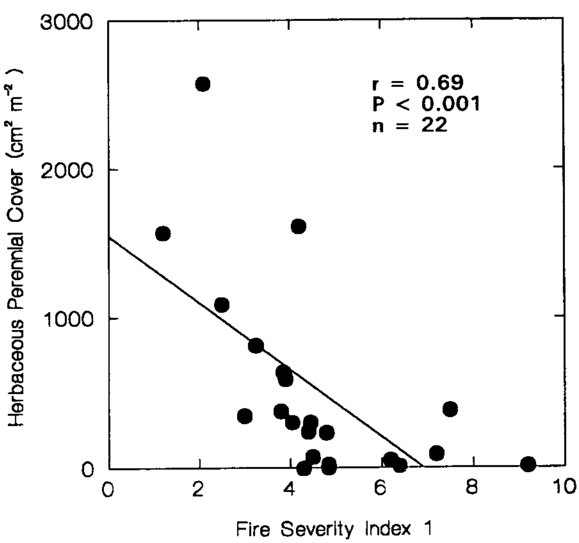


Fig. 7. Correlation between fire severity and proportion of total cover by herbaceous perennial species, for all sites combined.

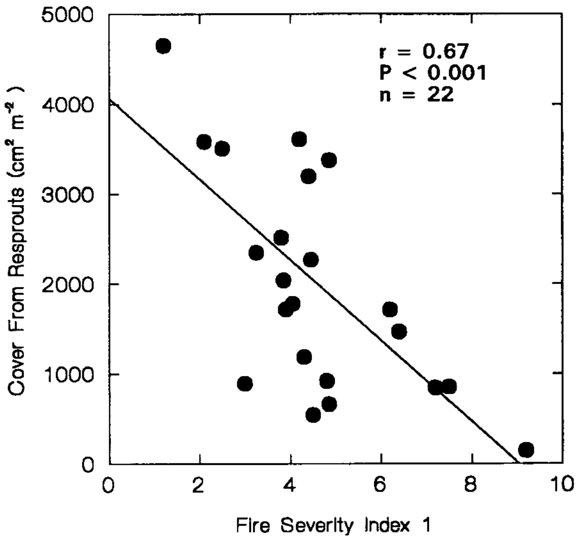


Fig. 8. Correlation between fire severity and cover from resprouts from herbaceous perennial and shrub species (annuals and suffrutescents regenerate entirely by seed after fire), for all sites combined.

(Keeley and Keeley 1984; Keeley, unpublished data from this study), it is not surprising that the cover from resprouts (both herbaceous and woody species) was also negatively correlated with this same index of fire severity (Fig. 8). It seems plausible that higher fire severity reflects higher fire intensity and destruction of underground vegetative organs. However, reduced herbaceous perennial cover was apparently compensated for by annuals and other growthforms, thus there was no significant correlation between total cover and fire severity.

Conclusions

This study compared postfire plant recovery on the Green Meadow burn, which was managed passively by relying solely on natural regeneration, with recovery on the Old Topanga burn, which was actively managed by aerial seeding of mostly non-native annual grasses and forbs. Establishment of the non-native seeded species was very poor and largely insignificant, relative to the natural regeneration. The single native species seeded on these sites comprised a minor portion of the seed mix and contributed little to the postfire cover. Comparing recovery on the Old Topanga burn and Green Meadow burn, there was no significant difference in plant cover on the two burns. Aerial seeding did contribute to a significantly greater number of non-native species on the Old Topanga burn, but it is unknown whether or not this will have any long term impact. The patterns observed in this study are consistent with those summarized in the recent synthesis of research on postfire seeding (Keeley and Scott 1995). Here, as in other regions, postfire seeding is not a reliable means of increasing plant cover, and thus is not a reliable means of reducing erosion and sedimentation after wildfires.

Acknowledgments

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Literature Cited

Anonymous. 1993a. Special publication. California Division of Forestry, Sacramento. CDF Communiqué, (December 1993):1–2.

———. 1993b. CALABASAS/MALIBU. Supervisors approve reseeding of fire area. Los Angeles Times, 18 November 1993.

Bond, W. 1983. On alpha diversity and the richness of the Cape flora: a study in southern Cape fynbos. Pp. 338–356 *in* Mediterranean-type ecosystems. The role of nutrients. (F. J. Kruger, D. T. Mitchell, and J. U. M. Jarvis, eds.), Springer-Verlag, Berlin.

Conard, S. G., J. L. Beyers, and P. M. Wohlgemuth. 1995. Impacts of postfire grass seeding on chaparral systems—what we know and where do we go from here. Pp. 149–161 *in* Brushfires in California wildlands: ecology and resource management. (J. E. Keeley and T. Scott, eds.), Association of Wildland Fire, Fairfield, Washington.

Hickman, J. C. (ed.). 1993. The Jepson manual. Higher plants of California. U. of California Press, Los Angeles.

Keeley, J. E., M. Carrington, and S. Trnka. 1995. Overview of management issues raised by the 1993 wildfires in southern California. Pp. 83–89 *in* J. E. Keeley and T. Scott (eds.), Brushfires in California: ecology and resource management. International Association of Wildland Fire, Fairfield, Washington.

———, and S. C. Keeley. 1984. Postfire recovery of California coastal sage scrub. Am. Mid. Nat., 111:105–117.

———, and ———. 1988. Chaparral. Pp. 165–207 *in* North American terrestrial vegetation. (M. G. Barbour and W. D. Billings, eds.), Cambridge University Press, Cambridge, United Kingdom.

———, and T. Scott (eds.). 1995. Brushfires in California wildlands: ecology and resource management. Association of Wildland Fire, Fairfield, Washington.

Moreno, J. M., and W. C. Oechel. 1989. A simple method for estimating fire intensity after a burn in California chaparral. Acta Oecologica/Oecologia Plantarum, 10:57–68.

O'Leary, J. F. 1984. Environmental factors influencing postburn vegetation in a southern California shrubland. Ph.D. dissertation, U. of California, Los Angeles, 92 p.

———, and W. E. Westman. 1988. Regional disturbance effects on herb succession patterns in coastal sage scrub. J. of Biogeography, 15:775–786.

Radtke, K. W. H. 1981. The effect of fire frequencies on species diversity, vegetative cover and floristic changes in chaparral communities. Ph.D. dissertation, University of California, Berkeley, 177 p.

Specht, R. L. (ed.). 1988. Mediterranean-type ecosystems. A data source book. Kluwer Academic Publishers, Dordrecht, The Netherlands.

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