Fire Frequency Effects on Soil Organic Matter, Vegetation, and Runoff in Chaparral Shrublands of the Sierra Nevada Foothills

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Chaparral and Fire

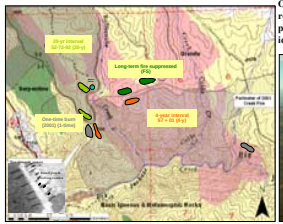
Chaparral shrubland is an extremely flammable, highly dynamic plant community that covers 13 million acres of California's coast ranges and Sierra Nevada foothills. Rapid urbanization across much of this area creates challenges for safe, effective natural resource management at the urban-wildland interface. High flammability, extreme fire weather, and steep, inaccessible terrain mean that fires often cover huge areas, suddenly and drastically altering fundamental ecosystem and soil organic matter (SOM) processes. Decisions on residential development, fuels management, and fire suppression strategies impact sustainability and habitat values of this ecosystem.

California chaparral is a crown-fire ecosystem where historically infrequent (30-60 yr), stand-replacing fires stimulated resprouting and fire-obligate reseeding brush species. Fire-adapted native shrubs and exotic annual herbaceous vegetation dominate chaparral plant communities in varying proportions depending upon the time since the most recent fire. Successive fires within a few years convert shrub-dominated vegetation to grasslands or herbaceous-dominated mosaics. Successive fires were rare historically but were used by livestock managers through the first three quarters of the 20th century.

Photographs by Harry Hinkley, Tuolumne County Farm Advisor from 1947 to 1970, taken near our current study site. Frequent burning eliminates the shrub component, which is good for forage production and fire management, but detrimental for wildlife habitat. Absence of woody roots and stems may deplete recalcitrant components in long-term SOM pools. Conversely, long-term fire suppression eliminates the herbaceous component, which may also deplete SOM by reducing fine below-ground OM inputs, slowing turn over, and transferring OM to above-ground biomass vulnerable to loss by fire.

We believe an intermediate prescribed fire frequency in high fire hazard zones will result in grass-shrub mosaics optimal for fire management, wildlife, and ecosystem functions. The purpose of this research is to define effects of four different fire return intervals on vegetation, runoff, erosion, and soil organic matter dynamics in two predominant soil types of Sierra Nevada Foothill chaparral.

Study Site and Fire History



Our study site lies in a high fire-hazard zone where recurring catastrophic fires create overlaying recovery patterns and motivate fire management agencies to identify strategic fuel management approaches.

We overlaid digital fire history and soil map layers to identify sites with four different fire histories on two soil types.

The 2001 Creek Fire burned 11,000 acres, destroyed 20 homes, and threatened four up-country communities.

Study site location.

Fire Suppressed (FS)

20-year: '50,'72, '92 (20-y)

California poppies (*Eschscholzia californica*) and annual grasses.

Four-year: '97, '01 (4-y)

One-time burn in 2001 (1-time)

Vegetation and Soils

Mature manzanita (*Arctostaphylos* spp)

Chamise (*Adenostoma fasciculatum*) -dominated chaparral

Toyon (*Heteromeles arbutifolia*)

Metabasic Soils
Soils formed in residual and colluvial weathered metabasic igneous and sedimentary rocks

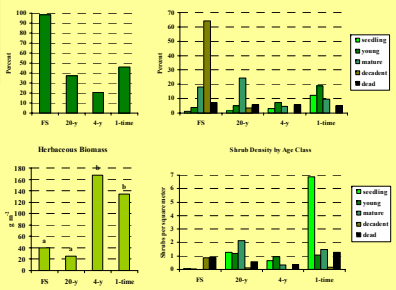
Rescue Series loam: Fine-loamy, mixed, thermic Mollic Haploxeralfs

Granitic Soils
Soils formed in residual and colluvial weathered granite

Auberry Series sandy loam: Fine-loamy, mixed, semiactive, thermic Ultic Haploxeralfs

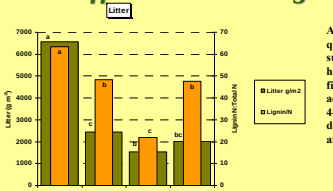
Effects on Vegetation

We measured ground cover and herbaceous biomass in 0.75-m² plots and shrub density in 1-m² plots along soil sampling transects.



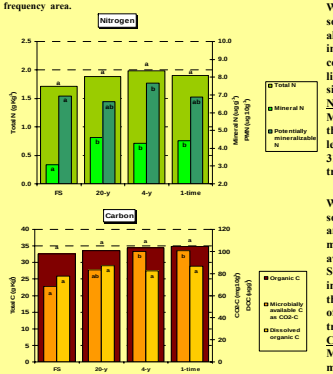
Fire changed vegetation by increasing cover and biomass of annual grasses and forbs and decreasing shrub cover. FS has a dense canopy of large, decadent chamise, but the lowest density of individual shrubs. The 2001 Creek Fire stimulated shrub seedling growth on the 1-time sites, but shrub regeneration was impeded on the 4-y sites.

Effects on Soil Organic Matter



Litter mass and quality, both soil types. Different letters denote significant differences. Bulk samples from four 225-cm² plots on 12 transects in each fire frequency area.

Any occurrence of fire in chaparral reduces quantity and improves decomposability of surface organic residues. Significant build up of highly recalcitrant litter in FS leads to C and N fixation in forms and locations (soil surface) not accessible by microbes and plants. In contrast, 4-y surface litter is largely derived from deposition of easily decomposable senescing annual grasses and forbs.



Soil carbon and nitrogen, both soil types, 0- to 5-cm depth bulked from four points along 12 transects in each fire frequency area.

When averaged across soils, fire does not affect soil total N, but enhances N mineralization in all fire treatments and potential N availability in the 4-y treatment. Higher litter quality and considerable fine, near-surface root production likely contributes to soil PMN pool size on these sites.

N Differences by Soil Type (not shown)
Metabasic soils have consistently more Total N than the sandier granitic soils but consistently less mineral N. In FS, Metabasic soils have 31% more PMN than granitic soils. Other fire treatment areas have similar levels of PMN.

When averaged across soils, fire does not affect soil TOC or DOC concentrations. Soil from areas burned most recently have elevated mineralizable C pools suggesting greater C availability to microbes than in FS or 20-y soils. Stores of mineralizable C in 20-y soils are intermediate between the recent fire soils and the FS soils, indicating a shift toward build up of more recalcitrant C pools derived from transition toward more woody vegetation.

C Differences by Soil Type (not shown)
Metabasic soils have 50 to 80% more mineralizable C than Granitic soils. 4-y and 1-time sites have significantly more TOC than 20-y and FS only in metabasic soils.

Effects on Runoff & Sediment

We collected runoff and sediment from six 1- x 5-m plots in FS and 4-y sites on both soil types (24 plots total). Runoff water was quantified and nutrient content measured. Sediment was quantified.

Total yield of runoff, sediment, and nutrients from 17 runoff events, January 4 to May 17, 2005 (average totals from six 1-m x 5-m runoff plots in each of two soil types and two fire frequencies; 24 plots total).

		Runoff Yield	Sediment Yield	Total Suspended Solids	Dissolved Organic Carbon	Available Phosphorus	Total Phosphorus	Ammonium-Nitrogen	Nitrate Nitrogen	Total Nitrogen
Fire Frequency Effects by Soil Type		*Lm⁻²*				*g m⁻² in runoff water*				
Both Soils	FS	7.47	85	0.16	14.39	0.35	1.57	2.99	0.07	4.54
	4-y	9.32	99	0.05	7.55	0.20	0.71	1.64	0.06	2.42
		*			**	***	***		*	
Metabasic Soils	FS	4.38	72	0.07	6.62	0.21	1.29	1.00	0.04	1.71
	4-y	7.80	99	0.04	4.02	0.11	0.45	1.09	0.05	1.59
					*	**	***		*	
Granitic Soils	FS	10.55	99	0.28	25.27	0.54	1.97	5.78	0.11	8.51
	4-y	11.25	98	0.07	11.85	0.30	1.01	2.32	0.07	3.43
				**	***	**	**	*		*
Effects of Soil Type within Treatments										
FS	Metabasic	4.38	72	0.07	6.62	0.21	1.29	1.00	0.04	1.71
	Granitic	10.55	99	0.28	25.27	0.54	1.97	5.78	0.11	8.51
		**	**	**	***	***		**	*	**
4-y	Metabasic	7.80	99	0.04	4.02	0.11	0.45	1.09	0.05	1.59
	Granitic	11.25	98	0.07	11.85	0.30	1.01	2.32	0.07	3.43
					*	**	***			

* P ≤ 0.10; ** P ≤ 0.05; *** P ≤ 0.01

The 4-y sites yielded slightly more water and sediment but retained significantly more nutrients, particularly DOC and phosphorus, than the FS sites. Granitic soils yielded more of each of the measured nutrients than the metabasic soils in both fire frequency treatments. FS plant communities on metabasic soils yielded significantly less sediment than those on granitic soils but sediment yields were almost identical from the grass-dominated 4-y fire frequency sites on both soils.

Conclusions

- Reintroduction of moderately frequent fire to this ecosystem should yield multi-level benefits of reducing wildfire hazard and improving resistance to fire, resilience, and sustainability, while improving biodiversity and hydrological attributes;
- Improved stand structure and ecosystem biochemistry from the 4-y fire treatment suggests that relatively frequent burning is desirable, but it may not be feasible in some areas. However, extending the fire frequency to 20 years does not generate the desirable effects; fire effects are no longer present;
- Chaparral management that results in one-time burn of mature or decadent stands by either prescribed or wildfire can result in rapid shrub regeneration and offset beneficial effects of recent fires on quality of soil C and N pools, fire hazard reduction, and nutrient retention;
- Soil parent materials impact estimates of the effects of fire management on belowground C stores, and therefore, need to be considered in determinations of ecosystem C budgets and C flow;

Acknowledgments

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