RECOVERY OF THE CHAPARRAL RIPARIAN ZONE AFTER WILDFIRE[1]

Frank W. Davis, Edward A. Keller, Anuja Parikh, and Joan Florsheim[2]

Abstract: After the Wheeler Fire in southern California in July 1985, we monitored sediment deposition and vegetation recovery in a section of the severely burned chaparral riparian zone of the North Fork of Matilija Creek, near Ojai, California. Increased runoff was accompanied by low magnitude debris flows and fluvial transport of gravel, most of which was added to the channel and nearby hillslopes by post-fire dry ravel. The pre-burn riparian forest was dominated by white alder, California sycamore, and coast live oak. Regeneration of these species was entirely by resprouting, due to the absence of local viable seed sources. Recovery of the herb layer was affected strongly by the seeding of Italian ryegrass. Species richness of annuals decreased considerably in the second year, when perennials dominated the riparian zone.

The impact of fire on geomorphic processes is significant in the steep basins of southern California. The dominant sediment transport process on steep chaparral hillslopes is dry ravel or dry sliding of coarse colluvial soil fragments under the force of gravity. Fire increases the rate of dry ravel by removing stabilizing vegetation and litter (Krammes 1965). Rice (1982) reported 1.4 cubic meters per hectare per year of dry ravel in unburned chaparral in southern California, in contrast to 39 cubic meters per hectare for the 3 months following the 1959 Arroyo Seco Fire.

Chaparral wildfire can cause high temporary fluvial sediment yields (Scott and Williams 1978). Over 70 percent of the total long term sediment yield occurs in the first year following a fire (Rice 1974). Wells (1987) suggested that debris flows are an important form of sediment transport following fire in small steep watersheds. Keller and others (1988) suggested that large debris flows that affect higher order basins are related to long term instability, with fire and high intensity storms acting as potential trigger mechanisms.

Chaparral vegetation reduces flood potential by increasing evapotranspiration, interception, and infiltration (DeBano and others 1979). Vegetation removal by fire reduces evapotranspiration and infiltration. Also, the creation of a water-repellent (hydrophobic) layer in the soil during fire decreases infiltration (DeBano 1974). These post-fire conditions cause an increase in overland flow and streamflow (DeBano and others 1979).

The relatively open understory, mesic soil conditions and the high fuel moisture content of riparian vegetation usually restricts the spread of wildfire through the riparian zone. Flooding is probably a more important recurrent disturbance (Brothers 1985). The combination of intense wildfire and post-fire flooding and sedimentation represents an extreme disturbance of riparian vegetation, and we know of practically no information on the nature of recovery processes after such events.

The purpose of this project was to document changes in sediment storage and recovery of riparian vegetation in a chaparral basin after wildfire. A specific objective of the research was to evaluate the effects of wildfire on sediment routing and storage in the chaparral riparian system. Other objectives were to compare the role of seedling recruitment versus sprouting in regeneration of the tree layer, and to evaluate the significance of ryegrass seeding on recovery of the herb layer.

Study Site

We monitored post-fire events in a 270 meter study reach on a tributary to the North Fork of Matilija Creek, a tributary of the Ventura River (fig. 1). The drainage area of the basin is 2.14 square kilometers. Matilija Creek drains the tectonically active San Rafael Mountains, Ventura County, California. The geology of the area is characterized by a sequence of steeply south-dipping Eocene marine sandstones and shales. At least two distinct large debris flow deposits are recognized in the basin. Radiocarbon dating suggests that the oldest deposit (Q2) is 1045 ±95 BP, and the younger deposit (Q1), sampled in two locations, is approximately 385 ±85 BP or 295 ±35 BP (Florsheim 1988). Channel morphology in the study reach is characterized by step-pool sequences, a characteristic bedform in steep channels with coarse, heterogeneous bed material.

Detailed data on the pre-burn herbaceous flora in the area were unavailable, but standing trunks of trees that remained after the fire could be identified as a riparian forest of white alder (*Alnus rhombifolia* Nutt.), California sycamore (*Platanus racemosa* Nutt.), and coast live oak (*Quercus agrifolia Nee. var. agrifolia*). Shrubby species included willows (*Salix L.* spp.), hollyleaf cherry (*Prunus ilicifolia* (Nutt.) Walp.), laurel sumac (*Mal-*

[1] Presented at the California Riparian Systems Conference; September 22-24, 1988; Davis, California.

[2] Assistant Professor of Geography, Professor of Geological Sciences, Ph.D. candidate in Geography, Ph.D. in Geological Sciences, University of California, Santa Barbara.

osma laurina Nutt. in T. & G.), poison oak (*Toxicodendron diversilobum* (T. & G.) Greene.), and Christmas berry (*Heteromeles arbutifolia* M. Roem.). All species nomenclature in this paper follows Munz (1974), and Abrams and Ferris (1960). A study of spatial distributions and regeneration of riparian tree species in three other canyons (Sisar Canyon, Horn Canyon, and W. Fork Santa Ana Creek) burned in the Wheeler Fire provided supporting data for the research at Matilija Creek (Parikh 1988, fig. 1).

Field Methods

In August 1985, we surveyed a longitudinal profile and 50 cross sections along the study reach (presumably the pre-fire condition), and constructed a contour map of the reach (fig. 2). The longitudinal profile and selected cross sections were resurveyed after the winter storms on January 30-31, 1986, and February 13-15, 1986. Dry ravel deposition was estimated by measuring the width, depth, and length of accumulations and then calculating the volume.

Rainfall data for storms that occurred during the winter following the Wheeler Fire were supplied by the Ventura County Department of Public Works. Flow discharge at the study site was estimated using the slope-area method for an ungaged channel (Dalyrymple and Benson 1967).

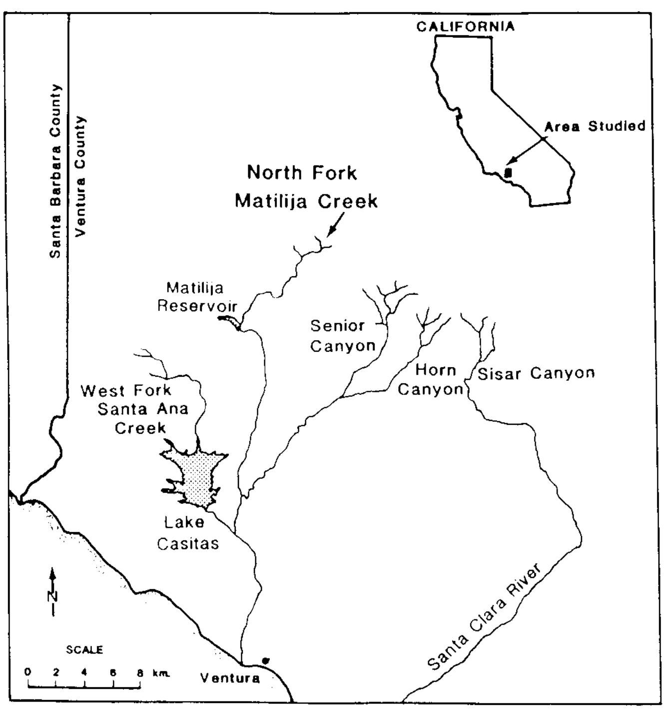

Figure 1– Locations of study sites.

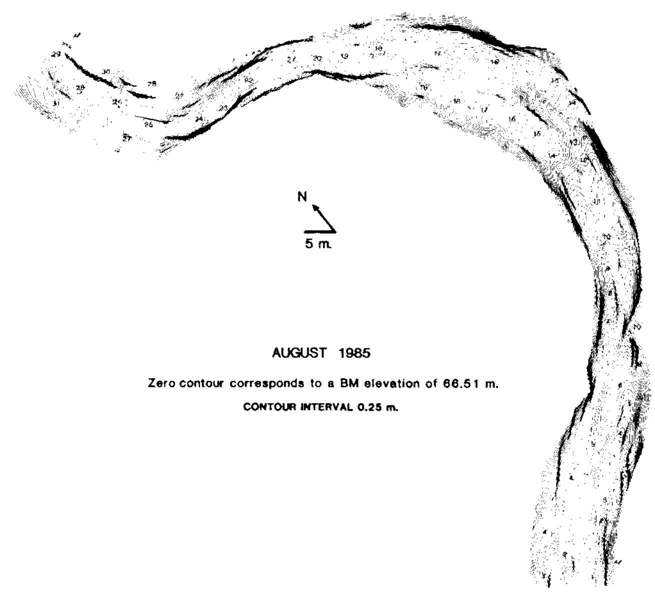

Figure 2– Contour map of the study reach.

The recovery of three riparian tree species and the herb layer in the study reach was documented at monthly intervals from September 1985 to May 1987. Three permanent plots of 250 square meters each were established in the upstream, middle, and downstream parts of the study reach. Sixty-three trees greater than 2.5 centimeters diameter at breast height (dbh) were tagged and mapped, including 23 alders, 19 sycamores, and 21 oaks. These trees were monitored to determine rates of re-sprouting, as well as the fate of dead standing timber in the riparian zone. Ten seed traps were located in each permanent plot to estimate monthly seedfall from alders and sycamores. Greenhouse germination tests for seed viability were also conducted on seeds collected at the site. Thirty plots of 1 square meter each were set up on different geomorphic locations to monitor the recovery of herbaceous species. The latter included Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot.), which was seeded in the area by the Forest Service, U.S. Department of Agriculture, for erosion control at an average density of 230 seeds per square meter.

Results

Effect of the Wheeler Fire on Hillslope Erosion

The Wheeler Fire burned 480 square kilometers in Los Padres National Forest, California in July 1985. Dry ravel was the dominant erosion process that occurred on burned slopes in the drainage basin following the fire. Slopes throughout the basin and in all lithologic units contributed dry ravel to the channel. Clasts averaged 4 millimeters in diameter. The volume of gravel which entered the channel in the study reach by the process of dry ravel was measured in August 1985 as 0.20 cubic meters per meter length of channel (it is assumed that this deposition post-dates the fire). The volume of dry ravel accumulation measured in a 176 meter reach in the burned headwaters of the North Fork of Matilija Creek near the study basin was 200 cubic meters per hectare (0.30 cubic meters per meter length of channel) for a 7 month period following the fire. Thus, we estimate the rate of dry ravel following the fire in the basin to be 29 cubic meters per hectare per month, much higher than the background rate suggested by Rice (1982).

Effect of the January 30-31 Storm

Two storms caused significant channel change the winter following the Wheeler Fire. The first storm, on January 30-31, 1986, resulted from 122 millimeters of precipitation (return period less than 2 years) and produced a flow of 2.1 cubic meters per second in the study reach. This was the first substantial flow following the Wheeler Fire, and the basin responded to this moderate sized event by contributing material from hillslopes and mobilizing sediment existing in the channel. The streamflow was clearly transport-limited and deposited fine-grained gravel-sized sediment, which filled pools and buried bedforms. Approximately 550 cubic meters of fine-grained gravel was deposited in the 270-meter study reach.

Based on a comparison of the volume of gravel-sized material deposited during the January storm (approximately 2 cubic meters per meter length of channel) to the volume of dry ravel existing in the channel following the fire but before the storm, only 10 percent of the gravel-sized material in the January fill was derived from gravel existing in the channel. The remainder was derived from fine material stored on hillslopes near the channel and contributed to the channel by rills and small surficial slope failures during the storm.

The pattern of sediment deposition during the January event was dependent on channel geometry. Sediment filled the channel both upstream and downstream of bedrock constrictions, completely burying the pre-storm bed morphology (fig. 3). Little aggradation occurred in the constrictions. The distribution of sediment deposits resulting from this low magnitude event is similar to that predicted using the HEC-2 step-backwater computation to model the distribution of unit stream power (Florsheim and Keller 1987). The model predicted that sediment should be deposited upstream of constrictions where backwater effects were present, and downstream of constrictions in channel expansions, leaving constrictions free of sediment.

Effect of the February 13-15 Storm

The second storm, resulting from 244 millimeters of precipitation (return period 2-4 years), occurred on February 13-15 and produced a flow discharge of 2.5 cubic meters per second, only slightly higher than the January 30-31 flow. This event scoured nearly all the gravel deposited by the late January event, suggesting that this flow was supply-limited. The February flow was capable of transporting the small gravel out of the system, and because slopes were depleted and little new sediment was added to the channel in the 2 weeks between the January and February storms, the later flow nearly eroded the channel to the level of its pre-January thalweg.

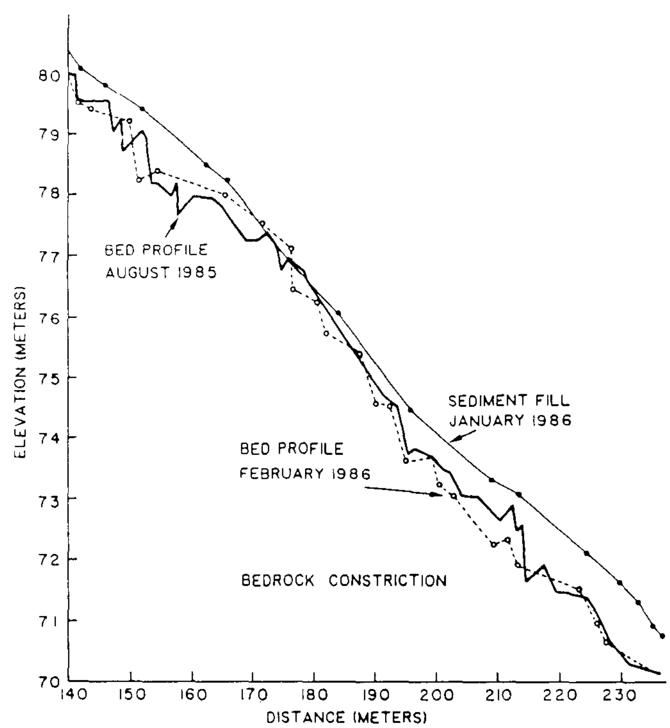

Figure 3— Longitudinal profile of lower portion of the study reach. Bed profile surveyed in August 1985; following the January 30-31, 1986 event; and following the February 13-15, 1986 event. Constriction extends from approximately 170-200 meters.

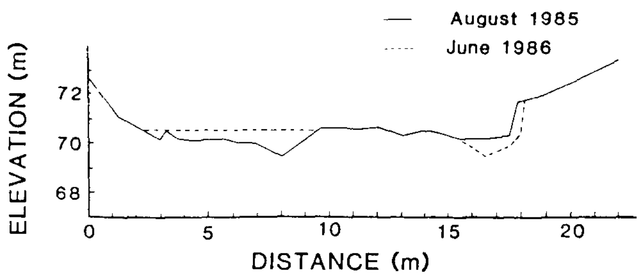

Figure 4– Cross section 6 surveyed in August 1985 and in June 1986 shows January fill in the left channel and scour resulting from the February storm in the right channel.

Pronounced changes in channel morphology occurred at the downstream end of the study reach during the February event. Sediment stored in the channel was eroded during the February flow and bank erosion occurred locally along vertical edges of the debris flow terrace. The channel widened 0.5 meters and deepened 0.7 meters at cross section 6 as a result of erosion during the February flow (fig. 4).

Importance of Fire on Long Term Sediment Storage and Yield

The impact of fire on long term sediment storage and yield can be estimated by comparing the volume of sediment deposited during sediment transport events such as the January 30-31 storm to deposits of large debris flows preserved in the channel. The volume of sediment deposited in debris flows Q1 and Q2 before subsequent incision is estimated as 32,800 cubic meters and 65,600 cubic meters, respectively. Thus, the total volume of sediment deposited in debris flows in the study basin in the past 1000 years is approximately 94,000 cubic meters. The average volume of sediment deposited during the January 30-31 storm was approximately 2 cubic meters per meter length of channel. Assuming that the upper 850 meters of the basin was too steep to allow for sediment deposition, and that sediment was transported to the lower part of the basin (1640 meters upstream of the mouth), the volume of sediment deposited in the first substantial post-fire storm was 3,280 cubic meters.

Assuming that the recurrence interval for fire in the Santa Barbara area is 30-65 years (Byrne 1979), and that a sediment transport event such as that on January 30-31 occurs following every fire, then 15-33 such events occur in 1000 years. Therefore, the volume of sediment contributed to the basin due to post-fire fluvial sediment transport is estimated as 49,200 to 108,200 cubic meters per 1000 years. This calculation suggests that fire may cause 30 to 50 percent of the total debris deposition over a 1000-year period. The remaining deposition is due to high magnitude debris flows related to factors such as basin stability and intensity of precipitation, with fire and earthquakes acting as potential trigger mechanisms. Small gravel deposited in the channel is stored for short periods of time, on the order of months or several years. However, large debris flows remain in the channel as terraces and lag deposits for hundreds to thousands of years.

Vegetation Recovery

Tree Overstory Layer

The riparian zone of North Fork Matilija Creek was dominated by a central corridor of white alders, with California sycamores and coast live oaks situated at higher elevations above the stream on upper terraces and hillslopes. These relationships were typical of the watersheds in the region (Parikh 1988). There was no apparent relationship between the spatial and size-class distributions of the three species. The range of occurrence of the three species above the channel is given in table 1.

Most tree trunks along the channel reach remained standing until the storm events in winter 1986, when large flows caused the erosion of mid-channel bars, and subsequent uprooting of many alders growing near the stream. In the first year after the fire, 8 of 23 alders fell, and 2 more were uprooted in the next 2 years (i.e., 44 percent of alders in the study reach, and 3.84 percent of the total basal area of alders on that plot). No sycamores fell during the first 2 years after the fire. During the second year, 6 of 19 oak trees fell following severe windstorms (i.e., 29 percent of oaks in the study reach, 11.04 percent of the total basal area of oaks on that plot). The combined effect of wind and rain during winter storms in the second year caused much breaking of dead tree trunks and branches, and the accumulation of debris in the wider parts of the channel.

Table 1 – Elevations of species in meters above the channel, North Fork Matilija Creek

Species	Range of Occurrence	Mean elevation	Standard deviation
White alder	0.05 to 1.32	0.51	0.33
California sycamore	0.41 to 4.76	2.84	1.11
Coast live oak	1.29 to 7.80	4.15	2.63

The regeneration of alders, sycamores, and oaks occurred exclusively by sprouting. Seedlings were not observed in the permanent plots, although they occurred in unburned areas immediately downstream of the study reach. Less than 1 percent of alder seeds collected from the burned areas were viable. Alder seedfall was consistently low (< 7 per square meter) during the study period. Burned sycamores released large numbers of seeds (up to 170 per square meter) immediately after the fire, but viability was low (< 5 percent). The maximum number of seeds fell about 6 months after the fire (late fall and early winter are the seasons of seed dissemination of both species).

Among the trees surveyed in May 1987, 7 percent of alders had sprouted, 83 percent of the sycamores, and 70 percent of the oaks. Surviving alders sprouted several months after the other species. At the study site and in sample transects located in three other burned canyons in the Ojai area (Parikh 1988, fig. 1), alders sprouted the least, and sycamores the most. Alder seedlings were more numerous than sycamore seedlings along the unburned channel in the second year. In the third year after the fire, some of these alder seedlings grew rapidly during the spring season, reaching heights of almost 2 meters; others were flooded out during preceding winter storms.

Stepwise logistic regression analysis (Ezcurra and Montana 1984) was used to test the rate of re-sprouting by each species as a function of canyon (N. Fork Matilija Creek, W. Fork Santa Ana Creek, Sisar and Horn Canyons), size-class (dbh), and height above the stream (Parikh 1988). The sprouting of alders was affected most by canyon location ($p < 0.0001$). The sprouting of sycamores was negatively and significantly related to height above the stream ($p < 0.005$) and secondarily to regional location ($p < 0.1$). The sprouting of oaks was positively and significantly related to size class ($p < 0.0001$). The differences between canyons in rate of resprouting by alders and sycamores is probably due to regional variation in fire intensity. Height above the stream is a factor operating at a smaller scale. More sycamores sprouted closer to the stream, probably due to fire being less intense in the mesic areas of the canyon, and more water being available for sprouting. The thick bark of larger oaks probably accounts for their higher survival rate (Plumb 1980).

Herb Layer

We began monitoring the herb layer in September 1985. Fifteen annuals occurred in the plots during the first year after the fire, the most frequent of which are listed in table 2. Some of these were fire-followers (e.g., *Eucrypta chrysanthemifolia*, see Keeley and others 1985). The second-year annual flora decreased in species richness, and annual species present in both years generally showed considerably reduced frequencies in the second year. Most annuals occurred patchily on higher geomorphic surfaces such as hillslopes and upper terraces (fig. 5). *Sanicula crassicaulis* and *Dichelostemma pulchella* also occurred on higher geomorphic areas in the first year after the fire.

Perennials such as *Toxicodendron diversilobum, Rubus ursinus,* and *Calystegia macrostegia* were common in the entire riparian zone, while others such as *Solanum douglasii, Artemisia douglasiana, Urtica holosericea* and *Mimulus cardinalis* were more frequent on lower and middle terraces (fig. 5). Several shrub species developed and persisted after the burn on various geomorphic surfaces, e.g., *Malosma laurina, Eriophyllum confertiflorum,* and *Prunus ilicifolia.* A number of species were flooded out in winter storms during the first year. Some species, viz *Artemisia douglasiana* and *Solanum douglasii,* did not recover fully from these storms until the second year.

The second-year perennial flora was somewhat different in species composition. Although *Toxicodendron diversilobum, Rubus ursinus, Urtica holosericea,* and *Solanum douglasii* persisted, species such as *Baccharis glutinosa, Heteromeles arbutifolia,* and *Eriogonum fasciculatum* ssp. *foliolosum*– normally components of undisturbed riparian, chaparral, and coastal sage scrub communities – also appeared. Woody perennials dominated the lower riparian zone in the second year, notably willows (*Salix* L. spp.).

Ryegrass that was seeded in the area in October 1985 germinated in December. Sedimentation events that followed the fire affected the spatial distribution of the species considerably – it grew most densely on lower hillslopes and on terraces where sediment accumulated due to dry ravel processes (fig. 6). Maximum density occurred soon after germination (January 1986) and declined thereafter due to thinning and, on lower terraces, due to mortality during flooding (fig. 6). The ryegrass attained an average frequency of 35 percent and average density of 91 plants per square meter (i.e., 39 percent recruitment from broadcasted seed) in the first year. Second year growth started in November 1986, and the species occurred at 50-100 percent frequency on all geomorphic surfaces.

At the end of the first year growth in spring 1986, the subplots were harvested, and dry biomass was measured for all herbaceous species on each subplot (fig. 7). Ryegrass dominated the plant communities at all locations, suggesting that native plants were reduced considerably by the growth of this species (Nadkarni and Odion 1986).

Table 2 — Frequent post-fire species observed (*) at North Fork Matilija Creek

Scientific Name	Common Name	Abbre-viation	Year 1	Year 2
Annuals and Biennials				
Allophyllum divaricatum (Nutt.) A. & V. Grant	Straggling gilia	Ad	*	*
Claytonia perfoliata Donn. var *perfoliata*	Miner's lettuce	Cp	*	*
Collinsia concolor Greene.	Southern chinese houses	Cc	*	*
Dichelostemma pulchella (Salisb.) Heller.	Wild hyacinth	Dp	*	*
Eucrypta chrysanthemifolia (Benth.) Greene var. *chrysanthemifolia*	Common Eucrypta	Ec	*	*
Callum aparine L.	Goose grass	Ga	*	*
Gnaphalium californicum DC.	Green everlasting	Gc		*
Lolium perenne L. ssp. *multiflorum* (Lam.) Husnot	Italian ryegrass	Lp	*	*
Phacelia cicutaria Greene var. *hispida* (Gray) J.T. Howell	Caterpillar phacelia	Pc	*	*
Phacelia viscida (Benth.) Ton.	Sticky phacelia	Pv	*	*
Pholistoma auritum (Lindl.) Lilja.	Common fiesta flower	Pa	*	*
Rafinesquia californica Nutt.	California chicory	Rc	*	*
Sanicula crassicaulis Poepp. ex DC.	Pacific sanicle	Sc	*	
Perennials				
Artemisia douglasiana Bess in Hook.	Douglas' mugwort	Ad	*	*
Baccharis glutinosa Pers.	Mule fat	Bg		*
Calystegia macrostegia (Greene) Brummitt ssp. *cyclostegia* (House) Brummitt	Coast morning-glory	Cm	*	*
Eriodictyon crassifolium Benth. var *denudatum* Abrams.	Thick leaved yerba santa	Ecd		*
Eriogonum fasciculatum Benth. ssp. *foliolosum* (Nutt.) Stokes	California buckwheat	Ef		
Eriophyllum confertiflorum DC. Gray var. *confertiflorum*	Golden yarrow	Ecc	*	*
Heteromeles arbutifolia M. Roem.	Christmas berry	Ha		*
Lotus scoparius (Nutt. in T. & G.) Ottley ssp. *scoparius*	California broom	Ls		*
Malosma laurina Nutt. in T. & G.	Laurel sumac	MI	*	
Mimulus cardinalis Dougl. ex Benth.	Scarlet monkey-flower	Mc	*	*
Mimulus longiflorus (Nutt.) Grant ssp. *longiflorus*	Salmon bush monkey-flower	Mc	*	*
Phacelia ramosissima Dougl. ex Lehm. var. *suffrutescens* Parry.	Branching phacelia	Pr		*
Prunus ilicifolia (Nutt.) Walp.	Holly-leaved cherry	Pi	*	*
Rubus ursinus C. & S.	California blackberry	Ru	*	*
Salvia mellifera Greene.	Black sage	Sm	*	*
Solanum douglasii Dunal in DC.	Douglas' nightshade	Sd	*	*
Toxicodendron diversilobum (T. & G.) Greene	Poison Oak	Td	*	*
Urtica holosericea Nutt.	Hoary nettle	Uh	*	*

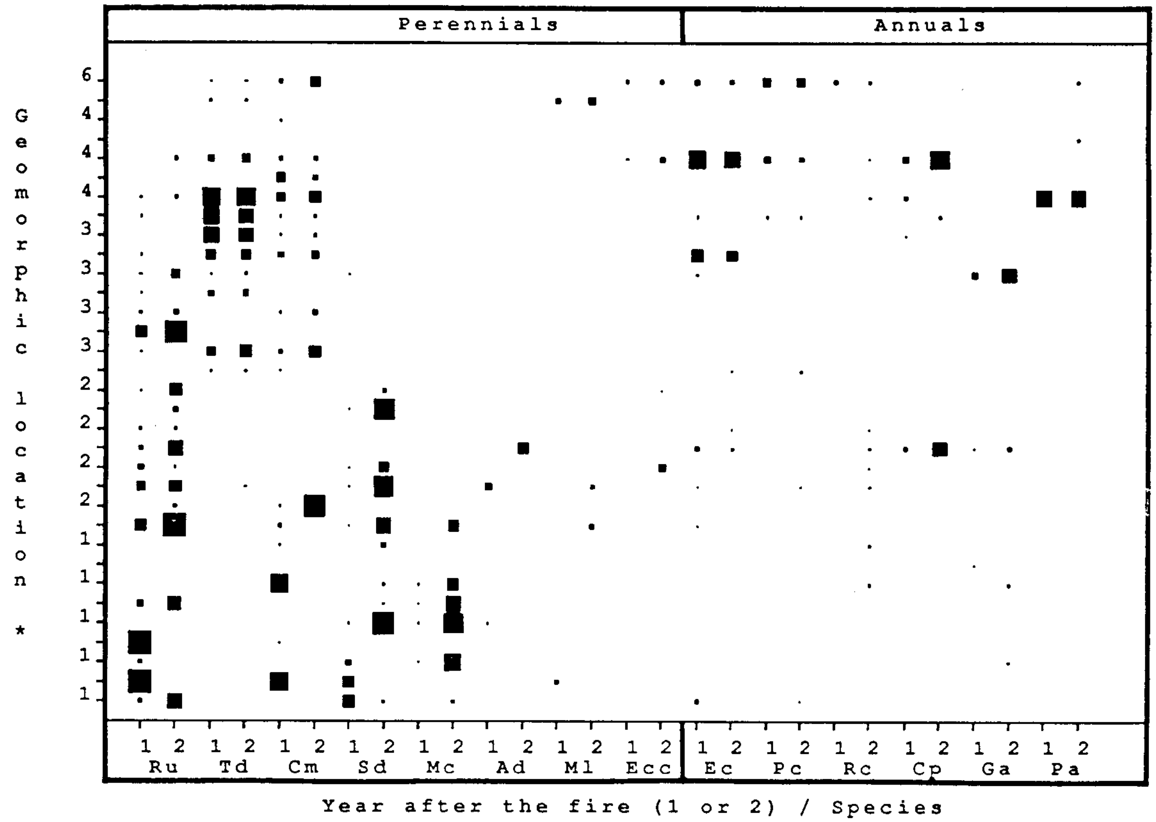

Figure 5– N. Fork Matilija Creek: post-fire development of species. Largest square represents maximum species frequency of 100 percent. 1,2,3 = lower, middle, upper terrace; 4,5,6 = lower, middle, upper hillslope. For abbreviations of species names, see table 2.

The study reach was monitored at quarterly intervals during the third year after the fire. A final survey of the site in spring 1988 (about 3 years after the burn) showed some changes in the flora. Most subplots were dominated by perennials such as *Rubus ursinus, Urtica holosericea, Baccharis glutinosa, Calystegia macrostegia, Mimulus cardinalis, Toxicodendron diversilobum,* and *Salix* spp. Shrubby chaparral species that persisted from the first 2 years included *Malosma laurina, Heteromeles arbutifolia, Prunus ilicifolia, Eriogonum fasciculatum, Eriophyllum confertiflorum,* and *Salvia mellifera.* Some new species were seen, for example, California lilac (*Ceanothus* L. sp.)

The most interesting feature of the third-year post-fire flora was a return to the species composition of the first year on some subplots. Species included *Phacelia cicutaria, Eucrypta chrysanthemifolia, Pholistoma auritum, Allophyllum divaricatum,* and *Galium aparine.* Ryegrass was frequent on most subplots. New species observed in June 1988 downstream of the study site in an area burned in August 1987 included short-lobed phacelia (*Phacelia brachyloba*) (Benth.) Gray), western morning-glory (*Calystegia purpurata* (Greene) Brumitt.,) and iris-leaved rush (*Juncus xiphioides*) E. Mey.)

Discussion and Conclusions

Hydrologic processes in drainage basins in southern California are controlled by infrequent storms and episodic streamflow, and erosional processes are dominated by frequent dry season gravitational sliding of small gravel sized clasts (dry ravel) and infrequent large magnitude debris flows. Hillslope stability and fluvial processes in chaparral basins are influenced by periodic fire.

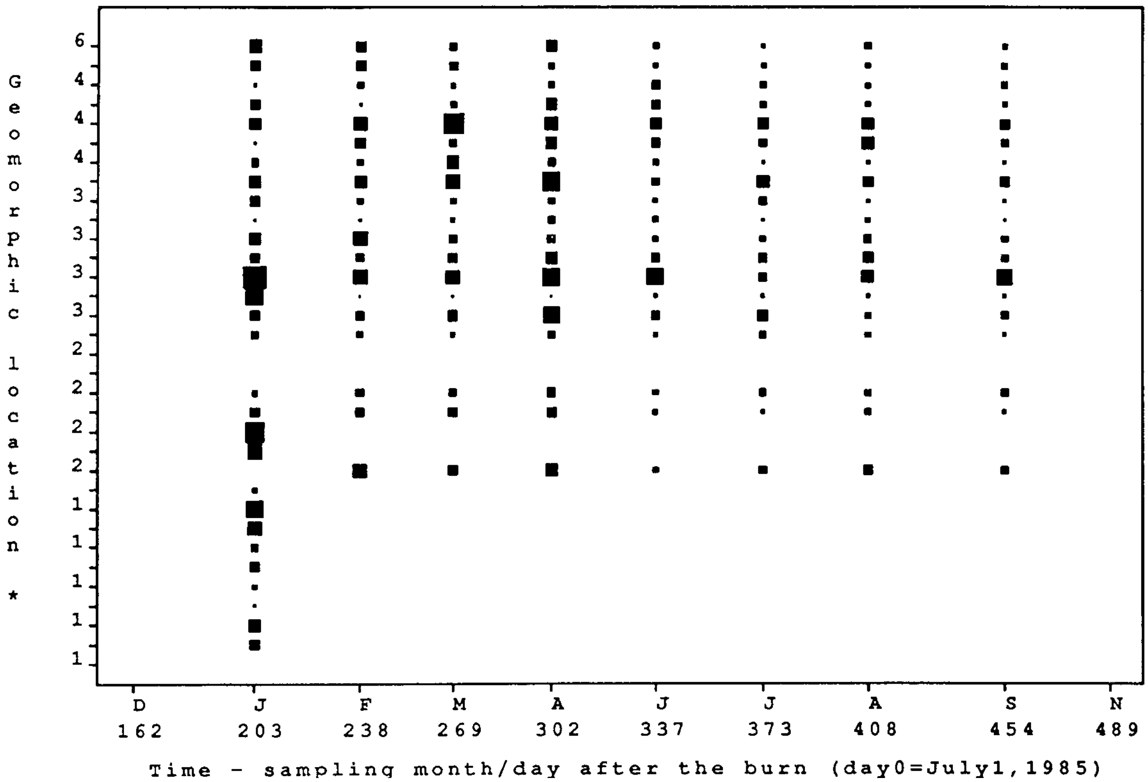

Figure 6– Matilija Creek: post-fire density of seeded ryegrass. Largest square scaled to represent maximum ryegrass density of 310 plants per square meter. 1,2,3 = lower, middle, upper terrace; 4,5,6 = lower, middle, upper hillslope.

Fire decreases basin stability; sediment deposition during the January 30-31, 1986, storm may be typical of the chaparral ecosystem following wildfire. Evaluation of debris flow deposits suggests that the recurrence interval of large debris flows in a particular basin is at least hundreds and perhaps thousands of years. By comparison, the recurrence interval of wildfire in the Santa Barbara area is 30-65 years (Bryne 1979). Thus fluvial transport of sediment derived from dry ravel and small landslides off hillslopes is much more common following a fire than is a large debris flow.

The recovery of vegetation following chaparral wildfire shows the combined disturbance effects of fire and flooding. Recovery processes in the herb layer are closely linked to geomorphic location in the riparian zone, and to the density of seeded ryegrass. Annuals become well-established on higher geomorphic locations less prone to flooding, but often in loose soil subject to dry ravel. Perennials, on the other hand, grow better on lower, more disturbed geomorphic locations near the stream. The overall species richness of annals decreased in the second year after the fire due to the predominance of ryegrass, although perennials took over the riparian zone to a large extent.

Sprouting is the dominant means of recovery of the tree species due to the lack of viable seeds following the fire. Certain species such as sycamore show rapid recovery, while others such as alder may be very slow to reestablish in the absence of a viable seed source. Full recovery of the alder canopy after unusually hot fires such as the Wheeler Fire may take many years or decades.

Acknowledgements

We thank personnel of the Forest Service, U. S. Department of Agriculture (Ojai Ranger District Office and the Supervisor's Office of the Los Padres National Forest in Goleta), especially Jim O'Hare, for logistical support during the study. We also thank Elva Rogers, Julia Boles, Ed Harvey, Kathryn Thomas, Nathan Gale, (and other students in the Geography and Biological Sciences departments at University of California, Santa Barbara, for field assistance; Susan Webb and Shirley Brous, Department of Geography, for typing the manuscript; and Janice LaTuchie, for cartographic assistance. This study was supported by Agency Award number W-687, Water Resources Center. University of California. Davis.

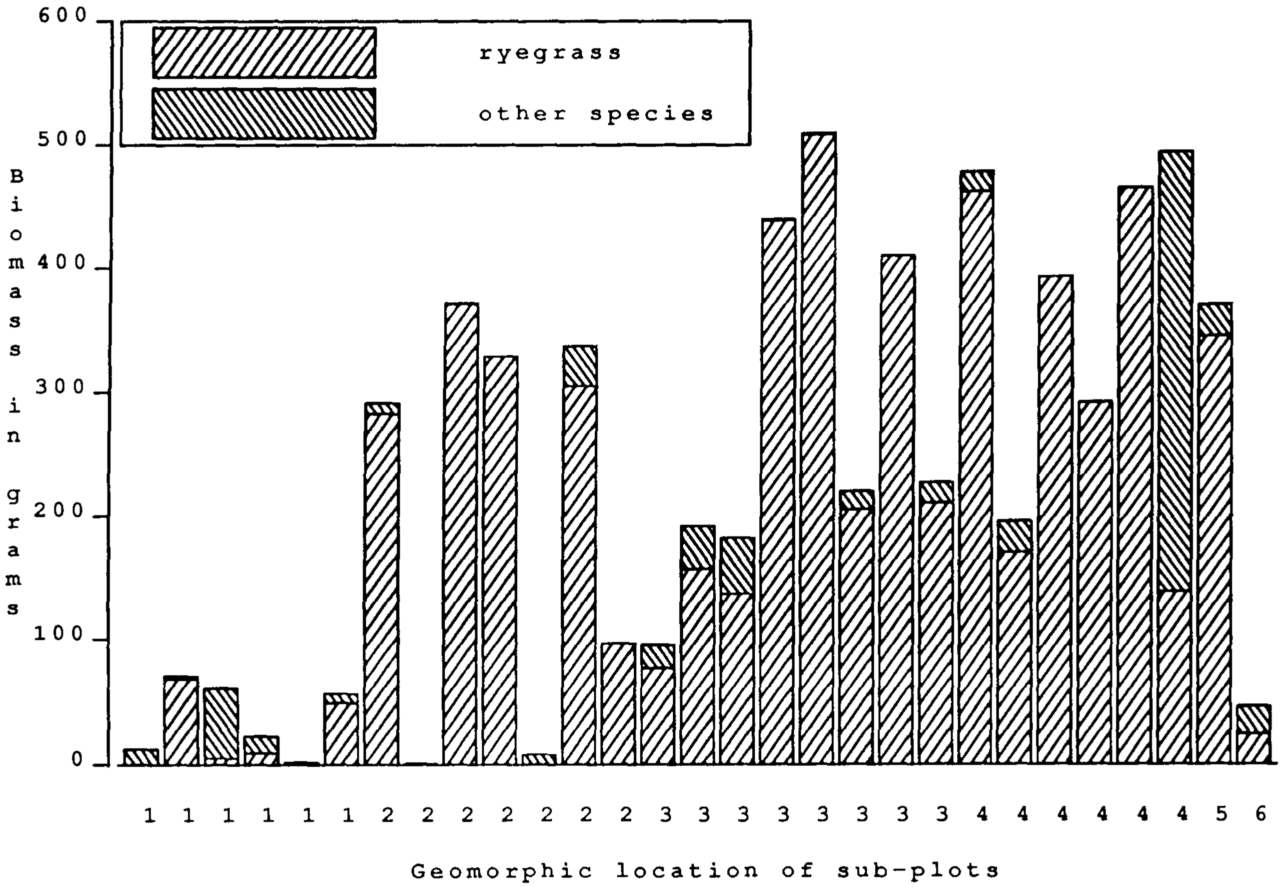

Figure 7– Matilija Creek: dry biomass of herbaceous species harvested June 2, 1986. 1, 2, 3 = lower, middle, upper terrace; 4, 5, 6 = lower, middle, upper hillslope.

References

Abrams, L.; Ferris, R. 1960. Illustrated flora of the Pacific states. Vol. I-IV. Stanford, CA.: Stanford University Press.

Brothers, T. S. 1985. Riparian species distributions in relation to stream dynamics, San Gabriel River, CA. University of California; Los Angeles: Ph.D. dissertation. 120 p.

Byrne, R. 1979. Fossil charcoal from varved sediments in the Santa Barbara Channel: an index of wildfire frequencies in the Los Padres National Forest (735 A.D. to 1520 A.D.). A report submitted to the USDA Forest Service-University of California, Berkeley, 69 p.

Dalyrymple, T.; Benson, M. 1967. Measurement of peak discharge by the slope-area method. Techniques of water resources investigations of the U.S. Geological Survey, A-2, 12 p.

DeBano, L.F. 1974. Chaparral soils. In: Symposium on living with the chaparral, Proceedings; March 30-31, 1973; Riverside, CA. Sierra Club: 19-26.

DeBano, L.F.; Rice, R.M.; Conrad, C.E. 1979. Soil heating in chaparral fires; effects on soil properties, plant nutrients, erosion and runoff. Res. Paper PSW-145. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 21 p.

Ezcurra, E.; Montana, C. 1984. On the measurement of association between plant species and environmental variables. Acta Oecologica/Oecologica Generalis 5: 21-33.

Florsheim, J.F., 1988. Channel form and process: A modeling approach. University of California; Santa Barbara: Ph.D. dissertation, August 1988, 170 p.

Florsheim, J.L.; Keller, E.A. 1987. Effect of fire and channel morphology on fluvial sedimentation. In: Erosion and sedimentation in the Pacific Rim. IAHS Publ. no. 165; 279-280.

Keeley, J.; Morton, B. A.; Pedrosa, A.; Trotter, P. 1985. Role of allelopathy, heat and charred wood in the germination of chaparral herbs and suffrutescents. Journal of Ecology 73: 445-458.

Keller, E.A.; Florsheim, J.L.; Best, D.W. 1988. Debris flows in the chaparral: myth and reality. GSA Abstracts with Programs 20(3): 172.

Krammes, J.S. 1965. Seasonal debris movement from steep mountainside slopes in southern California. In: Proceedings of the Federal Inter-agency Sedimentation Conference, Jackson, MS. U.S. Department of Agriculture, Misc. Pub. 970; 85-88.

Munz, P. 1974. A flora of southern California. Berkeley: University of California Press; 1086 p.

Nadkarni, N.; Odion, D. 1986. Effects of seeding an exotic grass Lolium multiflorum on native seedling regeneration following fire in a chaparral community. In: Proceedings of the Chaparral Ecosystems Research Conference;1985, May 16-17; Santa Barbara, CA. Report no. 62. Davis: California Water Resources Center, University of California, Davis; 115-121.

Parikh, A. 1988. Factors affecting the distribution of riparian tree species in southern California chaparral watersheds. Department of Geography, University of California, Santa Barbara: Ph.D. dissertation draft.

Plumb, T. R. 1980. Response of oaks to fire. In: Proceedings of the Symposium on the ecology, management and utilization of California oaks. General Technical Report PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture; 216-219 p.

Rice, R.M., 1974. The hydrology of chaparral soils. In: Symposium on living with the chaparral, Proceedings: March 30-31, 1973; Riverside, CA. Sierra Club:27-34.

Rice, R.M. 1982. Sedimentation in the chaparral: How do you handle unusual events? In: sediment budgets and routing in forested drainage basins. Swanson, Frederick J; Janda, Richard J.; Dunne, Thomas; Swanston, Douglas N. eds. 39-49 p.

Scott, K.M.; Williams, R.P. 1978. Erosion and sediment yields in the Transverse Ranges, southern California. U.S. Geological Service Professional Paper 1030, 37 p.

Wells, W.G. 1987. The effects of fire on the generation of Debris flows in southern California. In: Debris flows/ avalanches: processes, recognition, and mitigation. Costa, J.E.; Wieczorek, G.F. eds. Reviews in Engineering Geology 7:105-114.