North American Journal of Fisheries Management 20:562–569, 2000

Postfire Sediment Deposition in Geographically Restricted Steelhead Habitat

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Abstract.—In November 1993, fire burned the southeast portion of the Malibu Creek watershed, Los Angeles County, California. There was concern that sediment produced during the first postfire wet season would degrade pool habitat, thereby adversely affecting the population of steelhead *Oncorhynchus mykiss* confined to the 4.8-km reach between Rindge Dam and the Pacific Ocean. We tested the null hypothesis that first-year postfire sediment deposition had no effect on pool channel characteristics (depth, area, shape, and surficial sediment particle types) by monitoring pools after the fire but before and after the first postfire wet season. We added field observations of channel morphology to extend the results of the pool measurements. Our findings did not support a suggestion that pool habitat would degrade following the first-year wet season because pool-channel characteristics were generally unaffected by postfire sediment deposition. Consequently, no management action was needed to mitigate the effect of sediment deposition on pool habitat. The amount of soil erosion and sediment deposition that could have been produced during the first postfire wet season may have been reduced by various factors including the burn characteristics, below-average precipitation, and earthquake-induced recruitment of cobble and gravel.

Introduction

Wildfires have diverse effects on watersheds and the aquatic environment. Direct effects can include loss of streamside vegetation and alteration of soil characteristics (Brown 1990; Minshall et al. 1990; Swanston 1991; Rieman and Clayton 1997). Indirect effects can include increased flooding, soil erosion, sediment transport and deposition, and stream temperature (Swanson et al. 1987; Swanston 1991; Ewing 1996; Rinne 1996; Rieman and Clayton 1997); decreased fish and macroinvertebrate abundance (Novak and White 1990; Rinne 1996; Rieman and Clayton 1997); and degradation of instream habitat (Brown 1990; Minshall et al. 1990; Swanston 1991; Rieman and Clayton 1997). Although many effects of fire on stream habitat are adverse in the short-term, wildfire has a role for creating and maintaining landscape characteristics, habitat and species diversity, and life history complexity (Brown 1990; Rieman and Clayton 1997; Gresswell 1999). The potential impact of postfire changes on small, isolated populations can be devastating, however. Accordingly, postfire effects on aquatic habitat may warrant rescue or habitat rehabilitation actions where endangered species are of concern (Rinne 1991).

Therefore, when fire burned a portion of the Malibu Creek watershed in November 1993, we were confronted with a possible need for habitat rehabilitation. Land managers and advocacy groups believed sediment (mostly fine sediment i.e., sand and smaller particles) produced during the first postfire wet season would be deleterious to the creek's population of steelhead *Oncorhynchus mykiss,* recently listed as federally endangered (National Marine Fisheries Service 1997). The steelhead population is confined to only a 4.8-km reach between Rindge Dam and the Pacific Ocean. Pools appear to be important summer habitat for the local population (Entrix Inc., unpublished data), and loss of pools and cover has been attributed to sedimentation (Alexander and Hansen 1986; Everest et al. 1987; Gregory et al. 1987; Hillman et al. 1987), which increases after a fire. The loss of pools could have adverse consequences for the Malibu Creek population of steelhead. The objective of our study was to monitor pool habitat to determine if sediment deposition produced during the first postfire wet season resulted in significant sedimentation in Malibu Creek (decrease in cross-sectional area, widening of pool channel, and loss of depth) and, if so, to specify remedial actions to protect the steelhead population.

Study Area

The study area involved Malibu Creek and surrounding hillsides between Rindge Dam and the Pacific Ocean. Malibu Creek is in the Santa Monica Mountains, Los Angeles County, California

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Received June 22, 1998; accepted December 15, 1999

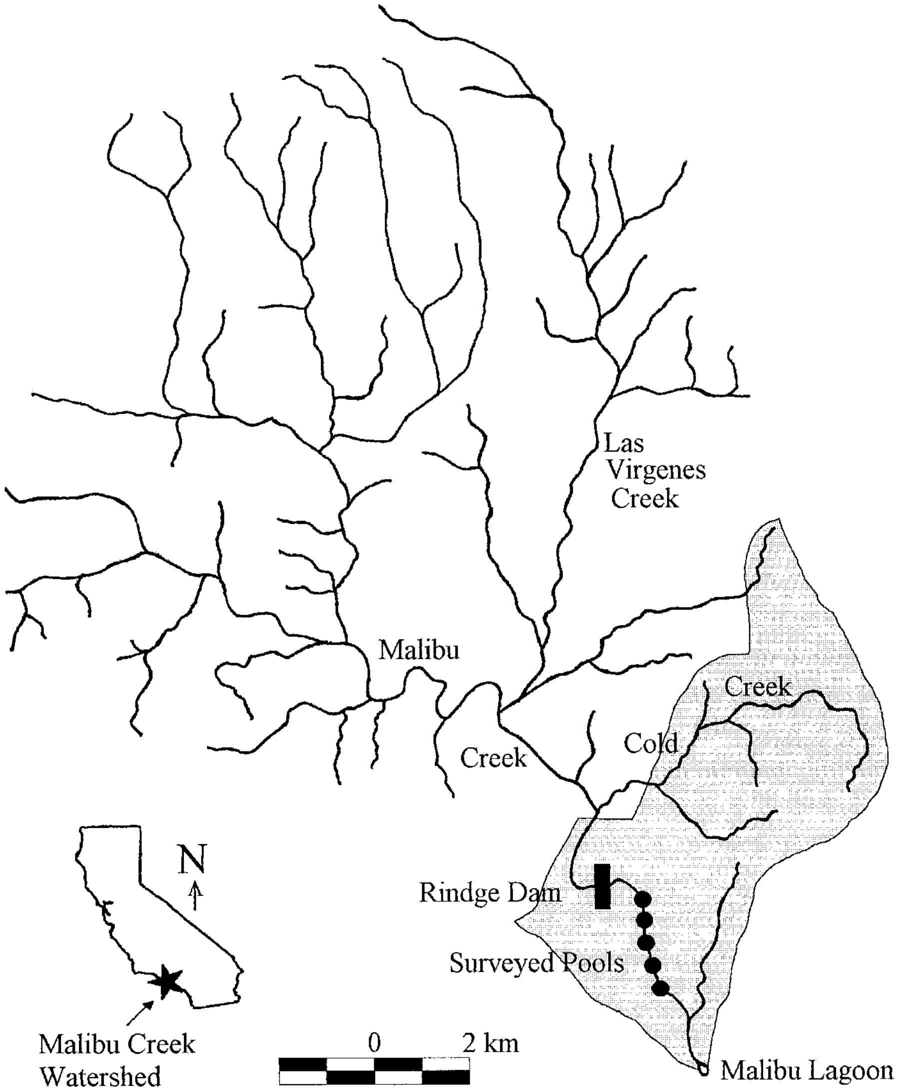

FIGURE 1.—The Malibu Creek watershed, the area burned by the November 1993 fire (shaded), and the location of pools surveyed (closed circles).

(Figure 1). Gorges and other drainages form steep transverse canyons within the 272-km^2 basin, which drains southward to the Pacific Ocean. The 4.8-km reach of creek downstream of the dam comprises a relatively short, narrow gorge (length, 0.8 km; slope, 2.7%) near the dam and a long, low-gradient valley (4.0 km, 1.4%) extending from the gorge mouth to the Pacific Ocean. The reservoir behind the dam is filled with sediment and has no capacity to store material routed from upstream sources. Pools, riffles, and runs are common. Boulder and cobble predominate the substrate within the gorge, but gravel and smaller particles are predominant in the valley channel. Relatively low annual rainfall and a Mediterranean climate are typical of the Santa Monica Mountains. Streamflow in Malibu Creek is characterized by short-duration, high-flow events associated with winter (January–March) storms and a base flow of about 0.14 m^3/s during summer and fall. High streamflows are typically 2.8–14.2 m^3/s and less typically (once every 2–3 years) 28.3 m^3/s. Chaparral is the dominant plant community on surrounding hillsides; oak woodland is present in some locations within the study area. White alder *Alnus rhombifolia* and arroyo willow *Salix lasiole-*

pis border the creek in many areas. Land-use activities throughout the drainage include livestock grazing, horticulture, recreational use of parklands, and limited residential development. Much of the land within the Malibu Creek watershed is within state or federal parklands.

Wildfire burned about 20% of the Malibu Creek watershed in November 1993, primarily in the southeast portion (Morgan et al. 1994). The west and east slopes surrounding the creek main stem downstream and slightly upstream of the dam (and much of Cold Creek) were affected by the fire (Figure 1). The forestry division of the County of Los Angeles Fire Department initiated seeding efforts soon after the fire to minimize soil erosion. Fires in 1956, 1970, and 1985 had previously affected the watershed.

Methods

We performed both a qualitative survey of the study area and a quantitative survey of pool channel characteristics (depth, area, shape, and surficial sediment particle types). All surveys were performed after the fire but before and after the first postfire wet season. We believe this monitoring design is justified because postfire sediment deposition typically occurs during runoff (e.g., Varley 1990; Rinne 1996). Precipitation data for the Malibu area (Malibu Beach-Dunne station 1025) and discharge data for Malibu Creek were obtained from the Los Angeles County Department of Public Works.

Qualitative survey.—To assess whether soil erosion and sediment deposition were likely to result from the first postfire wet season, we noted characteristics of the burn, such as whether vegetation was standing with root systems intact or had been eliminated, presence of coarse sediment and debris accumulations (dry ravel) in gullies, and the presence of a water-repellent (hydrophobic) soil layer and network of small channels (rills) that form during initial storms. Accumulation of dry ravel, presence of a water-repellent soil layer, and a high-intensity storm or series of storms constitute the fire–flood sequence (Rice 1982; Wells 1987; Barro and Conrad 1991). Although accumulation of sediments and debris occurs in steep-sloped terrain whether or not there has been a fire, vegetation that anchors much of this material can be removed by fire, thereby resulting in an increased source of sediment. We also inspected the creek channel and noted presence of extensive accumulations of fine sediment within the creek and along the banks. These surveys were performed December 9, 1993, and January 21, March 10, and April 15, 1994. Observations were made before, during (usually a few days after a storm produced substantial precipitation, which enabled us to monitor development of rills, debris flows, and new sediment accumulations), and after the wet season.

Quantitative survey of pools.—We surveyed five pools in the valley reach (Figure 1), which were randomly selected from the 16 pools identified in the study area. Length of the pools surveyed ranged from 14.1 to 28.5 m, and mean width ranged from 10.9 to 20.8 m. We estimated, using standard methods (Platts et al. 1983; MacDonald et al. 1991; Olson-Rutz and Marlow 1992), pool channel characteristics by measuring the distribution of depths (m) at equally spaced intervals (about 15 measurements for each cross-section) along cross-sections. Two cross-sections were placed in pools less than 20 m, and three cross-sections were used in relatively long pools (>20 m). Surficial sediment particle types were identified visually at each measurement location following criteria of Platts et al. (1983), except that we defined *fines* as sand and smaller particles. We surveyed the same pools before (January) and after (April) the first postfire wet season to determine if the net sediment deposition had an effect on pool channel depth, area, shape (distribution of depth measurements; Olson-Rutz and Marlow 1992), and surficial sediment particle types. Although we collected data after the traditional start of the wet season in southern California (generally November–December), precipitation was negligible in fall and early winter 1993.

Data analysis.—Pool-specific means for depth, percent change in area, shape, and frequency of the sediment particle types were calculated for sampling periods before and after the first postfire wet season. Equations presented in Olson-Rutz and Marlow (1992) were used to calculate percent change in area and shape. We used the one-sample *t*-test to test (type I error rate = 0.05) the null hypothesis that the mean difference between mean pool depth before and after the first postfire wet season was zero (our application of this test using the difference in means as the response variable is analogous to a test for dependent samples). This test was repeated using percent change in area as the response variable. The difference between means was always calculated by subtracting the mean pool depth determined after the wet season from the mean pool depth determined before the wet season. A posteriori power analysis for the one-sample *t*-test (Zar 1996) was used to determine

TABLE 1.—Precipitation data for Malibu Creek area, January 1 to March 31, 1994 (Station 1025, Malibu Beach–Dunne, Los Angeles County Department of Public Works). Values are amount (cm) of rainfall recorded in a 24-h period; data presented only for days when precipitation was recorded.

Day of month	Jan	Feb	Mar
4		0.89	
6			1.07
7		3.28	0.13
8		0.71	
17		1.45	
18		0.20	
19			1.40
20		2.97	0.08
25	0.76		1.45
Total	0.76	9.50	4.13

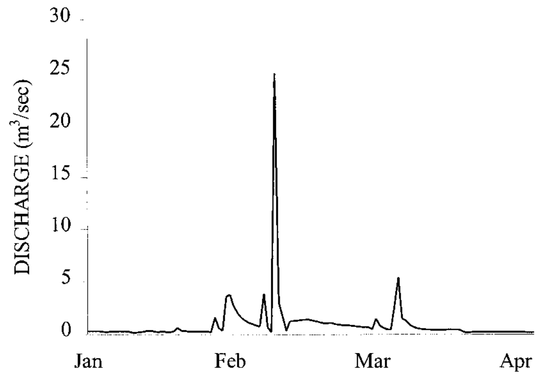

FIGURE 2.—Malibu Creek hydrograph, January 1 to April 31, 1994. Data obtained from Los Angeles County Department of Public Works.

the power of the performed tests. We used two-factor univariate analysis of variance (ANOVA) to test for interaction between time (before and after the first postfire wet season) and sediment particle types, mean frequency of occurrence of the sediment particle types being the response variable.

Results

Precipitation and Discharge

Precipitation during the winter of 1994 was 14.39 cm, well below the average of 40.6 cm. Generally, rainfall events were infrequent, and the amount of precipitation recorded in a 24-h period during any event was low to moderate (Table 1). One large discharge occurred in February (2–3 year recurrence interval) and a few smaller events in February and March (Figure 2).

Qualitative Observations

Components of the fire–flood sequence were not found in the study area during our inspection on December 9, 1993, which was before measurable precipitation had fallen in the southern California area, nor during subsequent qualitative surveys. A hydrophobic soil layer was not observed in the patchily distributed hillslope vegetation, and no rills were observed in the areas we inspected. Riparian vegetation along Malibu Creek appeared unaffected by the fire. Although ground cover was eliminated from west and east slopes, trees and shrubs, though badly burned, were generally standing with root systems intact. A large gravel bar, the only extensive area of spawning habitat in the study reach existing before the fire, was approximately 30 m downstream from Rindge Dam. Three large rockfalls (gravel- to boulder-sized clasts), which were induced by a Richter magnitude 6.8 earthquake that struck the Los Angeles area on January 17, 1994, were observed adjacent to the channel within the study area on January 21, 1994.

On March 10, 1994, we observed several effects from the moderate storms in February. Large amounts of fine sediment were brought into the creek immediately downstream of the dam. Extensive accumulations of fine sediment were observed within 70 m of the dam, and the large gravel bar downstream of the dam was entirely scoured. Fine sediment was deposited along the banks, in the lee of boulders, and within the channel. The extent of fine sediment appeared greater in shallow pools (<1.0 m) and habitats with low to moderate water velocities than in habitats with relatively high velocities. At distances more than 100 m downstream of Rindge Dam, the influx of fine sediment appeared to be much less than we observed within 70 m of the dam. New instream gravel deposits were observed emanating from the earthquake-induced rockfalls. A female steelhead with three males was observed excavating a redd in one of the new gravel deposits. On April 15, 1994, a new gravel bar downstream of Rindge Dam was observed near the position of the one observed initially.

Measured Pool Characteristics

Sediment deposition produced during the first postfire wet season had little effect on pool characteristics. Although mean depth of most pools decreased following the wet season, the decrease was relatively small (Table 2). The overall average change in mean depth was 0.07 m, and was not significant (t = 1.987; df = 4; P = 0.118). Power

TABLE 2.—Changes in pool depth and shape and percent change in area following the first postfire wet season. Negative values indicate pool narrowing (shape) and increased depth and area following the wet season. Positive values indicate pool widening and decreased depth and area.

Pool	N^a	Change in depth (m)	Change in shape (m)	Change in area (%)
1	30	0.014	0.0004	1.48
2	33	−0.007	−0.0003	−0.73
3	43	0.038	−0.0001	1.99
4	45	0.171	0.0011	22.50
5	46	0.116	0.0007	7.42

[a] Number of cross-sectional depths.

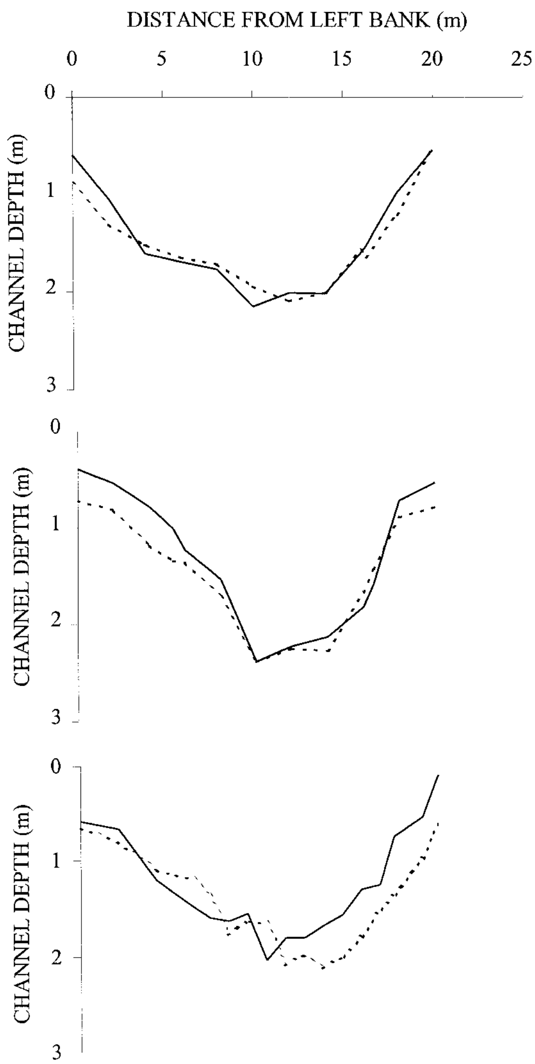

FIGURE 3.—Channel profile for pool 5. The dashed line is channel depth before and the solid line is channel depth after the first postfire wet season.

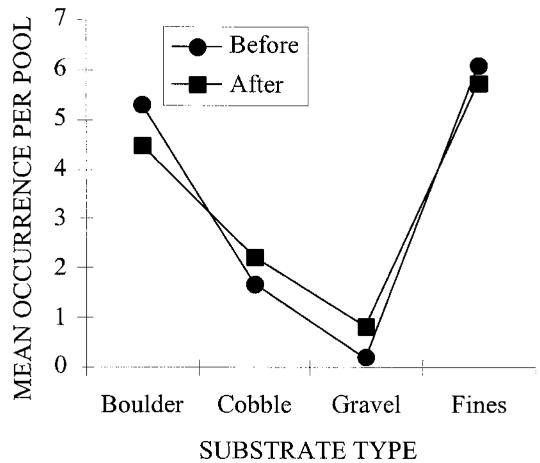

FIGURE 4.—Mean occurrence per pool ($N = 5$) of four sediment particle types before and after the first postfire wet season. Substrate classification follows Platts et al. (1983), but fines are defined here as sand and smaller particles.

analysis indicated a 4% chance of accepting a false null hypothesis when the average difference between means was 0.15 m. If sediment deposition produced during the first postfire wet season had an effect on pool depth, the effect was small. The percent change in area varied among the pools; the area of four pools decreased, whereas the area of one pool increased (Table 2). The mean percent change in area of 6.5% was not significant (t = 1.545; df = 4; P = 0.197). Power analysis indicated a 78% chance of detecting a true percent change in area of at least 15%. If sediment deposition had an effect on pool area, the effect was relatively small. Generally, we observed deposition along the bank and slope of most pools and scour at the thalweg (Figure 3). The shape of the pool channels changed negligibly following the postfire wet season (Table 2). Some pools widened slightly, as indicated by a positive change in shape, whereas other pools narrowed (Table 2; Figure 3). On average, more cobble and gravel were present following the first postfire wet season (Figure 4). The presence of sediment particle types was independent of the postfire wet season, as indicated by the nonsignificant time × sediment particle type interaction (ANOVA; $F_{3,32} = 0.264$; $P = 0.851$). The relatively large percent change in area noted for pool 4 (Table 2) resulted from input of cobble and gravel from an adjacent gully.

Discussion

Concern for loss of pool depth downstream of the dam following the fire was based in part on the role of pools as oversummering habitat for steelhead, particularly in arid regions. Pool water can stratify into relatively cool layers during summer, and groundwater seeps and intergravel flow can contribute cool water to pools. This provides thermally tolerable rearing and holding areas for steelhead where surface temperatures may approach or exceed lethal thermal thresholds (Nielsen et al. 1994; Matthews and Berg 1997). Pools may be the only instream area capable of supporting juvenile steelhead during summer. Many coastal streams in south-central California (San Luis Obispo County) and southern California (Santa Barbara, Ventura, and Los Angeles Counties) experience seasonal discharge decreases to the extent that pools are the only habitat in which depth appears appropriate for juvenile steelhead; such pools are the only habitat type in which juveniles are reliably found in these streams (A. Spina, personal observations). In Malibu Creek, we did not observe the significant changes in channel characteristics that would be expected (e.g., Alexander and Hansen 1986) to adversely affect salmonids. Extensive accumulations of sediment appeared to be confined only to the relatively short reach (about 70 m) of creek immediately downstream of the dam. Consequently, our findings did not warrant a habitat rehabilitation program to mitigate sediment deposition produced during the first postfire wet season. The basis to explain our observed results lies with the burn characteristics and postfire weather conditions.

The amount of soil erosion and sediment deposition that could have been produced during the first postfire wet season may have been reduced by the integrated effect of various factors. The magnitude and extent of fire effects on the aquatic environment depend in part on amount of heat transfer (i.e., intensity; Brown 1990), amount of vegetation burned (severity; Brown 1990), presence of hydrophobic soil layers, proximity of the subject site to the fire, and watershed characteristics (e.g., soil, vegetation, terrain, and topography; Brown 1990; Gresswell 1999). Generally, a relatively hot fire that eliminates vegetation, exposes soils, creates hydrophobic soil layers, and burns extensive areas, would be expected to cause substantial sediment deposition to receiving waters. The Malibu Creek fire exhibited relatively low intensity and severity, burned a small proportion of the watershed, and affected the landscape unevenly, and the most intensely and severely burned area (Cold Creek) was relatively far removed from our study area. Furthermore, while hillside vegetation was eliminated, roots of trees and shrubs remained. Such structures bind soil, thereby minimizing the amount and extent of erosion (Minshall et al. 1990; Rieman and Clayton 1997). Another factor that may contribute to the magnitude and extent of the effects is the postfire weather. The relatively mild to moderate and infrequent rainfall noted in the Malibu watershed during our study may have reduced the degree and amount of soil erosion and surface runoff and lessened sediment loads (Varley 1990). The fact that we noted few changes in pool characteristics may have been due, in part, to storage of sediment on the banks immediately downstream of the dam, within streamside vegetation, and along the bank slopes of most pool channels. Riparian vegetation in the study area, and perhaps farther upstream, was largely unaffected by the fire, thereby maintaining its functional value as a sediment trap (Copper et al. 1987; Murphy and Meehan 1991; Platts 1991; Welsch 1991).

Our results should be viewed within the context of the time and space in which the study was conducted. Changes to pool habitat before monitoring are unlikely because precipitation was negligible during this period, but postmonitoring changes resulting from a lagged response are possible (e.g., Varley 1990). The magnitude and extent of fire-induced soil erosion and sediment impacts to aquatic habitat, however, are usually greatest during first-year runoff events and wane thereafter (Wells 1987; Brown 1990; Minshall et al. 1990). Slurry and (or) toxic flows (sensu Rinne 1996) could have affected the local population of steelhead. The volume of flow in Malibu Creek, particularly through the reach containing steelhead, was probably sufficient to dilute the concentration of any toxic flow, given the size of the watershed compared with the relatively small burn area. Although our results generally indicate favorable conditions for the population of steelhead, instream habitat upstream of the dam, because of its proximity to the fire, may have been adversely affected by the first postfire wet season (Gresswell 1999). Intrusion of fine sediment in spawning habitat is a concern not addressed by our quantitative study design. While fine sediment in spawning gravels can decrease survival to emergence of salmonids (Chapman 1988), the nest-digging behavior of anadromous salmonids and characteristics of their redds may mitigate to some extent the potential effect of fine sediment on survival to emergence (Everest et al. 1987). Furthermore, after the wet season and the earthquake-induced rockfall, we observed numerous instream locations downstream of the dam that appeared suitable for spawning, including areas of cobble and gravel relatively free of fine sediment. Although habitats other than pools could have been affected by sediment deposition, our observations of the study reach indicated that deposition of fine sediment appeared to be confined to the relatively short reach of instream habitat downstream of the dam. Downstream of this reach, the amount and extent of surficial sediment we observed in habitats after the wet season appeared similar to that observed before the wet season.

Overall, our study documented deposition of sediment immediately downstream of the dam but not significant sedimentation in pools. Several factors, including the intensity and severity of the fire, the below-average precipitation, and the earthquake-induced recruitment of cobble and gravel, may have produced the observed postfire conditions. The scope of our study limits extending the results through time and space, however. The absence of prefire data emphasizes the importance of periodic baseline monitoring in habitats, particularly where listed species are present. A monitoring program focused only on a subset of these factors would not have detected the apparent integrated effect. Rather, combining comprehensive qualitative observations with a focused quantitative survey provided us with an efficient procedure to make fisheries and land-management decisions in the context of physical processes and resource knowledge.

Acknowledgments

John Crandall and John Southwick provided field assistance for data collection, and Tom Keegan provided input during the early phase of the study. The Santa Monica Mountains Conservancy funded the study, and California Trout sponsored the study. The Editor, Associate Editor, Ed Pert, John Rhodes, John Rinne, and an anonymous referee provided comments and recommendations for revision, which we subsequently incorporated into the manuscript.

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