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Effects of Fine Sediment on Salmonid Redds in Prairie Creek, a Tributary of Redwood Creek, Humboldt County, California

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Abstract. We studied the effects of fine sediment derived from a highway construction alignment on salmonid redds in Prairie Creek, a creek flowing through Redwood National Park and Prairie Creek Redwoods State Park, California. We used infiltration bags, permeability standpipes, and colander mesh baskets filled with gravel and eyed steelhead trout (*Oncorhynchus mykiss*) eggs, to measure changes in fine sediment, gravel permeability, dissolved oxygen, and egg survival to hatching in artificially constructed redds. Infiltration bag results indicated fine sediment was greatest in a Prairie Creek tributary affected by highway development, next greatest in Prairie Creek mainstem, and the least in the control stream. However, fines smaller than 1 mm in the egg-containing baskets placed in the mainstem were low (1–8% by volume) and did not differ significantly from the control stream. Permeability decreased over the season at all Prairie Creek sites, including a site that received minor amounts of sediment from the highway alignment. Intragravel and surface dissolved oxygen decreased over the winter, but never below 7.7 ppm. Survival of steelhead eggs was high in affected and control streams. Fine sediment did not seem to be the major factor affecting these parameters. These results were obtained during a low rainfall year. Streamflows were too low to move sediment into the cleaned gravel of the redds; consequently, egg survival was probably less adversely affected than it would have been in a year of more normal streamflow. Similar studies will be conducted to document effects of higher flows.

Key words: Salmonid, egg survival, redd, dissolved oxygen, gravel permeability, fine sediment.

In October 1989, a storm delivered tons of fine sediment from an unprotected highway construction alignment into Prairie Creek and many of its tributaries. A layer of silt- and clay-textured sediment settled on the surface of the streambed and infiltrated into subsurface gravels of this relatively pristine salmonid stream system (Redwood National Park 1991). Infiltration of large amounts of fine sediment into salmonid redds can reduce reproductive success

(Everest et al. 1987). Sediment can reduce gravel permeability and intragravel water flow (Cooper 1965) and, thus, availability of dissolved oxygen (DO: Coble 1961). Low DO can cause direct egg mortality (Alderice et al. 1958). We studied the effects of fine sediment in Prairie Creek, beginning in December 1989. The objective was to determine if the fine sediment reduced gravel permeability, DO, and salmonid egg survival in the creek. During the first year of this multiyear study, we specifically addressed the effect on survival to hatching of eyed steelhead trout (*Oncorhynchus mykiss*) eggs. We present the results of the first year of study in this paper.

Study Area

Prairie Creek is in Redwood National Park and Prairie Creek Redwoods State Park near the town of Orick in northern California. Prairie Creek, tributary to the coastal stream Redwood Creek, is 22 km long. The average stream gradient in the study area is 1%, and the drainage area is 35 km^2. Much of the Prairie Creek watershed vegetation is old-growth redwood (*Sequoia sempervirens*) forest. Anadromous and resident stocks of cutthroat trout (*Oncorhynchus clarki*) are common in Prairie Creek and its tributaries (Anderson 1988). The creeks support large runs of anadromous coho salmon (*O. kisutch*), steelhead trout, and chinook salmon (*O. tshawytscha*).

A four-lane highway was being constructed upslope and parallel to Prairie Creek on the east side for 10 creek km in second-growth redwood forest. The terrain of the highway alignment was steep and highly erodible. During the October storm, sediment was delivered into Prairie Creek from the tributaries Ten Tapo, Brown, Big Tree, Boyes, and May creeks. The study area included the affected Prairie Creek reach, the affected Brown Creek tributary, and a control stream, Lost Man Creek (Fig. 1). Lost Man Creek is a large tributary to Prairie Creek that was unaffected by highway sediment inputs. This stream was not an ideal control because it has been affected by some logging and is somewhat dissimilar geologically. However, it is identical climatologically, has supported successful salmonid spawning, and was the best control available.

Methods

To test permeability, fine sediment infiltration, and egg survival, we constructed artificial salmonid redds and measured the cumulative effect of subsequent storms on those three parameters. To simulate a redd, we sifted pockets of gravel to clean out fine sediment using a shovel or sieve at potential spawning sites. For the egg survival experiment, we also mimicked the shape and pot of a natural redd. We recorded Prairie Creek water and sediment discharge near the sites (Fig. 1) during the study.

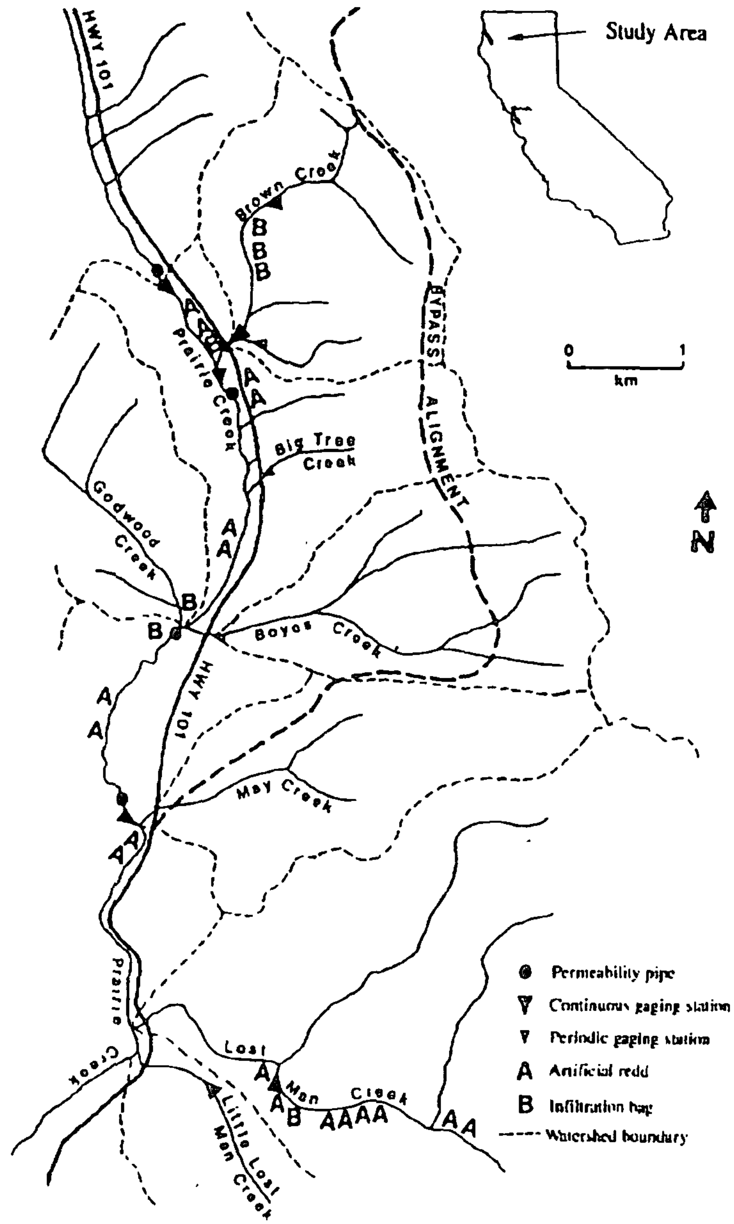

Fig. 1. Study area showing Prairie Creek, its tributaries, the highway bypass alignment, water and sediment discharge gaging stations, and location of artificial redds containing clusters of permeability pipes.

Fine Sediment Infiltration in Redds

In December 1989, we placed three infiltration bags on Prairie Creek, one on the control stream, and three on Brown Creek, a sediment-affected tributary to Prairie Creek (Fig. 1). These collapsible, waterproof bags with floats were placed beneath columns of stream gravel sieved of all fines smaller than 4 mm in Prairie Creek and smaller than 2 mm in Brown Creek. All bags were removed with a winch and tripod by June 1990 and sieved to determine percent of the total sample weight in various particle size classes smaller than 4 mm. Sample size was only one in the control stream because of time constraints, therefore little could be inferred statistically. Differences found were interpreted as apparent trends.

Redd Gravel Permeability and Dissolved Oxygen

In January 1990, we placed four clusters of four permeability standpipes, modeled after those of Gangmark and Bakkala (1958), in shovel-cleaned artificial redds in Prairie Creek. The most upstream cluster was in the least affected section of Prairie Creek, which was above the Brown Creek confluence. The other three were downstream of Brown Creek and other tributaries known to have contributed large amounts of sediment (Redwood National Park 1991; Fig. 1).

Permeability testing procedures followed those of Terhune (1958). Pipes remained in the streambed throughout winter, and subsurface gravel inflow rates were measured in January and July 1990. Beginning in February, we also lowered a probe into the standpipes to measure DO concentrations in the subsurface gravels. Dissolved oxygen was measured in the adjacent surface water at the same time.

Inflow rate was used as an index of permeability. Differences in inflow rate and DO between the standpipe clusters and over time were tested using two-way analysis of variance. One-way analysis of variance and Tukey's multiple range tests (Neter et al. 1990) were performed to determine which groups differed significantly ($P < 0.05$). We used paired t-tests to test differences between intragravel and surface water DO.

Egg Survival

We constructed 10 artificial steelhead redds in Prairie Creek and eight in the control stream. Three enamel-coated colander baskets (0.31-cm mesh), filled with shovel-cleaned stream gravel and eyed steelhead eggs, were covered with a fiberglass screen mesh and buried in each redd. The eggs were incubated between mid-February and April 1990, similar to the natural incubation period. After eggs were expected to have hatched, we removed the baskets and counted the number of alevins.

During removal, baskets were slid into a dishtub underwater to minimize loss of fine sediment. Basket gravel was wet-sieved to determine percent volume of fines smaller than 1.0 mm. Differences in survival and fines between Prairie Creek and the control stream were tested using analysis of variance. To reduce nonnormality, all percentage estimates were converted by an arcsine square root transformation. Additionally, percent egg survival was regressed on percent basket fines.

Results

Peak streamflows following artificial redd construction were low. The highest flows to which the permeability and infiltration redds were subjected were 20–40% of the stream's 2-year recurrence interval flow (RI), respectively (2-year RI = 17 m^3/s downstream of the Brown Creek confluence). The egg-survival redds were exposed to even lower flows, the highest being 10% of this RI.

Fine Sediment Infiltration in Redds

Brown Creek infiltration bags received a greater proportion of fine sediment than bags in Prairie Creek or the control stream. The control sample had the lowest percent fines (Fig. 2). Mean percent by weight of fines smaller than 1.0 mm ranged from 4.9% (SE = 1.9) in Brown Creek to 2.9% (SE = 0.28) in Prairie Creek and 1.9% (n = 1) in Lost Man Creek.

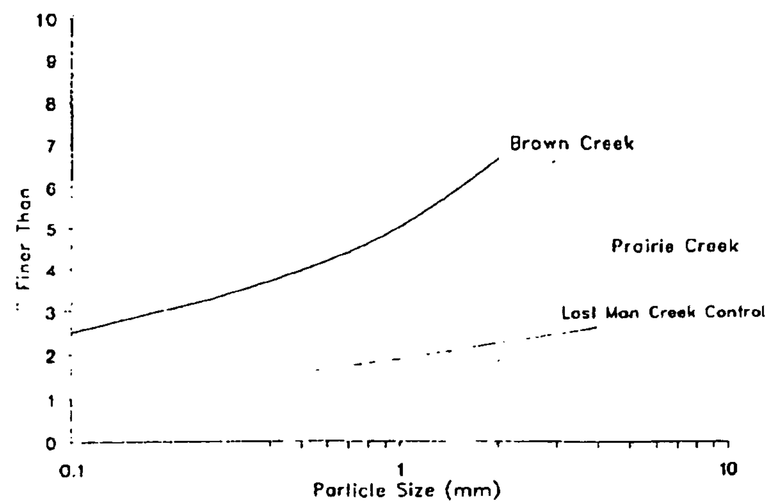

Fig. 2. Distribution of fine particle sizes in redds artificially constructed in Prairie, Brown (affected streams), and Lost Man (control stream) creeks, northern California, in late May and early June 1990. In December 1989, the redds were cleaned of fines smaller than 4 mm in Prairie and Lost Man creeks and smaller than 2 mm in Brown Creek.

Redd Gravel Permeability and Dissolved Oxygen

One standpipe in the third downstream cluster was damaged and not included in the results. Inflow rate decreased in all but one of the 15 pipes from January to July. Mean inflow rate significantly decreased over this period ($P = 0.002$) and varied between clusters ($P < 0.001$). Two-way interactions were insignificant ($P = 0.84$). Means were lower in pipe clusters below Brown Creek confluence (clusters 2–4) than above during both sampling months (Tukey's test, $P < 0.05$). However, the winter decrease in the upstream cluster did not differ significantly ($P > 0.05$) from downstream clusters (Table).

Dissolved oxygen decreased in all but two standpipes from February to July. Mean DO significantly decreased over this period ($P < 0.001$), and varied between clusters, although not at the 95% confidence level ($P = 0.10$). Two-way interactions between time and location were significant ($P < 0.001$). In February, the lowest mean concentration was in the cluster just downstream of Brown Creek confluence (Tukey's test, $P < 0.05$). However, unlike the other clusters, the mean in this cluster increased over the winter, becoming similar to all but the most downstream cluster by July (Table). Average decrease over time did not differ significantly ($P = 0.20$) between intragravel water ($\bar{x} = 12\%$, SE = 3) and surface water ($\bar{x} = 15\%$, SE = 1). Surface DO ranged from 0.1 to 1.0 ppm greater than intragravel DO. Intragravel DO never dropped below 7.7 ppm in any of the pipes.

Egg Survival

Egg survival to hatching was relatively high for all but two redds (Fig. 3). Mean percent survival was 71% (SE = 12.0) in Prairie Creek and 85% (SE = 2.5) in the control stream. This difference was not statistically significant ($P = 0.36$). Two redds on Prairie Creek had 0% survival. These two redds were heavily infested with oligochaete worms. Fines smaller than 1.0 mm in the baskets of these two redds fell within the range of the other redds, 1.2 to 8.1% by volume. Means for fines were 2.6% (SE = 0.6) of the basket gravel for Prairie Creek and 3.7% (SE = 2.8%) for the control stream; those values did not differ significantly ($P = 0.24$). Basket fines did not explain much of the variance in egg survival ($r^2 = 0.06$, $P = 0.089$).

Table. Mean inflow rates and dissolved oxygen concentration measured from clusters of four standpipes placed in artificial salmonid redds constructed on Prairie Creek in January 1990.[a]

	January		July		Decrease (%)	
Pipe cluster	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
			Inflow rate (cm³/s)			
1	108^{b}	7	87^{b}	10	-20^{b}	5
2	57^{c}	9	35^{c}	3	-32^{b}	12
3	47^{c}	8	35^{c}	5	-22^{b}	13
4	67^{c}	5	54^{c}	3	-19^{b}	10
			Dissolved oxygen (ppm)			
1	10.4^{b}	0.3	$8.2^{b,c}$	2.5	-20^{b}	3
2	8.6^{c}	0.4	9.1^{b}	0.1	$+3^{c}$	5
3	10.7^{b}	0.3	9.0^{b}	0.1	-16^{b}	2
4	10.5^{b}	0.1	8.7^{c}	0.1	-17^{b}	2

[a]Pipe clusters were ordered from upstream to downstream.
[b,c]Similarly superscripted values in the same column did not differ significantly at the 0.05 level (Tukey's test).

Discussion

Rainfall during the winter of 1989–90 was low, averaging 114 cm at Prairie Creek Redwoods State Park compared with the 19-year average of 170 cm. Stream discharge was low during all experiments. Scour and fill studies showed that very little of the streambed was mobilized during this period (Redwood National Park 1991). Consequently, flows were insufficient for scouring and moving much sediment into the cleaned artificial redds. This accounts for the low mean value of fines found in the redds toward the end of winter.

Infiltration bag results indicated that fines were greatest in the Brown Creek tributary, least in the control stream, and intermediate for Prairie Creek. This was expected because eastern tributaries, such as Brown Creek, received direct inputs of sediment from the highway alignment. Surface and subsurface

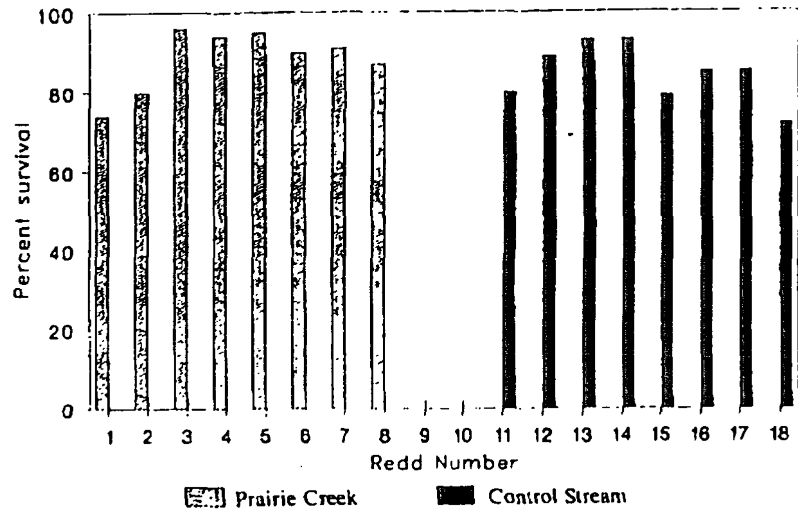

Fig. 3. Percent of eyed steelhead eggs (200 eggs/redd) that survived to hatching when incubated in artificial redds from February to April on Prairie Creek (affected stream) and Lost Man Creek (control stream) in northern California, 1990.

fines were found in greatest amounts in the tributaries (Redwood National Park 1991) and would, therefore, provide a larger source of infiltrating sediment on mobilization.

In contrast, levels of fine sediment in the egg survival redds in the affected stream were similar to the control stream. These redds, however, were subjected to smaller flows than redds with infiltration bags, which may explain the different results. Levels of fines reported to be deleterious to salmonid egg survival have varied (Chapman 1988) but are generally higher (at least 10% fines) than levels found during this study.

At the end of winter, permeability was lower in Prairie Creek redds exposed to sediment inputs from Brown Creek tributary than the most-upstream redd. This difference, however, was present immediately after installing the pipes and cleaning the gravel in January. Factors other than fines seem to be affecting permeability. Dissolved oxygen similarly decreased over the winter; but this seemed to be a function of decreasing surface water DO, which, in turn, was probably caused by increasing water temperature. Dissolved oxygen concentrations were above those reported in the literature as causing egg mortality (generally < 5 ppm; Alderice et al. 1958), although decreases below 11 ppm have restricted embryonic growth (Chapman 1988). Finally, steelhead egg survival to hatching was largely unaffected by fines or changes in permeability; instead, worm infestation seemed to be responsible for the two cases of high mortality. Further investigation is needed to determine if presence of worms is related to fine sediment.

We expect different results in the future if large storms occur. Most of the fine material in the system was still present in the gravel at the end of winter (Redwood National Park 1991). Following a large storm, we would expect these fines to be deposited in redds, increasing fines and reducing permeability to a greater extent than found in 1989–90, which could, in turn, adversely affect egg survival. Even during 1989–90, species such as coho and chinook salmon, which spawned earlier in the season and were exposed to more storms, may not have had as high egg survival as steelhead trout. For these reasons, we are repeating a refined version of this study for the years 1991–93, which addresses the effect of sedimentation on coho salmon egg survival and emergence.

Acknowledgments

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