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Effects of sediment loads on the fish and invertebrates of a Sierra Nevada river, California

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Abstract

This study examined the effects of sediment loadings from an abandoned hydraulic mining site on potential trout spawning gravels, large aquatic macroinvertebrates, and fish growth, survival and reproduction in the South Yuba River (Nevada County) California. Effects of sediment loadings, which are transported to the South Yuba River via Humbug Creek, were investigated by comparing data from sites on the South Yuba River upstream and downstream of Humbug Creek. The study did not find any deleterious effects of sediment loadings on fish survival and reproduction (based on snorkel survey data), or large aquatic macroinvertebrate populations. In addition, the lack of a significant difference in the percentage of 0.30 to 3.35 mm material in substrate samples suggests that sediment loads are not affecting trout spawning gravels. In contrast, Sacramento pikeminnow (*Ptychocheilus grandis*) growth appears to be affected by both water temperatures and sediment loadings. Downstream of Humbug Creek, growth during the first year was significantly faster, based on calculated standard lengths at the age 1 annulus, but condition factor was significantly lower than above Humbug Creek.

1. Introduction

Between 1853 and 1884, hydraulic mining for gold resulted in the transport and deposition of millions of cubic meters of sediment in central California rivers (Table 1), destroying fisheries and filling in stream beds (McPhee, 1993). One of the most devastated drainages was the South Yuba River (Nevada County), as a result of hydraulic mining at Malakoff Diggins, with deposition of up to 30 m of sediment at some locations (Palmer & Vileisis, 1993). This former hydraulic mining site, with colorful "badlands", is now protected as part of Malakoff Diggins State Historic Park.

Sediments eroded from Malakoff Diggins are still transported to the South Yuba River via Humbug Creek. Suspended sediments concentrations in the South Yuba River at Jones Bar (Figure 1) have been as high as 1000 mg/L in the last few decades (USGS, 1967–1974). Although low in comparison to those during hydraulic mining, and within the range of those in other Sierra Nevada rivers (Table 1), the California

Table 1. Historic sediment loads (million cubic meters) from hydraulic mining and current maximum suspended sediment concentrations (mg/l) in central California streams. Sediment load data is from Hagwood (1981). Suspended sediment concentrations are from USGS (1942–2002). Suspended sediment concentrations for Butte Creek were calculated from turbidity (NTU) measurements.

Stream	Historic Sed. Loads	Maximum Susp. Sed. Conc.
Yuba River	524	1000
American River	195	2550
Bear River	195	473
Mokelumne & Tuolumne Rivers	176	176
Upper Feather River	76	457
Butte Creek	23	2953

Department of Fish and Game has expressed concern that these levels are depressing fish populations in the river, especially rainbow trout (*Oncorhynchus mykiss*) (Sandy Harrison, State Parks, personal communication).

The main purpose of this study was to determine the effects of recent sediment loadings on the fishes and large macroinvertebrates (defined as those that are retained on a 3.2 mm mesh) of the river to help determine if corrective actions were needed at Malakoff Diggins. A secondary purpose was to determine if there were native fish species that could be restored to the system, that were missing from the South Yuba River as a result of sediment loadings during hydraulic mining. The objectives of this study were to assess the impact on potential trout spawning gravels in the South Yuba River from deposition of fine sediments from Malakoff Diggins, and to assess the effects of sediment loadings from Malakoff Diggins on: (1) large aquatic macroinvertebrates; (2) fish survival and reproduction; and (3) Sacramento pikeminnow (*Ptychocheilus grandis*) growth. Sacramento pikeminnow were chosen for investigations of effects of sediment loadings on fish growth because they are the numerically dominant fish species in most of the study area. Suspended sediment concentrations were used as an index of the dose of sediment loadings, while substrate (used as an indicator of the quality of potential trout spawning gravels), large macroinvertebrates and fish were used as three independent responses to the sediment loading.

2. Study area

The South Yuba River is located on the western slope of the Sierra Nevada, in the Sacramento River basin. The South Yuba River is 102 km long, with a mean gradient of 10.4%, and drains approximately 900 km^2 (Palmer & Vileisis, 1993). The study area, flowing though a narrow canyon, comprised the lowermost 38 km of the South Yuba River (165–701 m above sea level), from Missouri Bar to Bridgeport (Figure 1), where the South Yuba River enters Englebright Reservoir. Mean monthly South Yuba River flows at Jones Bar (Figure 1), in the study area, during 1940–1949 and 1959–1992 ranged from 1 m^3/s in August and September to 23 m^3/s in May (USGS, 1942–1992). Flows are highly regulated as a result of twenty upstream reservoirs (Palmer & Vileisis, 1993).

Table 2. Fish assemblage composition. Percentages are calculated from the total number of each taxon in each reach.

Taxon	Reach 1	Reach 2	Reach 3	Reach 4
Catostomus occidentalis	18%	4%	2%	2%
Ptychocheilus grandis	76%	95%	43%	11%
Oncorhynchus mykiss	6%	1%	0.1%	0.1%
Mylopharodon conocephalus	0%	0%	55%	39%
Micropterus dolomieui	0%	0%	0%	46%
Lepomis cyanellus	0%	0%	0.02%	1%
Ictalurus nebulosus	0%	0%	0.02%	0%
Lepomis macrochirus	0%	0%	0.02%	1%

Three native fish species, Sacramento pikeminnow, Sacramento sucker (*Catostomus occidentalis*), and rainbow trout, are found throughout the study area (Table 2). These are the only fish species found in Reaches 1 (above Humbug Creek) and 2 (Humbug Creek to Purdon Crossing) (Figure 1). Introduced species, primarily smallmouth bass (*Micropterus dolomieui*) and several sunfish species, are found almost exclusively in the lower 5 km of the study area (Reach 4), while an additional native species, hardhead (*Mylopharodon conocephalus*), is found in the lower 15 km of the study area (Reaches 3 [Hoyt Crossing to above smallmouth bass distribution] and 4 [within smallmouth bass distribution], Figure 1). The study area was split into four reaches to distinguish between the effects of sediment and the effects of changes in species composition (the addition of hardhead and smallmouth bass to the fish assemblage found in Reaches 1 and 2).

3. Methods

3.1. *Suspended sediments*

Multiple regression (Wilkinson, 1990) was used to determine whether suspended sediment concentrations at Jones Bar (data from USGS, 1967–1974) could be predicted using Jones Bar (Figure 1) flows (data from USGS, 1967–1974) and two categories of rainfall (less than and greater than 1.2 cm) in the previous 48 h at North Bloomfield, located in the Humbug Creek watershed (data from NOAA, 1967–1974). In addition, the median particle size was calculated for the suspended sediment samples for which the USGS (1967–1974) had determined the particle size distribution.

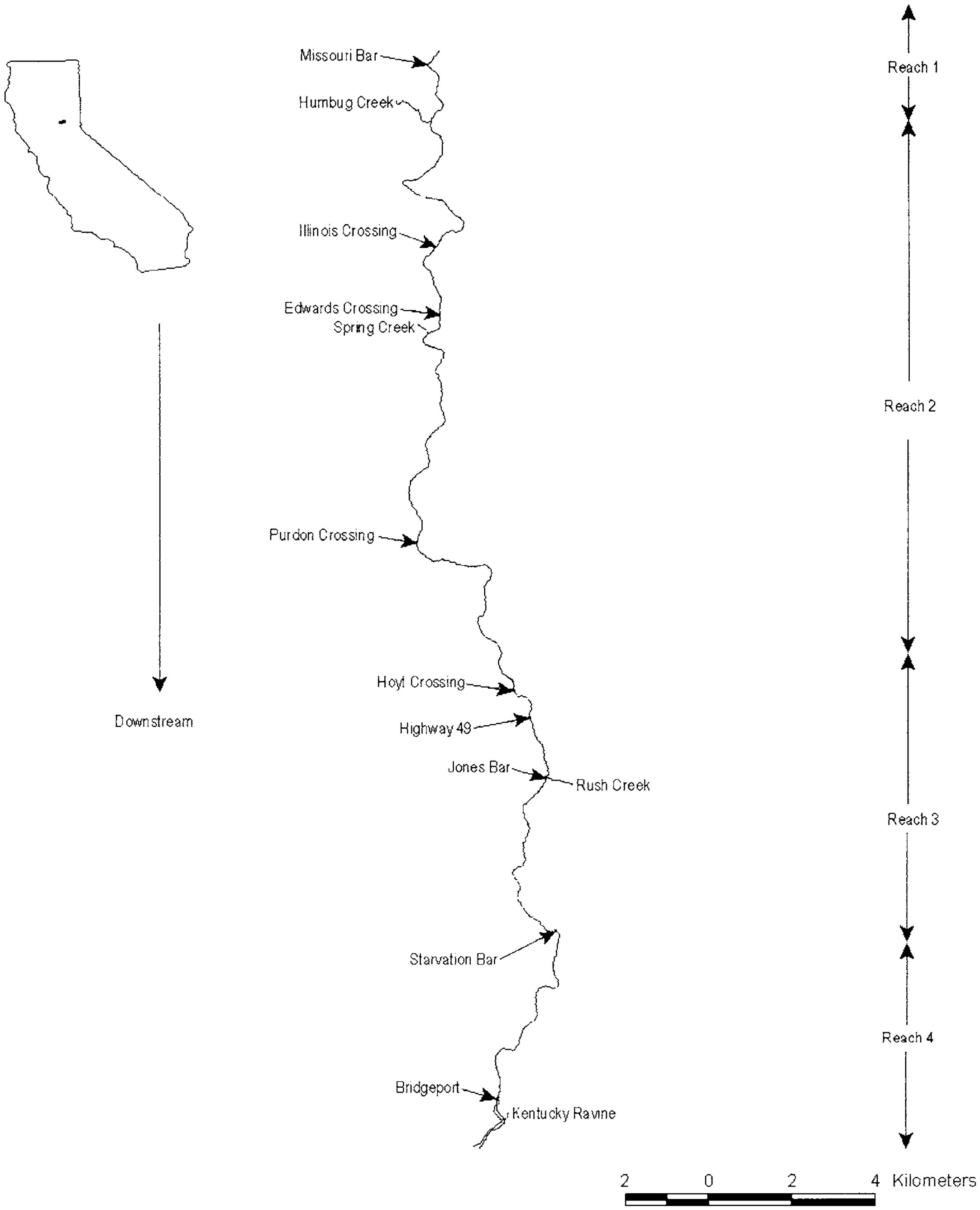

Figure 1. Map of South Yuba River sampling sites.

3.2. *Substrate*

Thirty-three grab samples of substrate (12 from upstream of Humbug Creek and 21 from downstream of Humbug Creek) were collected in July and August of 1991 from the finest-substrate areas of South Yuba River pools to see if deposition of sediments from Malakoff Diggins was altering potential trout spawning gravels in the South Yuba River. The samples were processed by drying them for 24 h at 60 °C, passing the samples through a series of soil sieves (sized 0.30, 0.60, 1.00, 2.36 and 3.35 mm), and weighing the portion of substrate that was retained on each sieve, and the portion which passed through the finest sieve.

Lisle & Lewis (1992) state that particles with a diameter of 0.25 to 4 mm are the predominant sizes that infiltrate salmonid spawning gravels, because these particles are large enough to be transported in contact with the stream bed and small enough to enter the spawning gravel interstices. Chapman (1988) notes that particles 0.5 mm in size seal the surface of spawning gravels, while smaller particles (0.2 mm in size) infiltrate into the spawning gravels. Due to the constraints imposed by the soil sieve sizes used in this study, substrate 0.3 to 3.35 mm in size was the closest obtainable range to Lisle & Lewis' (1992) particle sizes of 0.25 to 4 mm. Due to the difference in size ranges, the effects of Humbug Creek sediment loadings on potential trout spawning gravels were tested by determining whether the percent (by weight) of substrate between 0.30 and 3.35 mm was significantly different for samples upstream and downstream of Humbug Creek (*t*-test, SAS Institute Inc., 1982).

Because the main concern of sediment deposition is the effect of sand and smaller particles, only material smaller than 3.35 mm were included in the subsequent analysis. The percentage of weight passed through the finest sieve (% <0.15 mm, representing the dominant size class from Malakoff Diggins), and that retained by each soil sieve, was calculated to determine the median particle size and the quartile deviation (QD_{Φ}) (Krumbein, 1939). These data were then used to determine if there was a significant effect of sediment loadings from Malakoff Diggins on the median particle size and QD_{Φ} (Mann–Whitney U test, Steel & Torrie, 1980), and on the percent material <0.15 mm (*t*-test, SAS Institute Inc., 1982).

3.3. *Invertebrates*

In July and August 1991, 36 macroinvertebrate samples were collected, using a kick screen, from South Yuba River riffles. Eight samples were collected from three riffles upstream of Humbug Creek, while 24 samples were collected from nine riffles downstream of Humbug Creek; two to five samples were collected from each riffle. The kick screen was constructed of window screening measuring approximately 1 m^2 with a 3.2 mm mesh, and an area of approximately 1 m^2 was kicked for approximately 15 minutes for each sample. The organisms were removed from the kick screen with tweezers, preserved in 70% ethyl alcohol, and returned to the laboratory for identification and enumeration. Organisms were identified to family, genus or species and assigned to functional groups using the keys of Wiggins (1977), Usinger (1956), Pennak (1989) and Merritt & Cummins (1984). Average water column velocity was measured using an electronic velocity meter (Marsh McBirney, Model 201), water column depth was measured using a depth rod, and median particle size was visually estimated (to the nearest 5 cm) at each of the sample locations.

The following measures, which would be relatively insensitive to the amount of area sampled, were used to test for differences between South Yuba River sites upstream and downstream of Humbug Creek: the percentage of organisms in each functional group, the percentage of organisms that were Ephemeroptera, Plecoptera or Trichoptera (EPT), the number of EPT taxa, and two measures of diversity – the percentage of individuals in the dominant taxon and the Shannon Diversity Index (H') (Ludwig & Reynolds, 1988). The number of large aquatic macroinvertebrates was not used as a measure because the lack of a uniform area for kick screen samples would have increased the within-treatment variance.

Before examining the effects of sediment loadings, the following confounding factors were evaluated: (1) the relationship between the abundance of specific macroinvertebrate taxa and physical variables (depth, velocity and substrate particle size) (Hynes, 1970; Minshall, 1981; Statzner, 1981; Erman & Erman, 1984; Gore et al., 2001); and (2) increased variability of the above measures due to small numbers of organisms in each sample. Using only samples with more than 50 organisms, simple linear regression (Wilkinson, 1990) was used to determine if there were relationships between the macroinvertebrate measures and the physical variables. In addition, one-way ANOVA (SAS Institute Inc., 1982) was used to test for differences among the twelve riffles sampled for the three physical variables.

The sample results within each riffle were then pooled. Finally, *t*-tests (SAS Institute Inc., 1982) were used to determine whether there were significant differences between the values of the macroinvertebrate measures for the three pooled samples upstream and the nine pooled samples downstream of Humbug Creek.

3.4. *Fish*

Sampling was conducted on the South Yuba River at one site above Humbug Creek (Missouri Bar); one site within 300 m, above and below, Humbug Creek; and seven sites below Humbug Creek (Illinois Crossing, Edwards Crossing, Purdon Crossing, Hoyt Crossing, Jones Bar and Bridgeport) (Figure 1). The sites were divided into sampling units with uniform habitat types (pool, run, riffle or glide). In 1991 through 1993, fish abundance was estimated in pools and runs (maximum depth greater than 1 m) using snorkel surveys, where two or three people swam upstream and counted the number of fish (enumerated by species and size class). In addition, for each pool or run, pool length and three to six pool widths were measured, maximum pool depth (numeric value) was visually estimated (within 0.5 m), and turbidity was visually assessed (as high or low).

In 1991 and 1992, fish were collected from riffles and glides by electrofishing. Fish were captured from pools and runs with seines, gill nets and minnow traps. All fishes captured were identified, and their weights and standard lengths (SL) recorded. Some of the fish (primarily Sacramento pikeminnow less than 150 mm SL) were preserved in formalin, and the remaining fish released. Scales were removed from Sacramento pikeminnow greater than 150 mm SL from the area under the tip of the left pectoral fin. In the laboratory, scales from smaller preserved pikeminnow were also removed. All scales were mounted between two glass slides and viewed on a scale reader (23× magnification). The age at capture (to the nearest year) and the length of the pikeminnow at each annulus (year) were determined from unregenerated scales, using the methods of Tesch (1971). The age at capture of age 0 and age 1 pikeminnow was validated by a comparison with length-frequency histograms. The age at capture of older pikeminnow was independently verified by reading some of the scales by two people.

Seven measures were used to assess the effects of sediment from Malakoff Diggins on the South Yuba River fish assemblage: (1) the number of fish per pool or run; (2) the biomass of fish per pool or run; (3) the number of age 0 fish per pool or run; (4) the percentage of age 0 fish per pool or run; (5) the proportion of Sacramento pikeminnow and hardhead in different size classes; (6) the condition factor (Moyle & Cech, 1982) of individual pikeminnow; and (7) the standard length of pikeminnow at the age 1 annulus. The first five measures were calculated using snorkel survey data. Biomass estimates were calculated using the number of fish per species and size class and estimated individual weights (Gard, 1994a). The number of age 0 fish was estimated as the number of fish in the smallest size class for each species.

Simple linear regression (Wilkinson, 1990) was then used to determine which of five pool dimensions (length, average width, maximum depth, surface area and volume) explained the largest percentage of the variation in each of these measures. For snorkel survey measures that did not have a significant linear relationship with any of the pool dimensions, the effects of above/below Humbug and year, plus the interaction of these two factors, were investigated (two-way ANOVA, Wilkinson, 1990). For the other snorkel survey measures, the effects of the following three independent variables, plus all interactions, were tested (general linear model, Wilkinson, 1990): (1) the four reaches (Figure 1); (2) year; and (3) the corresponding pool dimension. The analysis was carried out in a step-wise process, with factors and interactions with P-values greater than 0.05 eliminated at each step.

Pearson's test for association (Steel & Torrie, 1980) was used to determine whether the size class structure of pikeminnow and hardhead (the proportion of pikeminnow and hardhead in four different size classes (<50 mm, 50–150 mm, 150–250 mm, >250 mm)) was significantly different for the following comparisons: (1) Reach 1 and Reach 2; (2) Reach 2 and Reach 3; and (3) Reach 3 and Reach 4 (excluding uppermost one or two pools).

The effects of sediment loadings from Malakoff Diggins on pikeminnow growth were investigated by comparing the calculated standard length of pikeminnow at the age 1 annulus (during the winter) upstream and downstream of Humbug Creek (*t*-test, SAS Institute Inc., 1982). The effects of above/

below Humbug and fish standard length on condition factor were then examined (multiple linear regression, Wilkinson, 1990).

4. Results

4.1. *Suspended sediments*

Suspended sediment concentrations (mg/L) at Jones Bar can be predicted using daily average Jones Bar flows (m^3/s) and two categories of rainfall in the previous 48 h at North Bloomfield (multiple regression, $R^2 = 0.77$, $P < 0.001$):

for rainfall <1.2 cm: susp. sed. = $0.918 \times$ flow

for rainfall >1.2 cm: susp. sed. = $4.24 \times$ flow

The median particle sizes of suspended sediments, computed from the USGS's (1967–1974) particle size distribution data, were relatively small (Table 3).

Table 3. Suspended sediment particle size characteristics. Suspended sediment concentration data from USGS (1967–1974). Median particle sizes were computed as the values at 50 percent of cumulative weights, using USGS's (1967–1974) characterization of the particle size distribution of its suspended sediment samples.

Susp. sed. conc. (mg/L)	*n*	Median particle size (mm)
53 (30–77)[a]	6	<0.062
92	1	0.171
435	1	0.218
1000	1	0.406

[a] mean (range)

4.2. *Substrate*

The percentage of substrate between 0.30 and 3.35 mm did not vary significantly with above/below Humbug (*t*-test, $P = 0.17$). Although there was a statistically significant difference in median particle size and QD_Φ (Mann–Whitney *U*-test, $P < 0.05$) for upstream and downstream of Humbug Creek, with larger mean values downstream of Humbug Creek, the percentage of material <0.15 mm did not show an effect of sediment loadings from Malakoff Diggins (*t*-test, Table 4).

Table 4. Substrate sample characteristics of pools (mean ± SE). Differences in median particle size and QD_Φ evaluated by Mann-Whitney U tests. Difference in percent material < 0.15 mm evaluated using t-test.

Measure	Upstream of Humbug Creek	Downstream from Humbug Creek	*P* value
Median particle size (mm)	1.44 ± 0.063	2.068 ± 0.059	0.004
QD_Φ	0.535 ± 0.019	0.638 ± 0.02	<0.001
Percent < 0.15 mm	0.26% ± 0.04%	0.40% ± 0.12%	0.35
Sample size	12	21	

4.3. *Invertebrates*

The samples had a total of 2,595 organisms from 40 taxa (Gard, 1994a). Six taxa (*Hydropsyche* sp., *Baetis* sp., *Calineuria californica*, *Ironodes lepidus*, Simuliidae, and *Rhyacophila* sp.) represented almost 75% of the organisms collected (Table 5). In addition to the macroinvertebrates in the kick screen samples, signal crayfish (*Pacifastacus leniusculus*) were found at Missouri Bar and Bridgeport, and freshwater mussels (*Margaritifera falcata*) were found in one pool in the South Yuba at Humbug Creek.

There were significant positive relationships (linear regression) between the percentage of scrapers and depth ($R^2 = 0.26$, $P = 0.018$) and between EPT taxa richness and velocity ($R^2 = 0.19$, $P = 0.046$), and a significant inverse relationship between the percentage of predators and substrate median particle size (linear regression, $R^2 = 0.238$, $P = 0.029$). There were no significant differences (ANOVA) among the twelve riffles sampled for depth ($P = 0.43$), velocity ($P = 0.65$) or substrate median particle size ($P = 0.30$).

The pooled samples had at least 91 organisms per pooled sample. There were no statistically significant differences for indices upstream and downstream of Humbug Creek for any of the macroinvertebrate measures (*t*-test, Table 6).

4.4. *Fish*

A total of 150 pools and runs were snorkel-surveyed in 1991, 1992 and 1993. Pool length explained the highest proportion of variation of the number of fish and number of age 0 fish (linear regression, $R^2 = 0.126$ and 0.028, respectively), and pool volume explained the highest proportion of variation of biomass (linear regression, $R^2 = 0.127$). Although the correlation coefficients were small, all three regressions were significant at $P = 0.05$.

Table 5. Large macroinvertebrate assemblage composition. Percentages are calculated from the total number of each taxon in each reach. Numbers for *Rhyacophila*, *Baetis*, and *Argia* are the total numbers for two species of each genus.

Taxon	Reach 1	Reach 2	Reach 3	Reach 4
Hydropsyche sp.	34%	33%	19%	20%
Calineuria californica	12%	11%	17%	11%
Baetis sp.	10%	11%	14%	12%
Metacnephia sp.	3%	5%	0.2%	31%
Ironodes lepidus	4%	5%	16%	7%
Rhyacophila sp.	13%	8%	1%	1%
Chimarra sp.	2%	5%	7%	3%
Isonychia velma	0%	0.4%	14%	0.2%
Hesperoperla pacifica	5%	2%	5%	1%
Chironomidae	3%	1%	2%	7%
Glossoma sp.	2%	2%	0.2%	2%
Psephenus sp.	2%	2%	0.4%	0.2%
Serratella sp.	4%	1%	0.4%	0%
Helicopsyche borealis	0%	4%	0%	0%
Argia sp.	1%	1%	1%	1%
Polycentropus sp.	1%	2%	0%	0%
Discomoecus sp.	1%	2%	0%	0%
Ordobrevia sp.	1%	1%	1%	0%
Oligiochaete worm	0.3%	0.4%	0.2%	1%
Pteronarcella regularis	0.2%	1%	1%	0%
Physa sp.	0%	1%	0.2%	0.2%
Leptohyphes sp.	0.2%	0.4%	0.2%	0.5%
Antocha monticola	1%	1%	0.2%	0%
Blephariceridae	0%	0%	0%	1%
Stenocolus scutellaris	1%	0.3%	0.2%	0%
Erpetogomphus compositus	0%	0.3%	0.2%	0%
Ophiogomphus occidentis	0%	0.3%	0.2%	0%
Somatochlora sp.	0%	0%	0.4%	0%
Orohermes crepusculus	0.3%	0%	0%	0%
Gumaga sp.	0%	0.1%	0.2%	0%
Corydalus cognata	0%	0%	0%	0.2%
Hetaerina americana	0%	0%	0%	0.2%
Cordulegaster dorsalis	0%	0%	0.2%	0%
Aeshna interrupta	0%	0%	0.2%	0%
Lepidostoma sp.	0.2%	0%	0%	0%
Petrophila sp.	0%	0.1%	0%	0%
Gyraulus sp.	0%	0.1%	0%	0%
Ochrotrichia sp.	0%	0.1%	0%	0%

There were significant effects of reach, pool volume and the interaction of these two factors (general linear model, $P < 0.001$) on fish biomass, but no significant effects of year or interactions involving year. The mean values for Reaches 1 and 2 were not significantly different (Table 7); therefore, there were no significant effect of sediment loadings from Malakoff Diggins on fish biomass.

Table 6. Characteristics of samples of large macroinvertebrates collected from the South Yuba River, upstream and downstream of Humbug Creek, with kick screens (mean ± SE). H' = Shannon Diversity Index. Percentages given for functional groups are the percent abundance represented by the functional groups in the total sample. Comparisons of all measures using t-tests.

Measure	Upstream of Humbug Creek	Downstream from Humbug Creek	*P* value
H'	0.910 ± 0.036	0.901 ± 0.026	0.79
% Dominant taxon	33.6% ± 5.0%	36.4% ± 5.2%	0.454
EPT taxa richness	11.3 ± 0.8	11.3 ± 0.3	0.50
% EPT	82.8% ± 1.8%	85.1% ± 1.8%	0.451
% Scrapers	14.9% ± 5.1%	16.8% ± 1.8%	0.651
% Collector-filterers	38.5% ± 5.6%	44.6% ± 4.2%	0.464
% Collector-gatherers	20.3% ± 5.4%	16.1% ± 1.2%	0.259
% Shredders	5.1% ± 1%	2.4% ± 0.9%	0.105
% Predators	21.2% ± 6.2%	20.1% ± 2.9%	0.857
Sample size	3	9	

Table 7. Effects of location on snorkel survey measures. Data in table are means for each measure and reach. See Figure 1 for location of reaches. Units of biomass are g fish/pool or run. Means connected by horizontal lines are not significantly different at P = 0.05 (general linear model, Wilkinson, 1990).

Measure	Reach 3	Reach 4	Reach 2	Reach 1
Biomass	6,823	6,557	2,958	3,453
Number of fish	200	144	102	64
Number of age 0 fish	152	104	47	28

There were significant effects (general linear model) of reach ($P < 0.001$), pool length ($P < 0.001$), the interaction of location and pool length ($P = 0.001$), and the interaction of year and location ($P = 0.01$) on the number of fish. There was a significant positive effect of sediment releases from Malakoff Diggins on the number of fish (Table 7). Since there was a significant interaction of year and reach, a general linear model (Wilkinson, 1990) was used to look at the simple effects, within each year, of Reaches 1 and 2, pool length and the interaction of pool length and Reaches 1 and 2. This analysis indicated that there was not a significant difference in the number of fish above and below Humbug Creek for 1991 ($P = 0.519$) or for 1992 ($P = 0.141$), but that there was a significant difference for 1993 ($P < 0.001$), with more fish downstream of Humbug Creek.

There were significant effects (general linear model) of reach ($P = 0.004$), pool length ($P = 0.044$), the interaction of reach and length ($P = 0.003$) and the interaction of reach and year ($P < 0.001$) on the number of age 0 fish. There was no significant effect of sediment loadings from Malakoff Diggins on the number of age 0 fish (Table 7).

There was no significant relationship between the percent age 0 fish and any of the five pool dimensions ($P > 0.05$, simple linear regression, Wilkinson, 1990). There was no significant effect of above/below Humbug, year, or the interaction of above/below Humbug and year on the percent age 0 fish ($P > 0.15$, two-way ANOVA, Wilkinson, 1990). Similarly, there was no significant effect of above/below Humbug, taken alone, on the percent age 0 fish ($P = 0.42$, *t*-test, Wilkinson, 1990). The overall percentage of age 0 fish was 64%.

The size class structure of pikeminnow or hardhead (Figure 2) was significantly different for all three comparisons (Pearson's test for association, $P < 0.01$). However, the effect of Malakoff Diggins ($C = 24.5$) was smaller than the effects of changes in the fish assemblage composition ($C = 2136$ and $C = 140$).

Sacramento pikeminnow downstream of Humbug Creek ($N = 65$) had a significantly greater mean standard length at the age 1 annulus (during the winter) (64 mm) than pikeminnow upstream of Humbug Creek (58 mm, *t*-test, $N = 39$, $P = 0.0004$). There were significant effects (multiple linear regression) of fish standard length ($P = 0.045$), above/below Humbug ($P = 0.003$), and the interaction of standard length and above/below Humbug ($P = 0.021$) on condition factor, with an overall R^2 of 0.107 ($N = 218$). Sacramento pikeminnow upstream of Humbug Creek had consistently higher condition factor values than pikeminnow downstream of Humbug Creek.

5. Discussion

Effects of sediment loads on aquatic life can be due to sediment either suspended in the water column or deposited onto the substrate. While the concentrations and duration of suspended sediments seen in the South Yuba River in the last few decades are too low to cause direct fish mortality, they can cause a variety of sublethal effects on fish; these include: (1) decreases in growth rates, condition factor, and feeding rates; (2) increased physiological stress; and (3) various behavioral reactions, including avoidance and alarm (Newcombe & MacDonald, 1991; Servizi & Martens, 1992; Gregory & Northcote, 1993; Bergstedt & Bergersen, 1997; Boubée et al., 1997; Rowe & Dean, 1998; Shaw & Richardson, 2001; Sweka & Hartman, 2001). For example, McLeay et al. (1987) and Gregory & Northcote (1993) found that suspended sediment levels as low as 100 mg/L can affect fish growth and feeding responses, while Shaw & Richardson (2001) found that suspended sediment levels of 705 mg/L for a six-hour duration caused reduced growth rates. Turbidity resulting from suspended sediments can reduce the primary productivity of streams by reducing periphyton growth (Van Nieuwenhuyse & LaPerriere, 1986). Deposition of fine sediment can: (1) change the composition of aquatic macroinvertebrate assemblages (Wiederholm, 1984; Harvey, 1986; Somer & Hassler, 1992; Angradi, 1999; Mebane, 2001; Shaw & Richardson, 2001; Zweig & Rabini, 2001); (2) decrease the abundance of benthic fishes, such as sculpins, by reducing available microhabitat (Harvey, 1986; Mebane, 2001); and (3) reduce the survival of salmonid embryos by entrapment and by reducing the permeability of spawning gravels, leading to decreases in the transport rate of water and dissolved oxygen to the developing embryos (Chapman, 1988; Argent & Flebbe, 1999).

5.1. *Suspended sediments*

Humbug Creek is a substantial contributor of sediment for the South Yuba River (Table 8). The relationship of suspended sediment concentrations with flows and rainfall suggests that loadings of sediment flushing down Humbug Creek are associated with rainfall events; for the period 1985–1992, there were an average of 47 d per year with greater than 1.2 cm of rainfall at North Bloomfield in the previous 48 h (NOAA, 1985–1992). Erosion from the former hydraulic mining pit at Malakoff Diggins State Park contributes most of the sediment loading to Humbug Creek, based on data from CDWR (1987).

Recreational suction dredge mining in the South Yuba riverbed mainly resuspends sediments, and may therefore be a source of suspended sediments during low flow periods. However, Harvey (1986) found that the effects of suction dredge mining on aquatic organisms, principally due to the deposition of sand and gravel, were very localized. In addition, turbidity resulting from suction dredge operations (an average

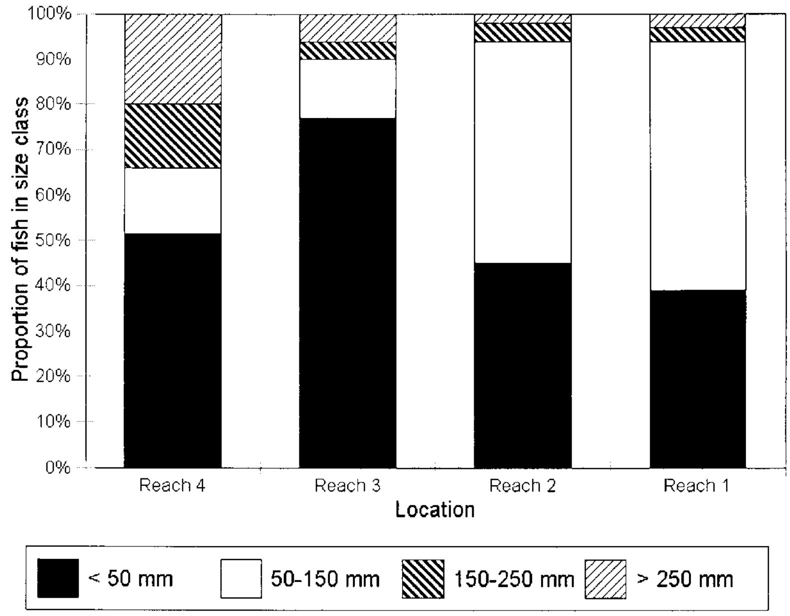

Figure 2. Size class distribution of pikeminnow and hardhead. Computed using all snorkel survey data. Size of fish is standard length. See Figure 1 for location of reaches. Difference between Reach 1 and 2 reflects effect of sediment loadings from Malakoff Diggins. Differences between Reaches 2, 3 and 4 reflect effects of changes in species composition of South Yuba River fish assemblage.

of 5 nephelometric turbidity units (NTU) downstream of suction dredge operations (Harvey, 1986)) is much less than the turbidity from Malakoff Diggins (an average of 33 NTU in the South Yuba River downstream of Humbug Creek (CDWR, 1987)). Similarly, based on field observations from this study, Secchi depths downstream of suction dredge operations were greater than 1 m, while the Secchi depths in the South Yuba River, after 1.2 cm of rainfall at North Bloomfield in the previous 48 h, were less than 1 cm downstream of Humbug Creek and greater than 3 m upstream of Humbug Creek. Thus, the effects of suction dredge operations on the substrate samples from upstream of Humbug Creek did not mask effects of sediment loadings from Malakoff Diggins.

Suspended sediment would not be likely to settle out of the water column, especially during high flows, until it reaches Englebright Reservoir, since most of the material in suspended transport has a median particle size less than 0.062 mm (Table 3). Supporting this conclusion are observations that Englebright Reservoir is turbid during heavy rains (California Department of Fish and Game files). In addition, the average concentration of suspended sediment measured just downstream of Humbug Creek, 254 mg/L (Table 8) (California Department of Water Resources (CDWR), 1987), is not significantly greater than the average predicted concentrations for those dates at Jones Bar (171 mg/L; calculated using the relationships of suspended sediment concentrations with flow and rainfall), given the confidence limits of the multiple regression.

Table 8. Humbug Creek confluence suspended sediment data. This data shows that the Malakoff Diggins historic hydraulic mining site (the primary sediment source in the Humbug Creek basin) is a substantial source of sediment loadings to the South Yuba River. Data from CDWR (1987).

Date	Suspended sediment concentration (mg/L)		
	S. Yuba upstream	Humbug Creek	S. Yuba downstream
3/7/86	7	636	42
2/19/79	1.5	632	84
3/23/79	1	380	34
3/27/79	41	5,200	856
Average	13	1,712	254

5.2. *Substrate*

The lack of difference in percent material <0.15 mm supports the conclusion that most of the sediment from Malakoff Diggins moves through the South Yuba

River to Englebright Reservoir, rather than being deposited in South Yuba River pools, given that the sediment load from Malakoff Diggins is largely material <0.15 mm (Table 3). In addition, the sediment samples are indicative of a lack of effect of sediment loadings from Malakoff Diggins on rainbow trout reproduction, since 0.25 to 4.0 mm material has the greatest impact on trout spawning gravels.

5.3. *Invertebrates*

The lack of a significant difference between riffles for the three physical variables suggests that the effects of these variables was controlled by pooling the sample results within each riffle. This procedure also increased the number of organisms within each pooled sample sufficiently to control for the other confounding factor (variability due to low numbers of organisms per sample).

Various kinds of disturbances, including sediment loadings, can result in lower diversity of macroinvertebrate communities (Reger & Kevern, 1981; Newbold et al., 1980; Somer & Hassler, 1992). EPT taxa tend to be adversely affected by sediment loadings (Angradi, 1999; Mebane, 2001; Zweig & Rabeni, 2001). In addition, collector-filterers can be directly adversely affected by sediment clogging their filtering apparatus, while scrapers can be indirectly affected by turbidity reducing growth of periphyton (Shaw & Richardson, 2001). The lack of any significant differences in EPT taxa, diversity or the proportion of functional groups between upstream and downstream of Humbug Creek indicates either that the limited duration and intensity of suspended sediment loadings are not affecting invertebrate populations, or that invertebrate populations downstream of Humbug Creek were able to rebound due to recolonization in the two-plus months between the end of the rainy season and the sampling in this study during mid-summer. The former explanation is consistent with the data presented in Newcombe & MacDonald (1991), while the latter explanation is consistent with Harvey's (1986) findings that macroinvertebrates had completely recolonized areas below suction dredge mining areas within 45 d after the cessation of suction dredge mining.

5.4. *Fish*

Speckled dace (*Rhinichthys osculus*), riffle sculpin (*Cottus gulosus*) and California roach (*Lavinia symmetricus*), which would be part of the expected native fish assemblage in a foothills Sierra stream (Moyle, 2002), such as the South Yuba River, may have been extirpated from the South Yuba River by the tremendous sediment loads from hydraulic mining in the late 1800s. These species are the smallest of the native fish species, and would thus have been most vulnerable to the effects of these historic sediment loads. In contrast, adult pikeminnow, hardhead, Sacramento sucker and rainbow trout could have moved far enough upstream in the South Yuba River, or into the Yuba River above its confluence with the South Yuba River, to avoid impacts of historic sediment loads. Based on the current fish species present in tributaries of the South Yuba (Gard, 1994b), Kentucky Ravine (at Bridgeport) could have served as a refuge from the effects of historic sediment loads for California roach, while the other tributaries were likely only refuges for rainbow trout and suckers, possibly due to their low temperatures and/or high gradients.

The difference in the number of fish upstream and downstream of Humbug Creek was only seen in one of three years and did not indicate a negative effect of Humbug Creek, suggesting that sediment loadings from Malakoff Diggins are not adversely affecting the number of fish presently in the South Yuba River. In addition, differences in the size class structure of fish upstream and downstream of Humbug Creek (Reach 1 versus Reach 2) are small, compared with the effects of changes in fish assemblage composition (differences between Reaches 2, 3 and 4). The above, together with the lack of differences upstream and downstream of Humbug Creek for fish biomass and the percentage of age 0 fish, leads to the conclusion that sediment loadings from Malakoff Diggins are not adversely affecting fish survival. While the lack of difference in the number of age 0 fish upstream and downstream of Humbug Creek is consistent with sediment loadings from Malakoff Diggins not adversely affecting fish reproduction, fish reproduction studies looking at comparative fecundity and health of offspring would be needed to definatively conclude that sediment loadings are not adversely affecting fish reproduction. Lower condition factor values for pikeminnow downstream of Humbug Creek may be due to turbidity from Malakoff Diggins suspended sediment loadings decreasing feeding rates during winter and spring. The response of fish (impact on growth but not survival) to the limited duration and intensity of sediment loadings from Malakoff Diggins is consistent with the data presented in Newcombe & MacDonald (1991).

Impacts on aquatic communities from historic mining site releases have often been attributed to low pH and elevated dissolved metals concentrations (Gower & Darlington, 1990; Clements & Kiffney, 1994; Beltman et al., 1999; Saiki et al., 2001). Limited water quality sampling downstream of Humbug Creek, and of the discharge from Malakoff Diggins to Humbug Creek (USGS, 1942–2002) has not shown pH and dissolved metals levels that would be likely to cause effects on aquatic life. Thus, it is not likely that lower condition factor values for pikeminnow downstream of Humbug Creek is due to water quality parameters other than suspended sediment.

6. Conclusions

The limited effects of current sediment loadings on the South Yuba River seen in this study are consistent with: (1) the relatively low concentrations of suspended sediments (less than 1000 mg/L); (2) the limited duration of loadings (approximately 47 d per year); and (3) limited sediment deposition, due to both the small particle size of the sediment and the discharges of sediment primarily during high flow periods. Overall, this study demonstrates that sediment inputs from historic hydraulic mining sites are no longer having major effects on the fauna of the South Yuba River. Other alterations to the river, especially upstream water diversions, are presumably more important because they change water temperature and flow regime (Gard, 1994b). For example, high water temperatures appear to be the main factor limiting rainbow trout populations in the South Yuba River (Gard, 1994b). The system has recovered enough, however, so that reintroduction of missing native fishes is warranted (Gard, 1994b).

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