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Effects of Suction Gold Dredging on Fish and Invertebrates in Two California Streams

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Abstract.—I examined the impact of small suction dredges (hose diameter, <16 cm) on fish and invertebrates in two California streams (North Fork of the American River and Butte Creek) in a 2-year study. I studied both the effect of one dredge (1980) and the effects of an average of six dredges in a 2-km section of stream (1981). Ten replicate Surber samples per station were taken monthly to compare macroinvertebrate abundances at control and dredged stations before, during, and after dredging in both years. Dredging significantly affected some insect taxa when substrate was altered. A recolonization experiment showed that numerical recovery of insects at dredged sites was rapid. Mask-and-snorkel censuses and observations of tagged fish indicated that major changes in available habitat caused local decreases in fish density. Dredging affected riffle sculpins (*Cottus gulosus*) more severely than rainbow trout (*Salmo gairdneri*), probably because of differences in microhabitat requirements. Local turbidity increases below active dredging probably did not affect invertebrates and fish.

Suction gold dredging has become a popular activity in streams of the western United States in recent years, but studies of the effects of suction dredging on streams are few (Griffith and Andrews 1981). The general topic of sedimentation, often considered in connection with placer mining or logging, has been extensively studied in relation to stream insects and fish (reviewed by Cordone and Kelly 1961; Gibbons and Salo 1973; and Iwamoto et al. 1978; also, Luedtke and Brusven 1976; Bjornn et al. 1977; McClelland and Brusven 1980; Newbold et al. 1980; Turnpenny and Williams 1980; Crouse et al. 1981). Although detrimental effects from disturbances that alter substrates are possible, these disturbances do not always result in extensive damage to stream biota (Ward 1938; Pearson and Jones 1975; Murphy and Hall 1981). Griffith and Andrews (1981) examined the effects of dredging on invertebrates and fish eggs, sac fry, and fingerlings that were entrained through a small suction dredge. All uneyed eggs of cutthroat trout (*Salmo clarki*) died within 1 h after entrainment; later life history stages showed generally less mortality. Fewer than 1% of 3,623 invertebrates entrained showed injury or died within 24 h. Griffith and Andrews also found substantial recolonization by insects in a dredged area after 38 d.

In this study, I examined the effects of dredging on benthic invertebrates by comparing populations in undisturbed areas to those in dredged areas. I studied the effect of one dredge in 1980 and, in 1981, the effect of a number of dredges in a limited area. I also examined invertebrate recolonization of a dredged area from 7 to 45 d after substrate disturbance. The effect of dredging on adult fishes was examined by comparing riffle sculpin (*Cottus gulosus*) abundances and rainbow trout (*Salmo gairdneri*) densities and patterns of movement in dredged and control areas. Finally, I made a series of turbidity measurements above and below active dredges. The null hypotheses tested were that no differences in insect abundances or fish densities and movements would occur between dredged and control sites.

Study Sites

The North Fork of the American River (NFAR; elevation 410 m) had flows of 30 m^3/min and daytime water temperatures between 10 and 16°C when sampled in late summer 1980. The fish fauna consisted of Sacramento squawfish (*Ptychocheilus grandis*), hardhead (*Mylopharodon conocephalus*), Sacramento sucker (*Catostomus occidentalis*), riffle sculpin, rainbow trout, and smallmouth bass (*Micropterus dolomieui*). A professional miner operated an 8 horsepower, gasoline-powered dredge (hose diameter, 15 cm) in the tail of a large pool (60 m long, 12 m wide, 2.5 m deep) at NFAR from 4 August 1980 through 15 October 1980 for an average of 2.5 h/d.

The 1981 study area on Butte Creek (BC; elevation 1,950 m) was characterized by large pools separated by short riffles in a mixed coniferous–deciduous forest. Discharge was 12.2 m^3/min in

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June and less than 4.0 m^3/min in September. Daytime water temperatures ranged from 10 to 18°C. In the 9.8-km study area, rainbow trout constituted 94% of the fish fauna and brown trout (*Salmo trutta*) 6%. The lower 2 km of the study area were mined with an average of six dredges (nozzle diameters 5–13 cm) from 1 June 1981 to 30 September 1981 by recreational miners. Dredging activity was not uniform in time or space, although some dredging occurred in 85% of the pools and riffles in the section.

Methods

I took 10 invertebrate samples at NFAR, each month at three stations limited to 5-m stream sections. I used a Surber sampler (1,024-μm mesh), and preserved samples in 70% ethanol; these were examined later under 7× power and all organisms were identified to the lowest possible taxon (usually genus) and counted.

I chose stations based on similarities in depth, velocity, and substrate. The control (station 0) was located in the tail of an extremely large pool (400 m long, maximum depth 3.5 m) that buffered the section from any upstream disturbances. Station 1 was 135 m below the control and 10 m below the dredged site; station 2 was 50 m below station 1. A Marsh-McBirney flow meter (model 201) and top-setting wading rod were used to measure water velocity and depth. The Wentworth particle size scale was used in a visual estimate of substrate composition following Bovee and Cochnauer (1977). I selected sampling sites at random from all locations at each station where depth ranged from 15 to 30 cm and velocity from 10 to 25 cm/s, and substrate was largely gravel and cobble.

I began sampling 1 August 1980 and continued on the first 3 d each of September, October, and November. August samples preceded dredging by 2 d, and November samples were collected 2 weeks after dredging stopped. At station 1, samples were randomly selected from locations that initially satisfied the physical criteria described previously, but in many cases dredging later altered substrate and water velocity.

Four stations were located within the dredged area at BC in 1981, and two control stations were 300 m and 2.6 km above the uppermost point of dredging. I again chose stations based on similar depth, velocity, and substrate; all were 3-m sections in the tails of large pools. Samples were selected at random from locations that satisfied the same criteria as used at NFAR. Substrate initially was 100% cobble at all stations. Ten samples per station were taken from June to November in the first 4 d of each month. June samples provided a temporal control and November samples were taken 1 month after dredging stopped.

I used a small run of BC for the invertebrate recolonization experiment; sand and gravel moved by dredging completely covered the original substrate in that section. Due to the limited area of the run, seven samples were taken on each of four sampling dates at sites satisfying the depth and velocity criteria used in the monthly sampling on both streams.

The monthly invertebrate data were analyzed by one-way analysis of variance of the abundances of individual taxa for each month of sampling; station was the treatment effect. All taxa that exceeded an average of three individuals per sample at any station were included in the analyses for that month. $\log_{10}$-transformed data $(x + 1)$ were used due to the relationship between the variance and the mean (Green 1979). When significant differences ($P < 0.05$) were found in NFAR data, Tukey's *w* procedure (Steel and Torrie 1980) was used to compare the control to the two "impact" stations. In the BC analyses, Scheffé's test (Steel and Torrie 1980) was used to compare the average of the two controls to each station within the impact area.

I determined the relative density of riffle sculpins at NFAR before and 1 month after dredging. Moving at a slightly upstream angle across the stream while snorkeling, I overturned all rocks larger than 30 cm in their longest visible dimension and recorded the number of riffle sculpins underneath. I examined two 12-m sections (which included insect sampling stations 0 and 1, respectively) on both dates. Rocks overturned with care usually could be replaced without disturbing the fish beneath; those fish that fled were easily detected. Each rock was scored as either providing no cover for riffle sculpins (> 50% embedded), providing at least some cover but with no riffle sculpins present, having one riffle sculpin present, or having two or more riffle sculpins present.

At BC, I counted all fish age 1+ and older within the dredged area at approximately 2-week intervals from 27 May to 4 October 1981 while snorkeling. I also censused two upstream control sections on two dates each: the 2.6-km section from the uppermost point of dredging to the upper insect sampling control station, and the next 5.2 km upstream to a diversion dam. Gradient and pool size were similar in the dredged area and lower control section, but the upper control area had a

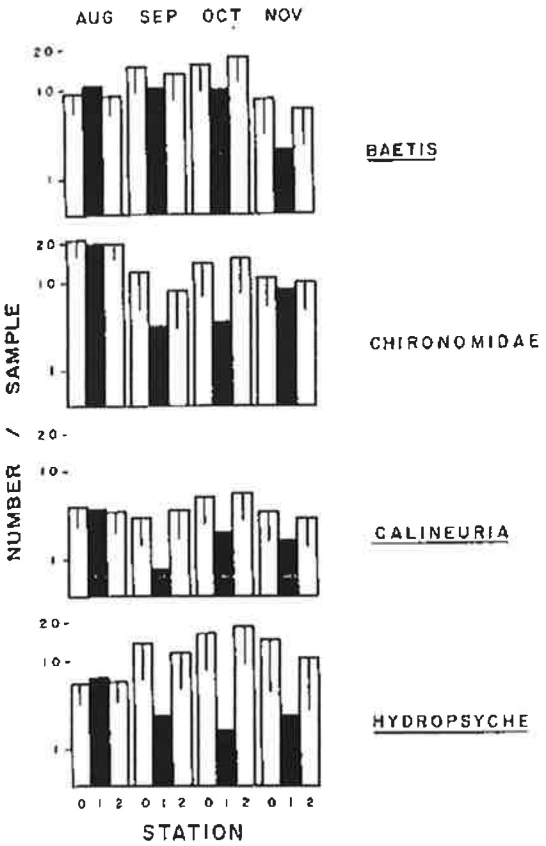

FIGURE 1.—Average number per sample of the four most abundant insect taxa in the North Fork of the American River in each month, August–November, at the three insect sampling stations (numbers 0–2). Center vertical lines in bars are ½ Tukey's 95% confidence intervals determined from a one-way analysis of variance among stations within each month for individual taxa.

higher gradient and a larger number of small pools per unit distance. I tagged 50 rainbow trout 90–180 mm long (standard length) in the dredged area and the lower control section (25 in each) from 5 to 25 June 1981. Different combinations of small colored beads attached to a monofilament line, which passed through the back of the fish just posterior to the dorsal fin (White and Beamish 1972), made underwater identification of individuals possible. I recorded the locations of all tagged fish on the nine fish-censusing dates in the dredged area. Fish movement was summarized by giving a score of 1 if a tagged fish had moved from a pool to one of the adjacent riffles or vice versa since the last observation date and a score of 0 if no movement had occurred.

Turbidity measurements were made immediately above and at 5-m intervals below active dredging sites on both streams with a portable turbidimeter (HF Instruments, model DRT 15).

Results

Insects

There generally were 10–15 insect taxa per sample each in both NFAR and BC, usually three to five relatively abundant taxa and seven to 10 rare taxa (commonly averaging less than 1.5 individuals each per sample). Taxa present at control stations usually were present at dredged stations. Species of *Baetis*, *Calineuria*, *Hydropsyche*, and Chironomidae were present at NFAR in numbers averaging more than three individuals per sample in at least one station in every month (Figure 1). There were no significant differences ($P > 0.05$) between stations in August, the control month (Table 1). When taxon abundances at control stations differed significantly (10 cases), they were always greater than abundances at one of the other two stations. In seven of 10 cases, the control station had more individuals than station 1, but station 2 also had more than station 1, indicating a recovery in abundance downstream. In September and October (samples taken during the period of dredging), not all taxa showed significant declines in the dredged area.

In the BC monthly insect analyses, the control month (June) again showed no significant differences among stations (Table 2). If there were a cumulative effect of dredging, an increasing number of taxa should have declined in abundance after June at downstream stations. Stations 2 and 4 had significantly fewer individuals of some taxa than the control stations, but station 3, 200 m above station 4, had no fewer individuals of any taxa in any month than control stations.

Significant differences between stations at both NFAR and BC were directly related to substrate changes as a result of dredging. Cobbles initially present at BC station 4 were partially embedded in June, resulting in lower numbers in some taxa in July. Dredging immediately upstream from BC station 2 began in June and continued in August, causing substrate alterations and significant differences for some taxa in the August and September samples. Differences in leaf litter among BC stations in October and November may have caused the significant differences in insect abundances shown for those months in Table 2.

Insects recolonized the sand and gravel deposited by dredging at BC fairly rapidly (Figure 2). By day 45 (23 September), the mean number of

TABLE 1.—Results of analyses of variance for August–November benthos data from the North Fork of the American River, showing significant differences among stations (Tukey's test; $P < 0.05$; 0 means control samples, 1 means samples 10 m below the dredge, and 2 means samples 60 m below the dredge). An X means average abundance was less than three individuals per sample at all stations; NSD means average abundance was greater than three individuals per sample for at least one station, but there were no significant differences between any stations ($P > 0.05$).

Taxon	Aug	Sep	Oct	Nov
Coleoptera				
Elmidae	X	X	X	X
Diptera				
Chironomidae a	NSD	0>1	0>1, 2>1	NSD
Chironomidae b	NSD	NSD	2>1	X
Ephemeroptera				
Baetis sp.	NSD	NSD	2>1	0>1, 2>1
Tricorythodes sp.	X	X	X	0>1, 1>2
Plecoptera				
Calineuria sp.	NSD	0>1, 2>1	0>1, 2>1	NSD
Chloroperlidae	X	X	X	0>1, 0>2
Trichoptera				
Hydropsyche sp.	NSD	0>1, 2>1	0>1, 2>1	0>1, 2>1

insects per sample in the recolonized area was not significantly different from the pooled average of the control stations for October.

Fish

Riffle sculpin abundance at NFAR was altered by dredging (Table 3). Abundances at the stations were significantly different from the expected in September ($\chi^2 = 24.5$; 6 df; $P < 0.005$), but not in August before dredging ($\chi^2 = 3.7$; 6 df; $P < 0.500$). The proportion of rocks providing no cover for riffle sculpins also was different from the expected in September but not in August (September: $\chi^2 = 11.1$, 2 df, $P < 0.005$; August: $\chi^2 = 1.8$,

TABLE 2.—Analysis of the benthos abundance data for Butte Creek, 1981. An A means the average abundance at the two controls was significantly greater than the abundance at the station given (Scheffé's method; $P < 0.05$); B means the average control abundance was significantly less than the value for the station given; a minus sign (−) means the abundance was less than three individuals per sample at all stations; a plus sign (+) means the average abundance was greater than three individuals per sample for at least one station but there were no significant differences between station and average control abundances.

	Month and station															
	Jun				Jul				Aug				Sep			
Taxon	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Coleoptera																
Elmidae (adult)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Elmidae (larvae)	+	+	+	+	+	+	+	A	+	+	+	+	+	+	+	+
Diptera																
Chironomidae	+	+	+	+	+	+	+	A	+	+	+	A	+	A	+	+
Ephemeroptera																
Baetis sp.	+	+	+	+	+	+	+	A	+	+	+	+	+	A	+	+
Cinygmula sp.	+	+	+	+	+	+	+	A	+	A	+	+	+	A	+	A
Epeorus sp.	+	+	+	+	−	−	−	−	−	−	−	−	−	−	−	−
Rhithrogena sp.	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
Plecoptera																
Calineuria sp.	+	+	+	+	+	+	+	+	+	A	+	+	+	A	+	B
Trichoptera																
Gumaga sp.	−	−	−	−	−	−	−	−	−	−	−	−	+	A	+	+
Micrasema sp.	−	−	−	−	+	+	+	+	+	+	+	+	−	−	−	−

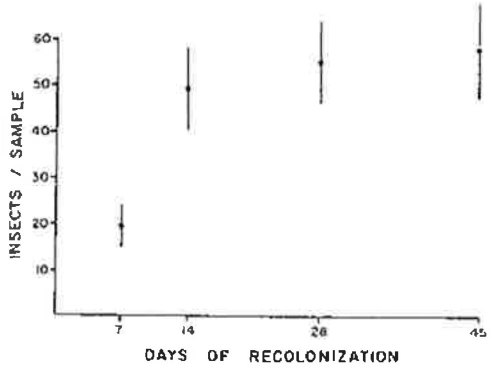

FIGURE 2.—Rate of recolonization of dredged material by insects in a shallow run on Butte Creek, showing the total number of insects/0.093 m^2 (vertical bars show ±1 SD).

TABLE 3.—Results of abundance experiments with riffle sculpins in the North Fork of the American River. Data are the number of rocks at each station before (August) and after one month of dredging (September) that either offered no cover for riffle sculpins (NC), offered some cover but had no riffle sculpins beneath (0), had one riffle sculpin beneath (1) or had two or more riffle sculpins beneath (2).

Month and station	Cover category			
	NC	0	1	2
August				
0 (control)	23	28	44	3
1	17	34	39	2
2	27	32	42	1
September				
0	20	25	44	1
1	39	34	16	0
2	25	28	40	2

2 df, $P < 0.250$). When only rocks that provided some cover for riffle sculpins were considered, the stations were again different in September but not in August (September: $\chi^2 = 17.2$, 4 df, $P < 0.005$; August: $\chi^2 = 1.9$, 4 df, $P < 0.750$). These results indicate that fewer fish were present at station 1 because (1) a significant proportion of the riffle sculpin habitat was eliminated and (2) the rocks remaining that provided some cover were not as likely to be occupied (probably because of the addition of sand).

Rainbow trout density in BC declined sharply over time in both the dredged area and the upstream control areas (Figure 3). The upper control area always had the greatest density, probably because of the higher gradient there. Much of the volume of the large pools in the dredged area was not occupied by fish, probably due to a lack of cover. Although pools in the upper control area were smaller, they provided at least as much cover as those in the dredged and lower control areas. The upper control averaged 25.5 fish per pool–riffle sequence on 12 July, whereas the dredged area averaged 22.9 fish per sequence on 14 July.

Tagged rainbow trout moved very little in either

TABLE 2.—Extended.

Month and station							
Oct				Nov			
1	2	3	4	1	2	3	4
−	−	−	−	−	−	−	−
B	+	+	+	B	+	+	+
+	+	+	A	+	+	B	+
+	+	+	+	+	+	+	+
+	+	+	+	+	+	+	+
−	−	−	−	−	−	−	−
−	−	−	−	+	+	+	+
+	A	+	+	+	+	+	B
+	+	+	+	+	+	+	+
−	−	−	−	−	−	−	−

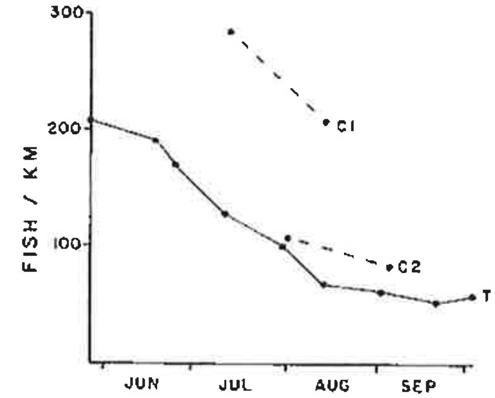

FIGURE 3.—Summer density of rainbow trout age 1+ or older in Butte Creek within the dredged area (T) and the two control areas (C1, upper control, and C2, lower).

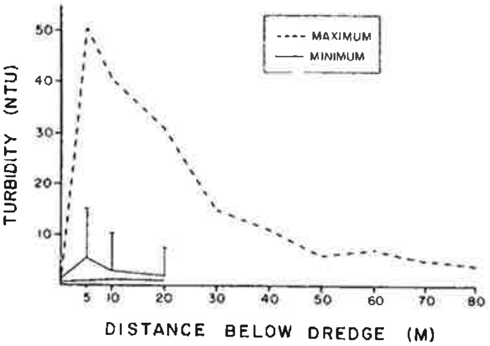

FIGURE 4.—Turbidity (nephelometric turbidity units, NTU) below active dredges showing the maximum, minimum, and average turbidities measured (vertical bars on the middle "average" line are 1 SD). Intersections of the lines with the ordinate show turbidities immediately above active dredges.

the dredged or control areas. No tagged fish moved further than from a pool to one of the adjacent riffles or vice versa in any 2-week period. Although the total amount of movement by fish in the dredged and control areas at BC was not significantly different overall ($\chi^2 = 0.03$; 1 df; $P < 0.750$), some tagged fish clearly responded to dredging. The basic pattern of physical change caused by small dredging operations is the formation of a hole where dredging occurs and the buildup of shallow sand–gravel areas downstream; piles of large cobbles and boulders also may be formed. Some of these alterations caused movement of fish from areas where pool volume was reduced or water velocity altered. Three of six fish in one small pool moved into the downstream riffle when dredging added sand that reduced the volume of the pool by 25%. After the sand was flushed out by a temporary high flow, two of those three fish returned to the pool. In contrast, during low flows in late summer, all eight fish in one riffle occupied a hole created by dredging. Commonly, dredging occurred in pools and caused no major change in volume but increased embeddedness of cobbles and boulders. Rainbow trout generally remained in place in these pools.

The results of the turbidity measurements indicated a localized effect of dredging (Figure 4). Because of low ambient levels of turbidity, increases of 4–5 nephelometric turbidity units (NTU) were very noticeable, although they probably were of little significance to invertebrates and fish. At 25–30 NTU, I observed rainbow trout feeding in Butte Creek.

Discussion

The overall effect of dredging on the benthic community apparently was highly localized. The monthly sampling data from both NFAR and BC showed that decreases in invertebrate abundances and species richness occurred only after a change in substrate. A change resulting in a partial imbedding of the substrate did not have a drastic effect on the invertebrate fauna, in agreement with other studies (Percival and Whitehead 1929; Chutter 1969; Bjornn et al. 1977). The specific effect of dredging on a given insect taxon depends on the substrate requirements and recolonization abilities of the animals, and perhaps on changes in biotic interactions resulting from changes in the physical environment.

Due to interspecific differences in the above factors, the lack of significant differences observed between control and dredged stations for some taxa is not surprising. For example, the abundance of *Baetis* sp. at NFAR (Figure 1) apparently was not altered by dredging. This was most likely due to the organic matter (in addition to sand and gravel) that was deposited there, a substrate that may be as suitable for this taxon as the partially embedded cobbles and gravel that were predominant there initially (Edmunds et al. 1976). Clearly, taxa not greatly affected by dredging must either recolonize at a relatively fast rate or maintain their positions as sediment is added. In contrast, *Hydropsyche* sp. abundance was severely reduced in the dredged area at NFAR. These animals require exposed cobbles or boulders (for net construction), which were not abundant below the dredge. In addition, Hemphill and Cooper (1983) have shown that *Hydropsyche* recolonization is slow even when appropriate substrate is available. Although they do not much affect *Hydropsyche*, biotic interactions may strongly influence the impact of dredging on the predaceous stonefly *Calineuria* sp. Although it was less abundant below the dredge at NFAR (Figure 1), *Calineuria* was approximately equally abundant on undisturbed cobble substrate and sand–gravel areas created by dredging 45 d after turnover in Butte Creek. Also, *Calineuria* abundance was not lower at BC station 4, where dredging caused a partial embedding of much of the stream bottom. This distribution may be explained by greater accessibility or abundance of prey organisms (in the appropriate size classes) on the finer substrate. Siegfried and Knight (1976) showed that chironomids and *Baetis* (both abundant at station 4 and in the recolonization experiment section) were preferred foods of *Calineuria* in another Sierra foothills stream.

Most taxa present in significantly lower numbers at dredged stations made a rapid recovery after dredging was stopped. The 45-d recolonization experiment indicated not only a rapid recovery in the total number of insects over time, but also that almost all taxa found on cobbles take part in the recolonization of sand and gravel areas. Both insect drift and the proximity of suitable habitats must play important roles in the recolonization of sand–gravel areas created by dredging. These areas probably do not support a biomass equivalent to those on cobble substrates because there is less available living space and a relative lack of organic matter for food (Scott and Rushforth 1959). The recolonization experiment also was performed during important months of recruitment, which probably influenced the quick recovery in numbers.

One problem inherent in all benthic sampling is the accuracy of the sampling methods (Resh 1979). The shallow run habitat was chosen for this study to reduce sampling variability and maximize the accuracy of the sampling device. Dredging in riffles probably is more damaging because sand and gravel deposited there are unstable. Pools probably are not as greatly affected by dredging because they naturally accumulate sediments (although normally in other seasons). All samples were taken by one person and compared to others taken with the same sampler on similar substrates. Importantly, this sampling method did not prevent within-station variability, which led to generally low experimental power. The NFAR data in particular may have underestimated the effects of dredging because the main channel was not sampled due to the depth limitation of the Surber sampler.

Like the insects, the fishes apparently were not affected by dredging unless a major change in their habitat occurred. However, interspecific differences in microhabitat requirements resulted in differences in the effect of dredging. At NFAR, visual observations indicated that species other than riffle sculpins were not sensitive to dredging, but riffle sculpin abundance in the dredged area was significantly less than in the control area. The microhabitats of riffle sculpins, and possibly those of other bottom-oriented stream fishes such as speckled dace (*Rhinichthys osculus*) and young-of-the-year rainbow trout, are altered more readily by dredging than those of less benthic species (and age-classes).

The decline in rainbow trout density observed at BC is likely the result of habitat loss due to naturally decreased flows. The large pools in the study area provided little cover for fish in late summer—in contrast to May and June when surface turbulence was greater. Also in late summer, many riffles became too shallow to provide adequate habitat. To implicate dredging in the observed decline in fish density, emigration from the dredged area, or mortality due to dredging would have to be documented. The tagging experiments showed that rainbow trout did not move over large distances in either dredged or control areas. Cargill (1980) found a similar lack of movement by rainbow trout in a Minnesota stream. Adult rainbow trout probably escaped entrainment in dredge-induced flows, and a small number of juvenile rainbow trout and riffle sculpins observed after passage through a dredge showed no immediate ill effects. Likewise, Griffith and Andrews (1981) found no mortality of cutthroat trout fingerlings after similar treatment.

No large-scale movement of rainbow trout occurred at BC, but tagging indicated local movement out of pools and riffles made uninhabitable by both dredging and seasonal flow reductions. The observed reduction in fish density as a result of decreases in pool volume agrees with work by Bjornn et al. (1977), who found that fish density decreases at a faster rate than the decrease in pool volume when sediment is added.

The turbidity changes caused by dredging often were very noticeable, but they probably had little effect on fish feeding. Brusven and Rose (1981) and Olson et al. (1973) found that turbidities exceeding the highest values measured in this study are required to cause declines in fish feeding (in sculpins and salmonids, respectively). The turbidity changes associated with dredging also normally occur during midday, which is not a peak feeding period for Sierra foothill fishes (Li and Moyle 1976; Moyle 1976).

Factors that affect the impact of dredging include dredge size and density, stream size, the fineness of the sediments, and flow regime. The dredge density at BC in 1981, although characteristic of many streams, was not as high as in some streams in California. Qualitative observations on large streams such as the North Fork of the Feather River and North Fork of the Yuba River indicated dredging was a highly localized disturbance on those streams. In contrast, 15 m of a tributary of Butte Creek were completely channelized and riffles were transformed into exposed gravel bars by the 10-d operation of one dredge. In streams with a relatively large proportion of fine sediments, the effects of dredging are probably more severe than those I observed.

Fish and invertebrates apparently were not highly sensitive to dredging in general, probably because the streams studied naturally have substantial seasonal and annual fluctuations in flow, turbidity, and (on a local scale) substrate (Moyle et al. 1982). These fluctuations, in the form of flushing winter flows, can greatly reduce the long-term impact of dredging. In May 1982, no substrate changes caused by dredging in Butte Creek during the previous summer were evident. Saunders and Smith (1965) observed a quick recovery in the trout population of a heavily silted stream after scouring. Along with the rapid temporal recovery of insects seen in this study, these results suggest that suction dredging effects can be short-lived on streams where high seasonal flows occur.

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