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Experimentally Determined Impacts of a Small, Suction Gold Dredge on a Montana Stream

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ABSTRACT

A small suction dredge was operated experimentally on Gold Creek in Missoula County, Montana to determine the effects of dredging on aquatic insects and the bottom habitat. A 10-m section was dredged from bank to bank. Sampling was conducted before dredging and at upstream and downstream stations for control. The experiments were replicated at an upstream site. Significant changes ($P < 0.01$) in aquatic insect abundance were restricted to the area dredged; downstream areas were not affected ($P > 0.05$). Recolonization was substantially complete 1 month after dredging. Intergravel permeability was not significantly changed by dredging ($P > 0.05$). Suspended sediment concentrations during dredging were highly variable. Suspended sediment discharge averaged a maximum of 340 mg/liter at the outflow and returned to background levels within 11 m. Impacts of suction dredging on the bottom fauna appeared to be highly localized. No immediate downstream impacts were recorded other than fine sediment deposition and movement of unstable gravel beds downstream during the next year's peak flows, filling a downstream pool.

The soaring price of gold in the late 1970's resulted in a proportional increase in suction gold dredging. Although suction gold dredges have been used in western rivers since the 1930's, modern portable dredges which are inexpensive and commercially available are used by many recreationists. However, the effects that these small dredges have on the aquatic environment are largely unknown.

A review paper on the effects of sediment on rivers noted detrimental impacts of gold dredging on salmonids and macroinvertebrates (see Cordone and Kelly 1961). These studies dealt with larger operations and heavier equipment than that used by casual prospectors. Recent work by Griffith and Andrews (1981) showed heavy mortality of trout eggs and sac fry entrained through a suction dredge but less than 1% mortality or injury of entrained aquatic insects. Harvey et al. (1982) found that a suction dredge caused significant localized alterations of the streambed habitat and abundance of aquatic organisms, especially insects. Lewis (1962) found a 1-ppm increase in intergravel dissolved oxygen and a three-fold increase in intergravel permeability after dredging.

Gold dredges operate by sucking the bottom gravels into a baffle box in which the current is reversed and turbulence increased. The flow continues past or through a classifier screen, then out through the sluice box and into the river. The heavier materials immediately settle on the stream bottom, while lighter fines are carried downstream where they are redeposited.

My research evaluated the impact of suction dredging on benthic invertebrates and stream bottom habitat in dredged areas and immediately downstream. Because I did the dredging, an experimental design with before and after observations on dredged and control sections was possible.

STUDY SITE

The experiments were conducted on Gold Creek in Missoula County, Montana July–September 1980 (Fig. 1). Gold Creek is a relatively undisturbed, third-order stream with late summer flows of about 0.4 m^3/second. Although the lower drainage basin is managed as a tree farm and large timber contracts have been let recently in the National Forest, the riparian zones have been left fairly intact. Turbidity, sedimentation, and channel instability are not serious problems. The creek supports good populations of cutthroat trout (*Salmo clarki*) and brook trout (*Salvelinus fontinalis*) and is a bull trout (*Salvelinus confluentus*) spawning stream.

Rock types in the Gold Creek drainage include Precambian Belt Supergroup sediments, principally Missoula and Wallace formations. The study site is covered by Tertiary alluvial gravel fill. The gravels are probably several hundred feet thick,

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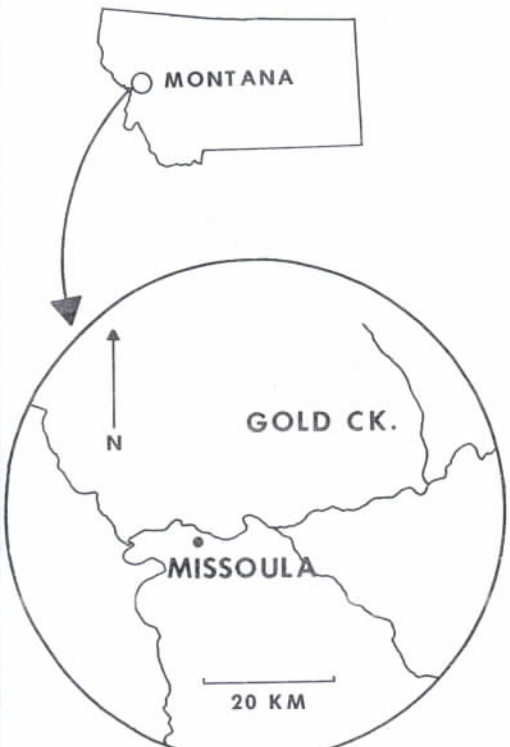

Figure 1. Location of study site on Gold Creek in western Montana.

although no definitive estimate was made. No gold has yet been found in the stream gravels (J. Thomas, U.S. Borax, personal communication 1982). The streambed is composed of gravel, cobble, boulders, and some sand and silt.

Methods

Study Design

Two lengths of stream 50 m long were chosen for their relatively uniform character. Each site (A and B) was divided into five 10-m sections. The section farthest upstream in each site (Section 1) was maintained as a control. The next 10-m site (Section 2) was dredged from bank to bank and to the greatest depth possible (<1 m). Three replicate lower sections (sections 3, 4, and 5) were studied to determine downstream impacts. Replicate Site B was upstream from Site A and was dredged later.

The dredge used in this study was manufactured by Keene Engineering. It had a 6.4-cm diameter nozzle and was powered by a 2-horsepower Briggs and Stratton engine. It is one of the most popular dredges used by weekend gold dredgers.

Aquatic Insects

Six random samples were taken in each of the five study sections before and after dredging. Samples were taken with a homemade, Hess-type sampler (area, 0.05 m^2). A solution of rose bengal stain was added to the samples in the laboratory to facilitate sorting the benthic invertebrates (Mason and Yevich 1967), and the samples were sorted to the lowest taxonomic level feasible, usually to genus. Samples were taken before and immediately after dredging took place, and the dredging took approximately 2 weeks to complete at each site. A complete set of macroinvertebrate samples was taken 1 month after dredging to determine the degree of recolonization.

To normalize the data, counts were transformed using the transformation $z = (\log_e x + 1)$ (Green 1979). Analysis of variance (ANOVA) was used to determine the location and magnitude of dredging impacts. A 2 × 2 × 5 (site × treatment × section) ANOVA was performed on the transformed data using SPSS (Statistical Package for the Social Sciences) subprogram ANOVA (Nie et al. 1975). The purpose of this analysis was to determine whether or not dredging affected both sites in the same way. If so, these findings may be applicable to other, similar streams treated in similar ways.

This design would not be applicable universally although it produced satisfactory results in this case. It is not a balanced design because every section received a different treatment. Consequently, the treatment effects were confounded by time effects. A balanced design would have a control section for each treatment section. In order to achieve control without confounding, a complete 50-m section would be needed with sampling but no treatment.

A one-way ANOVA was conducted on the before-and-after transformed data using SPSS subprogram ONEWAY (Nie et al. 1975) to determine if the five sections had significantly different numbers of aquatic insects before and after dredging. Each site was treated separately. Scheffe's test (Snedecor and Cochran 1980) was computed using SPSS to identify significantly different sections.

Each taxonomic group was analyzed separately to detect changes in species composition due to suction dredging. One-way ANOVAs were conducted for each of the common taxonomic groups. Rare genera were ignored because it was not possible to detect any change in their abundance. A one-way ANOVA was done on the samples taken 1 month after dredging in sections 1, 2, and 3. These ANOVAs were on the total counts and at the ordinal level because the fauna was not sorted below that level.

Sedimentation

Suspended sediment was measured before and during dredging using a depth-integrating sediment sampler, the DH-48 (Guy 1970). Samples of sediment concentration obtained by integration with the flow can then be used with the flow rate in the given cross section to compute the sediment discharge:

$$Q_s = Q_w C_s k$$

where

Q_s = sediment discharge in pounds per day,
Q_w = water discharge in cfs,
C_s = discharge weighted mean concentration in mg/liter,
k = a constant.

One sample was taken above the dredge outflow for a control. Directly below the dredge outflow three samples were taken 0.3 m apart. Three more samples were taken 1.5 m below the outflow, 0.6 m apart. Four samples were taken (representing the entire stream flow) 7.6 m below the outflow. The object of this sampling design was to map out the plume of suspended sediment. The amount of sediment discharged at any moment through a suction dredge is highly variable, depending on the type of bottom materials being dredged. Suspended sediment samples were taken when the discharge appeared to be the most murky in order to determine the "worst-case" situation. Sediment samples were filtered through Whatman #41 filter paper and the residue was dried for 1 hour at 100 C and then weighed. Current velocity and discharge were measured with a pygmy current meter.

Deposited Sediment

Deposited sediment was measured using a trap similar to that of Welton and Ladle (1979). The trap is made of aluminum beverage cans with the tops cut off. The cans were fitted with nylon rope handles and placed inside 7.6-cm diameter PVC pipes cut to fit the cans. The cans were filled with washed gravel larger than 3.962 mm, and buried in the bottom so that the tops of the traps were flush with the bottom of the stream. Five sediment traps were spaced equally across the middle of Section 1 and sections 4 and 5. The dredged section did not have any traps, but Section 3 had a row across the top of the section as well as one row across the middle.

Traps were left in place for 5 days before dredging began, then the gravel was washed, the wash water saved for analysis, and the traps replaced in the stream. The same procedure was followed after dredging. The wash water was filtered (Whatman #41 paper), dried for 1 hour at 100 C, and weighed. The same procedure was followed after dredging.

A curve was fitted to the deposited sediment data using a BMDP derivative-free, non-linear regression (Dixon 1981). This program uses iteration to find parameters that solve the problem with the smallest residual sum of squares.

Gravel Permeability

Developing salmonid eggs and fry need flowing water to carry away metabolic wastes and supply them with oxygen (Meehan and Swanson 1977). Reduction in water velocity and dissolved oxygen each result in a longer development period to hatching, smaller embryos, higher prehatching and posthatching mortality, and increased occurrence of structurally abnormal embryos (Silver and Douderoff 1963). Therefore, high gravel permeability is important to successful salmonid spawning. Intergravel permeability, at the velocities usually found in stream gravels, is a function of water viscosity and, especially, the composition and degree of packing of the gravel (Pollard 1955). Therefore, a layer of fine sediment on the stream bottom gravels can reduce intergravel permeability.

Mark VI groundwater standpipes were used to measure intergravel water permeability and dissolved oxygen (Terhune 1958). Intergravel permeability was measured before and after dredging at both sites.

Channel Morphology

Photos were taken of both study sites before and after dredging took place to document any changes in channel morphology. The sites were

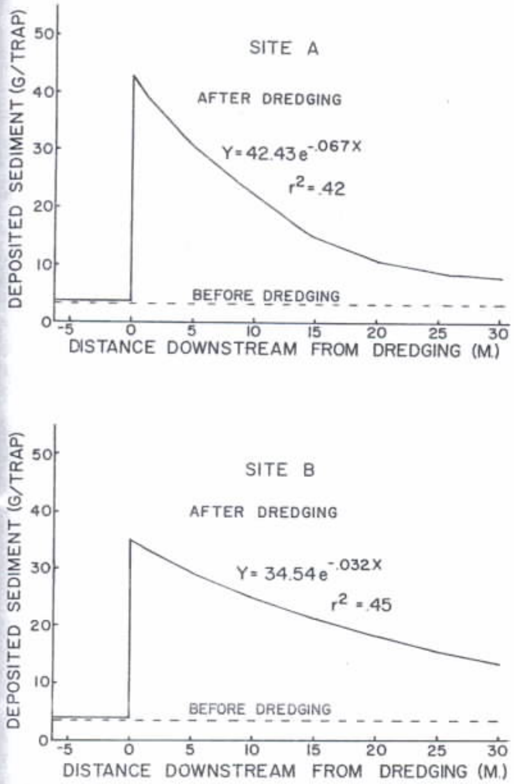

Figure 2. Deposited sediment before and after dredging at two sites. Y = deposited sediment (grams/trap), X = distance downstream (meters).

visited 1 year after dredging to determine if there were any long-term changes.

Results

Suspended Sediment

Upstream of the dredge outflow, the mean quantity of suspended sediment was 4.56 mg/liter. The concentration of suspended sediment was greatest at the dredge outflow (340 mg/liter) and decreased rapidly as the heavier particles settled out and the remaining material dispersed across the stream. Suspended sediment was 1.8 mg/liter at 30.5 m below the dredge, indicating a return to ambient levels. The rate of decrease in suspended sediment will vary with stream discharge and particle size.

Sediment discharge measured upstream from the dredge was 295.9 kg/day on August 21, 1980. On the same day, sediment discharge was 35,076.5 kg/day at the dredge outflow and 343.5 kg/day 11 m below the outflow. However, this is a point estimate of the worst sediment discharge experienced in Gold Creek and not a true representation of the average amount of sediment being discharged during dredging.

These data indicated that the bulk of the sediment stirred up by dredging was re-deposited within 6–11 m of the dredge. Consequently, impacts on the stream benthos due to fine sediment deposition should be limited to this zone.

Deposited Sediment

Deposited sediment measured before dredging was equal throughout the stream, with a mean of 86 g/m²/day. After dredging, the deposited sediment increased 10–20 times over background levels immediately downstream (Fig. 2). Deposited sediment decreased exponentially downstream with the distance from dredging.

There was a high variance of the downstream measurements of deposited sediment primarily because the sediment was not equally distributed across the stream. More of the sediment was deposited near the middle of the channel than near the edges which received near background levels of sediment. In addition, sediment deposition varied greatly from day to day, depending on the type of substrate being dredged and the stream's hydraulic characteristics.

Aquatic Insects

A three-way (site × treatment × section) factoral ANOVA conducted on log-transformed data showed no significant three-way interactions ($P = 0.12$). The treatment effects found at Site A were of the same degree and in the same direction as the effects at Site B. A plot of the mean number of insects found in each section showed that, in Section 2 (the dredged section), mean insect abundance decreased greatly after dredging (Fig. 3). Downstream insect abundance did not appear to be altered.

One-way ANOVAs showed that the mean number of aquatic insects was the same in all five sections before dredging began ($P > 0.05$) at both sites. After dredging, both sites showed a significant difference between sections ($P < 0.01$). Scheffe's test showed Section 2 contained significantly fewer insects than the control section or the three downstream sections at both

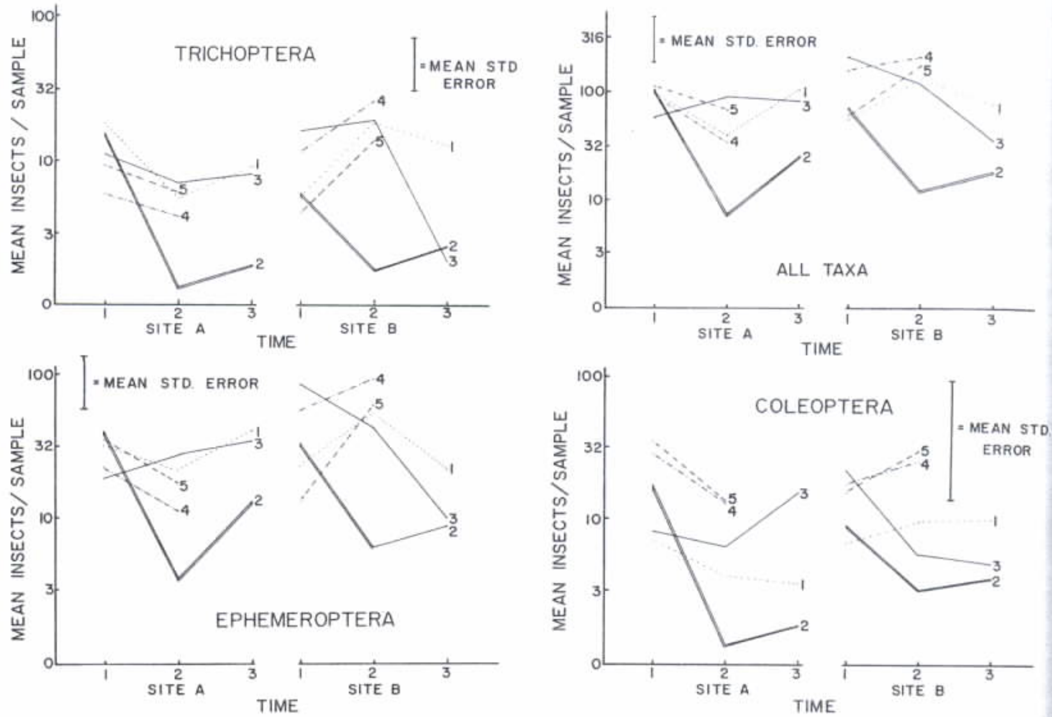

Figure 3. Changes in numbers of aquatic insects over time at sites A and B and sections 1-5. Time 1 = before dredging, Time 2 = 1 day after dredging, and Time 3 = one month after dredging. Section 1 = control, Section 2 = dredged section, and sections 3, 4, and 5 are downstream sections. Mean std. error = mean of the standard errors for all points.

sites. No change in downstream insect abundance could be detected relative to the control section. The data show that the immediate impacts of dredging on aquatic insect abundance were limited to the area dredged.

Analysis of variance by taxonomic group indicated that the mean number of insects in each group at Site B was the same at all five sections before dredging began (Table 1). After dredging, all groups showed significant ($P < 0.05$) variation between sections. Scheffe's test showed that Section 2 (the dredged section) contained significantly fewer organisms than the other sections (Table 1). None of the changes in abundance downstream of dredging were large enough or consistent enough to conclude that there were any immediate downstream impacts on any of the species. The data at Site A were less clear. At the ordinal level of taxonomic resolution, it was again fairly clear that the abundance of insects in Section 2 was greatly decreased and in the other sections there were no quantitative changes. However, at finer levels of taxonomic resolution the ability to detect changes in species density becomes weaker. Some of the genera did show statistically significant differences between sections after dredging. However, in every case except one, Section 2 contained fewer organisms than any other section after dredging, regardless of the abundance of insects in Section 2 before dredging. The trend for a large decrease in insects in this section after dredging was consistent.

The immediate effect of suction dredging was to reduce the number of all species of insects in the area dredged. The effect was very localized. No significant change in abundance was found downstream from the dredged section for any taxonomic group.

Recolonization was substantially complete for most groups of insects 1 month after dredging. Analysis of variance indicates that the mean number of aquatic insects was not significantly different between sections 1, 2, and 3 one month after dredging ($P > 0.05$). Only the Trichoptera

Table 1. Results of one-way analyses of variance of insect abundance at two sites and five sections within sites before and after dredging in Gold Creek, Montana. NSD = no significant difference.

	Site A			Site B		
Taxa	Before dredging[a]	After dredging[b]	Significantly different sections	Before dredging	After dredging	Significantly different sections
Ephemeroptera	NSD	*[c]	2 < 3	NSD	**	2 < 1, 3, 5, 4
Heptageniidae	NSD	NSD	NSD	NSD	**	2 < 3, 4, 5, 1
Epeorus	NSD	*	2 < 1, 3	NSD	**	2 < 4, 3, 1, 5
Rhithrogena	NSD	**[d]	2, 4 < 3	NSD	*	NSD
Cinygmula	NSD	NSD	NSD	NSD	*	2 < 3, 5, 1, 4
Ephemerellidae	NSD	NSD	NSD	NSD	**	2 < 1, 3, 5, 4
Trichoptera	NSD	**	2 < 1	NSD	**	2 < 5, 1, 3, 4
Brachycentridae	*	NSD	NSD	NSD	**	2, 1 < 5, 3, 4
Micrasema	*	NSD	NSD	NSD	**	2, 1 < 5, 3, 4
Polycentropus	NSD	*	2 < 3	NSD	**	2 < 1, 4, 3, 5
Coleoptera	**	**	2 < 3, 4, 5	NSD	**	2 < 3, 1, 4, 5
Diptera	NSD	NSD	NSD	NSD	**	2 < 1, 3, 4, 5
Chironimidae	NSD	NSD	NSD	NSD	**	2 < 1, 3, 4, 5
Plecoptera	NSD	**	2 < 4, 3, 5	NSD	**	2 < 1, 3, 4, 5
Zapada	*	NSD	NSD	NSD	**	2 < 1, 5, 3, 4
Chloroperlidae	*	**	2 < 4, 3, 5	NSD	**	2 < 3, 4, 1, 5

[a] Probability of the mean number of insects being equal in each of the five sections before dredging took place.
[b] Probability of the mean number of insects being equal in each of the five sections after dredging took place.
[c] Significant difference between sections ($P < 0.05$).
[d] Highly significant difference between sections ($P \leq 0.01$).

(caddisflies) had significantly lower numbers in the dredged section than in sections 1 or 3 ($P < 0.05$) 1 month later (Fig. 3). Caddisflies may find dredged areas unsuitable as habitat, or they may take longer to colonize the available substrate. At Site B, both sections 2 and 3 had significantly fewer caddisflies ($P = 0.02$) than the control 1 month after dredging (Fig. 3). At Site A, the caddisflies did not fully recover in the dredged section but no downstream impacts were indicated. It appears that downstream sediment deposition due to dredging may have impacted the caddisflies negatively at Site B. However, because the caddisflies were not impacted at Site A, the evidence was inconclusive.

The Coleoptera (family Elmidae) at Site A showed significantly higher numbers in the first downstream section than in sections 1 or 2 after one month ($P < 0.005$) (Fig. 3). This result was not substantiated at Site B where Elmids did not increase downstream from the dredging, and there was no significant difference between sections ($P = 0.88$).

The number of insects in the dredged section increased 1 month after dredging, even when the numbers in the control and downstream sections decreased—indicating that most aquatic insects find dredged areas to be suitable habitat. However, in almost every case the numbers in the dredged section after one month remained below that of the control and downstream sections. Possibly it takes longer than 30 days for complete colonization to occur or that dredging reduces the carrying capacity of the substrate.

Channel Morphology

The dredging technique and size of dredge used by the operator will have a large effect on the types of changes that will occur in channel morphology. Because most of the gold will be found at or near bedrock, most miners will find it necessary to dig a deep hole with their dredge. Pocket and pile dredging techniques have a greater impact on channel morphology than dredging to a uniform, shallow depth.

Gravel is deposited in piles immediately downstream of the dredge outflow. These piles could make excellent spawning sites except that they are very unstable. One year after dredging, all of the gravel deposited at the dredged area had moved downstream. In one case the gravel was moved into a downstream pool, completely filling it up. Deep pools are extremely important to stream fishes. Sheldon (1968) found that the number of species of fish was most strongly correlated with stream depth. Bjornn et al. (1977)

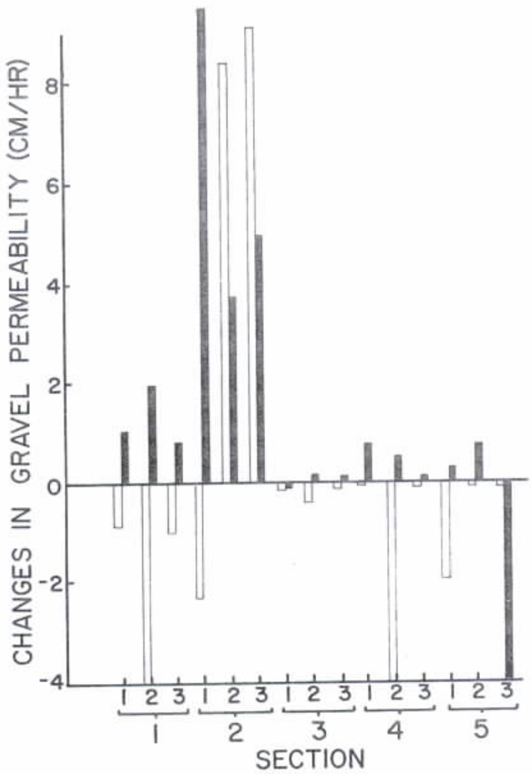

Figure 4. Changes in gravel permeability (after dredging minus before dredging). Solid bars are for Site B; open bars for Site A.

found that, when fines were added to pools in a test stream, the abundance of fish decreased proportionally to the decrease in pool volume or area. Large scale filling of pools could be expected to reduce the number of species and abundance of fish living in the stream. Possibly, the pool habitat created upstream by dredging deep holes would compensate for the loss of pool habitat downstream.

Any rock too large to fit through the dredge intake has to be removed from the miner's path. At Site A, I moved all the boulders into several piles in the middle of the stream. At Site B, I moved the boulders to the edge of the stream. When I returned to the study site 1 year after dredging, it was difficult to see that any dredging had been done at Site B. However, the boulder pile at Site A remained in the stream, although somewhat reduced in size despite high spring flows.

Dredge miners could damage the stream by cutting streambanks and destroying riparian vegetation. This is illegal in Montana so I chose not to damage the streambanks in Gold Creek for this study. It is possible for a suction dredge to make highly localized changes in channel morphology. Pool and riffle configuration can be altered. The degree of damage is determined largely by the amount of material discharged into the stream. Very large quantities of material could fill pools and change a single channel into a braided stream.

Gravel Permeability

Intergravel permeability apparently did increase slightly in the dredged section (Section 2) after dredging (Fig. 4). However, this difference was not significant ($P > 0.05$). No changes in downstream intergravel permeability were detected.

The data indicated that silt deposition from suction dredge mining should not be detrimental to developing salmonid eggs. However, it is possible that harm could be caused if either the dredge were larger, the stream smaller, or the substrate more silty. In a stream where intergravel flow and dissolved oxygen is marginal to begin with, a small decrease in permeability could cause a decrease in salmonid growth rate or result in increased mortality of eggs and/or alevin.

Discussion

I found that gold dredging had a short-term impact on the numbers of benthic insects in the area dredged. In addition, dredging changes the stream substrate in ways that would be expected to have qualitative effects on the benthic community. The micro-distribution of benthic insects depends strongly on substrate particle size (Cummins and Lauf 1969). Before dredging, the substrate of Gold Creek contained a mixture of sizes dominated by cobble and gravel-size rocks. Rabeni and Minshall (1977) found that the optimum substrate size for benthic invertebrates was about 3 cm in diameter.

Dredging removes all particles smaller than the nozzle intake diameter (6.4 cm in this case). Material smaller than 6.4 cm is redeposited in large, unstable piles downstream. One would expect to find the dredged area recolonized by the relatively few species that prefer larger substrate. The remaining substrate is cleaned of any sediment seal. Hart (1978) found that the number of aquatic insect species per area was higher on small rocks (average surface area 95 cm^2) than large rocks (average surface area 602 cm^2). Therefore, dredging may decrease the number of species in the area. As the substrate gradually returns to normal, the benthic community would return to its previous condition. The length of time needed for recovery probably depends primarily on the amount of bedload movement in the particular stream.

Griffith and Andrews (1981) and Lewis (1962) found a low mortality rate for insects entrained through a suction dredge (1 and 7.4%, respectively). Many of these insects, however, may be unable to find suitable unoccupied habitat in the immediate downstream area and, in addition, insects set adrift in the daytime may suffer from predation. During this study, cutthroat trout were observed swimming in the area of the dredge outflow, feeding on dislodged invertebrates. Lewis (1962) observed similar activity with up to 12 squawfish (*Ptychocheilus* sp.) feeding on insects in the outflow.

Gold dredging did not have any impact on the quantity of benthic insects in the downstream area in this study. The critical factor determining the degree to which sediment impacts the stream benthos may be the amount of the sealing of undersides of cobble. Unimpacted cobble provides habitat for insects that cannot burrow or live under or on the cobble surface (Brusven and Prather 1974). As the quantity of sediment increases, more of the critical under-cobble microhabitat becomes unavailable, thus reducing the percentage of cobble harboring insects (McClelland and Brusven 1980).

The purpose of this study was to assess the impact of one small dredge operated for a relatively short period of time. The effects seemed to be small, very localized habitat modifications that had a minimal effect on the stream community. It should be noted, however, that a 6.4-cm dredge is one of the smallest made and Gold Creek had a small proportion of fines in the substrate, factors that would reduce the impact of dredging. Small modifications occuring over time and/or in a number of places within a watershed can often reach levels resulting in major biological and ecological change. The effects of sediment should always be considered in the context of the whole drainage network. Fine sediment exported from a large number of disturbed tributaries might overload downstream reaches with sediment and reduce water quality and productivity (Murphy et al. 1981). Suction dredges pose a very difficult management problem due to their portability. Managers should concentrate their control efforts on very sensitive areas and areas of intensive dredge activity.

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