AN ABSTRACT OF THE THESIS OF

Diana H. Perez for the degree of Master of Science in Fisheries Science presented on April 29, 1999. Title: Effects of a 4-inch Suction Dredge on Benthic Macroinvertebrates in Southwestern Oregon.

Redacted for Privacy

Abstract approved: ______________________

Gordon H. Reeves

Effects of 4-inch (10.16 cm) suction dredge mining on benthic macroinvertebrates in 3rd to 4th order streams were investigated in 1996 by evaluating four mining claim operations in Althouse Creek, Sucker Creek, and Taylor Creek in southwestern Oregon's Rogue River basin. The effects were site-specific. The study showed no significant ($p > 0.05$) differences between treatment and control areas in density and species diversity of benthic macroinvertebrates. However, mean taxa richness significantly ($p < 0.05$) increased thirty days following the end of the mining period. Collector-filterers were significantly ($p < 0.05$) lower in dredged areas thirty days after the mining season. Because of constraints in sampling design, sample sizes and relatively small treatment areas, the results from this study are tenuous at best. There were apparent inherent differences in species dominance among sites possibly a result of differences in stream size and riparian conditions. This further confounds results of this study.

Effects of a 4-inch Suction Dredge on Benthic Macroinvertebrates in Southwestern Oregon

by

Diana H. Perez

A Thesis Submitted
to
Oregon State University

In Partial Fulfillment of
the requirements for the
degree of

Master of Science

Presented April 29, 1999
Commencement June 2000

Master of Science thesis of Diana H. Perez presented on April 29, 1999

Approved:

Redacted for Privacy

Major Professor, representing Fisheries Science

Redacted for Privacy

Chair of Department of Fisheries and Wildlife

Redacted for Privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Redacted for Privacy

Diana H. Perez, Author

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF APPENDIX TABLES

Effects of a 4-inch Suction Dredge on Macroinvertebrates in Southwest Oregon

INTRODUCTION

Gold was the primary reason for the settlement and early growth of southwestern Oregon (Brooks and Ramp 1968), thus subjecting the Siskiyou Mountains of the Klamath Province to intensive levels of mining. In 1850, fortune hunters from California flooded into the Siskiyou Mountains of southwestern Oregon. Initial work was done primarily with pick, shovel, and pan. Streams were often diverted for short distances during work on stream beds. These operations were then followed by large-scale hydraulic mining with giant ditches and pipes. Water was conveyed around the hillsides in ditches (Brooks and Ramp 1968). Today, those ditches are among the remnants of this intensive mining history.

Hydraulic mining is no longer allowed, and for individuals or small groups of miners, suction dredging is one of the few economically feasible methods for mining gold. Suction dredges are used in streams and rivers to remove gravels overlying bedrock in order to access gold. Dredges use a high pressure water pump that creates suction in a flexible 5.08 to 30.48 cm (2 to 12-inch) diameter intake pipe. A mixture of streambed sediment and water is vacuumed into the intake pipe and passed over a sluice box mounted on a floating barge, trapping dense particles including gold (Fig. 1 and 2). The remaining material is discharged into the stream as “tailings” or “spoils”,which can form large piles especially where dredges have remained in one location (CA Dept. Fish & Game 1993). Substrate too large to pass through the intake pipe is moved by hand, and relatively large rocks are commonly piled into the stream.

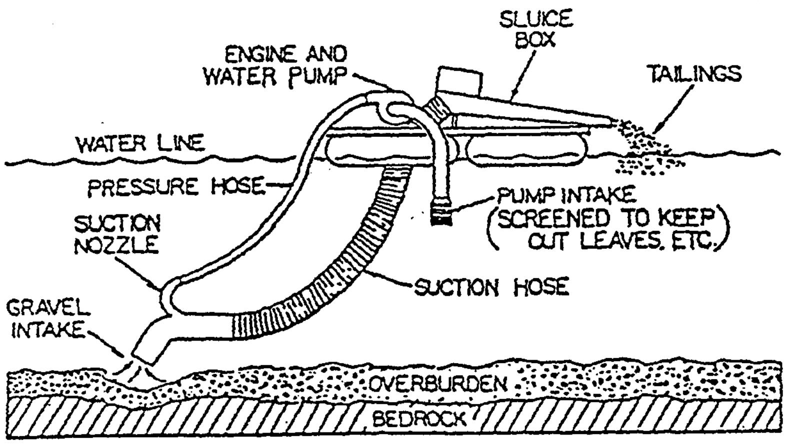

Figure 1. Diagram of a common suction dredge.

Figure 2. Photograph of a 4-inch suction dredge in operation, Siskiyou National Forest, Sucker Creek, OR, 1996.

Most of the mining that takes place in the Siskiyou Mountains today is more recreational than commercial in nature and consists of small suction-dredge operations (Mike Cooley, pers. comm., Siskiyou National Forest), usually 10.16 cm (4-inch) intake pipes. Current restrictions on in-stream suction dredging is limited to the period between June 15 to September 15 in Siskiyou National Forest. Many dredged streams now contain protected, endangered, threatened, and sensitive fish species and agency managers find themselves with insufficient information on the impacts of dredge mining on streams and biota in order to make necessary management decisions affecting fisheries.

Relatively few studies have examined the effects of suction dredging on river ecosystems in the western United States (Harvey and Lisle 1998). Limited research on the effects of suction-dredge mining indicate that dredging may affect aquatic insects, fish, and channel morphology. Direct mortality from passing through dredges is low (CA Dept. Fish & Game 1993, Griffith and Andrews 1981) but aquatic insects can be dislodged and removed from their substrates, discharged into the flowing water environment during dredging operations, thereby increasing mortality rates. Studies show increased predation by fish downstream from gold dredging sites when invertebrates fail to locate suitable habitat after being dislodged (Hassler et.al. 1986, Somer and Hassler 1992). The specific effect of dredging depends on substrate requirements and recolonization abilities of the insects, and perhaps on changes in biotic interactions resulting from changes in the physical environment (Harvey 1986). Juvenile and adult fish readily avoid active dredge sites while the early life history stages of fish are likely to be killed by entrainment (Griffith and Andrews 1981).

Research has shown that dredging may indirectly affect benthic macroinvertebrates by altering their habitat characteristics. The micro-distribution of benthic insects depends strongly on substrate particle size (Cummins and Lauff 1969) and the optimum substrate size for benthic invertebrates is about 3 cm in diameter (Rabeni and Minshall 1977). Macroinvertebrates may colonize small (1.0-3.5 cm) substrata primarily because these serve as a better food collecting device than do larger or smaller substrata (Rabeni and Minshall 1977). A Montana study indicated that the bulk of suspended sediment caused by dredging in a 3rd order stream was redeposited within 11 m downstream from the dredge (Thomas 1985). Dredge tailings may cover substrate containing benthic invertebrates, which traps them and results in death or lowered production. Hiding places for macroinvertebrates may be reduced because of increased sedimentation and consequently increased predation (Somer and Hassler 1992).

Instream productivity of macroinvertebrates may be affected until recolonization is completed. After 45 days required to recolonize tailings in a California stream, the number of insects in the tailings were not significantly different from the number in control areas (Harvey 1986). Almost all taxa found in undisturbed cobble areas were recent colonizers. Other research suggests it may take 1 to 5 months for benthic invertebrates to substantially recolonize dredged sites (Griffith and Andrews 1981, Hassler et. al. 1986).

The ability of aquatic organisms to survive entrainment varies among species and life history stage. Early life history stages of fishes are likely to be killed by entrainment in suction dredges whereas juvenile and adult fish are not. Griffith and Andrews (1981) found that un-eyed cutthroat trout (*Oncorhynchus clarki*) eggs from natural redds suffered 100% mortality after passage through a dredge along with the surrounding gravel. Mortality of eyed eggs ranged from 29% to 62% using cutthroat trout eggs from natural redds. Sac fry of hatchery rainbow trout (*O. mykiss*) suffered >80% mortality following entrainment, compared with 9% mortality for a control group (Griffith and Andrews 1981). Eggs and fry that did survive entrainment probably suffered higher mortality than those which remained in redds as a result of predation and conditions outside the redd environment. All adult fish that Griffith and Andrews (1981) entrained through a dredge survived.

In contrast to fish, benthic invertebrates passed through a 5-inch (12.7 cm) dredge experienced 7% mortality; invertebrates passed through a 2.5-inch (6.4 cm) dredge experienced less than 1% mortality (Griffith and Andrews 1981). This suggests that as dredge intake pipe increases so does mortality.

The most obvious downstream effects of dredging is increased turbidity and suspended sediment. Field measurements in turbidity and suspended sediment below suction dredges have focused on individual dredges. They fail to measure the effects from numerous dredges operating in a single watershed. In watersheds with numerous dredge operators and a history of hydraulic mining, turbidity and suspended sediment may be a concern. In Canyon Creek, California, turbidity was 0.5 NTU (nephelometric turbidity units) upstream, 20.5 NTU 4 m downstream and 3.4 NTU 49 m downstream of an active dredge (Hassler et. al. 1986). Suspended sediment concentrations at the same locations were 0, 244 mg/L and 11.5 mg/L, respectively. Studies by Thomas (1985) and Harvey (1986) indicate that on some streams where dredges operate at low density, suspended sediment is not a significant concern because effects are moderate, highly localized, and readily avoided by mobile organisms.

The purpose of this study is to identify effects of a 4-inch (10.16 cm) suction dredge on benthic macroinvertebrate communities in selected 3^{rd} to 4^{th} order streams in southern Oregon's Siskiyou Mountains. Specifically, I determined effects on species diversity, taxa richness, functional feeding groups, and habitat complexity of benthic macroinvertebrates. The effects of instream dredging activities on macroinvertebrates should be considered because: 1) macroinvertebrates are a dominant component of stream biodiversity; and 2) their role as prey for fish and other vertebrates is central in maintaining biologically diverse and productive aquatic and riparian communities. Altering macroinvertebrate communities may have direct and indirect negative impacts on fish.

STUDY AREA

The study was conducted during June through October of 1996 in Althouse, Sucker and Taylor Creeks on the east side of Siskiyou National Forest located in southwestern Oregon (Fig. 3). Althouse Creek is 300 ha in size and Sucker Creek 620 ha. Both creeks are tributaries to the East Fork of the Illinois River, which is a tributary to the Rogue River in southwestern Oregon. Elevation for Pergeson site is 536 m and 610 m for Blue Jay on Althouse Creek. Elevation for Taylor on Taylor Creek is 427 m and 768 m for Sucker on Sucker Creek. In June, discharge for Pergeson site is 8 m^3/s and 5 m^3/s for Blue Jay, 1.1 m^3/s for Taylor, and 9.1 m^3/s for Sucker. Taylor Creek watershed is 175 ha and is a tributary to Rogue River. The Rogue River valley floor is dominated by pasture, forest, and homesites. Climate is mediterranean, with cool wet winters and hot dry summers (USDA 1989). Althouse, Sucker, and Taylor Creeks have populations of chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), winter steelhead (*O. mykiss*), cutthroat trout, and resident rainbow trout.

Taylor Creek basin is underlain by northeast trending bands of metasediments and metavolcanic rock from the Galice formation (Orr 1992). Douglas fir (*Pseudotsuga menziessi*) is the primary conifer species and tanoak (*Lithocarpus densiflora*) and madrone (*Arbutus menziesii*) are dominant hardwoods.

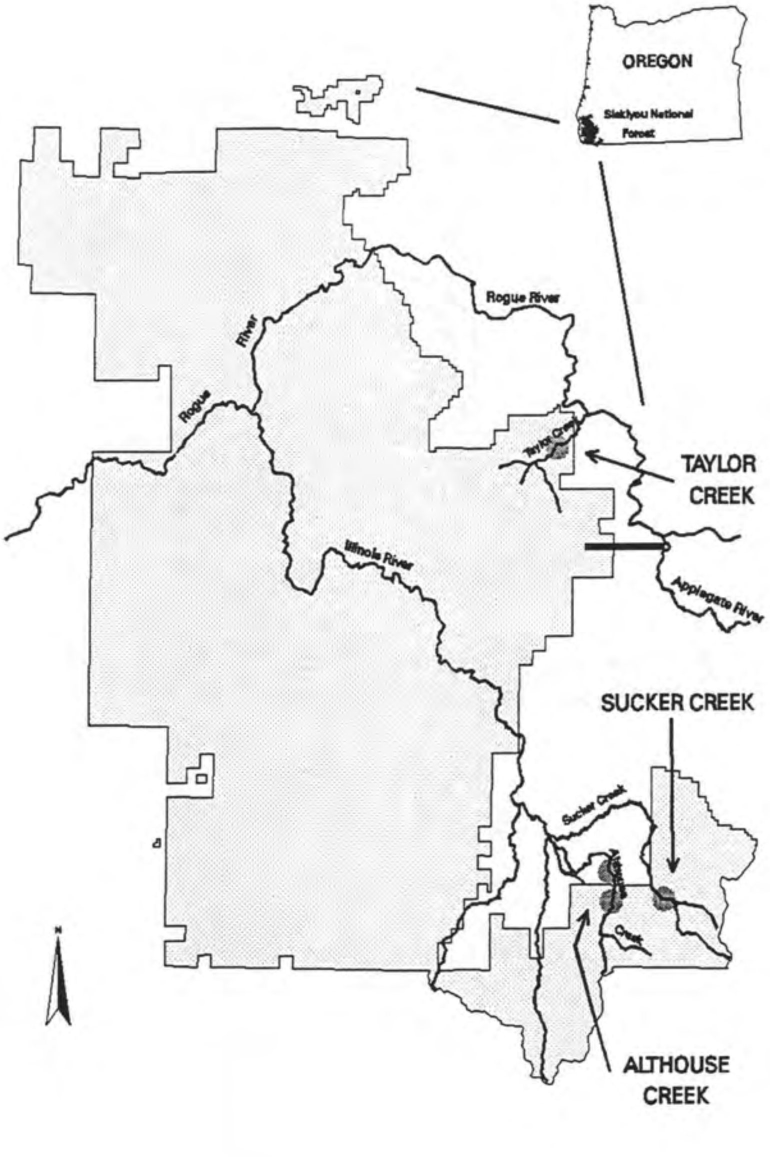

Figure 3. Location of study sites on Althouse, Sucker, and Taylor Creeks in Siskiyou National Forest, Josephine Co., Oregon, 1996.

Althouse and Sucker Creeks are dominated by metavolcanics from the Applegate group with common inclusions of serpentinite rock. Douglas-fir and tanoak are dominant conifer species while madrone, chinkapin (*Chrysolepis chrysophylla*), and blueblossom ceanothus (*Ceanothus thyrsiflorus*) are frequent understory species.

METHODS

Four active mining claims were selected non-randomly based on their similarities in gradient (2-3%), hydrologic regime, stream order, geology, dredge size used on the sites, and miner cooperation. The four claims are referred to as Blue Jay, Pergeson, Sucker, and Taylor. Blue Jay and Pergeson are located on Althouse Creek, Sucker on Sucker Creek, and Taylor on Taylor Creek. I am limited to making conclusions on only these 3 streams because of the non-statistical selection process.

Initially, the study design included 30 m long treatment and control reaches. Each claim owner identified an area ned for dredging and that area was designated as the treatment reach. However, treatment reaches were not entirely treated or dredged. Only the lower portion of each treatment reach was dredged during the study period, which meant that only 3 rather than 6 benthic macroinvertebrate samples were taken from the treatment reach (Fig. 4).

The upper portion of the original treatment section became the control reach. No samples were collected in the original control section after the first sampling period. Sampling periods were at beginning, end, and 1 month after the mining season (June 15 to Sept 15). Sampling was initiated within the first two weeks of the mining season. However, some level of activity occurred prior to the initial sampling in all sites.

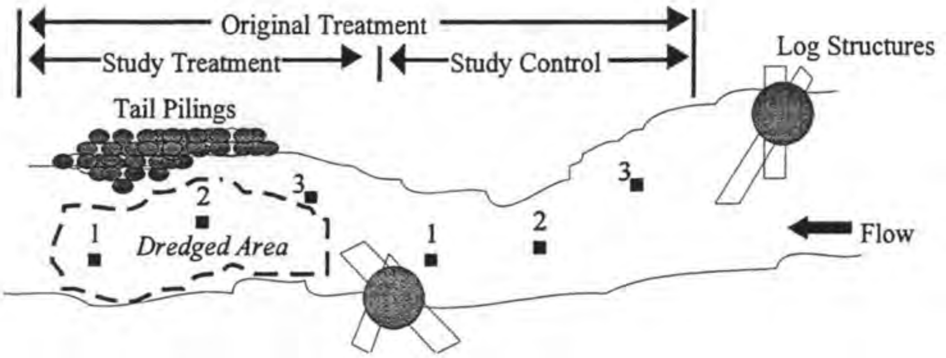

Figure 4. An example of proposed treatment and control reaches. Example is from Taylor Creek and shows location of macroinvertebrate samples and dredge area.

There was no comparison to pre-treatment levels because there was no sampling before the mining season or downstream from dredged areas. Pre-treatment samples were not taken because of availability of time before the mining season. In May 1996, I attended the Waldo Miner's Association meeting in Cave Junction, OR to recruit professional miners to participate in this study. Several people were interested but leery of the project. With the help of John Nolan, Forest Service Minerals Technician, I had to wait until the beginning of the mining season to visit some known active claims to obtain the cooperation of four miners.

Measurement of Habitat Conditions

Each reach was mapped to show the location of dredging and placement of dredge tailings. A 30 m fiberglass tape was used to measure distance. An engineer's depth rod was used to measure diameter and depth of dredged holes at the end of the mining season. Flows and discharge were measured with a pygmy meter for descriptive purposes only at the beginning of the mining season.

Field determination of stream substrate composition utilized the "Zig-Zag pebble count" procedure of Bevenger and King (1995). The starting point of the zig-zag procedure was at the edge of the bankfull flow channel at the downstream end of a reach. I then located a point 2 m upstream on the opposite bank. The line between the points established the transect to be sampled. At the starting point, I moved forward 2.1 m, reached over the toe of my wader with the forefinger without looking down, picked up the first pebble I touched and measured it's diameter in mm. If it was <64 mm, the actual size was recorded. If it was ≥ 64 mm, the sample was assigned to the appropriate Wentworth size class (Wentworth 1922), see Appendix I for substrate categories. After recording size, the pebble was discarded, 2.1 meters paced off on the transect, and another sample collected. At total of at least 100 substrate samples were taken throughout the zig-zag procedure. Substrate samples were taken from each reach at the beginning and 1 month after the mining season.

The Kolmogorov-Smirnov (K-S) two-sample test (Gibbons 1971, Zar 1974) was used to detect differences in the locations and shapes of substrate distributions. The K-S test is more powerful than the chi-square test when n or the frequency of expected values are small (Zar 1974). The maximum absolute difference between the observed cumulative distribution functions for beginning and 1 month after the end of mining season substrate samples was tested by the K-S test.

The mean proportion of fines < 8 mm in diameter for each reach was calculated and a t-test conducted to detect whether there was a difference between treatment and control in the proportion of fines after one mining season. Although opinions among fish biologists differ on the exact size of fine sediment, particles less than 6.3 mm in diameter are generally defined as fine sediment (King and Potyondy 1993). I used 8 mm as the cut off point for testing fines because 6.33 mm fell in the category of fine gravel (2 - 8 mm) and 8 mm closely approximates what is generally defined as fine sediment.

One to two cross-sections were placed within each reach to measure any changes in streambed configuration caused by dredging activity. Cross-sections were placed on riffle areas within each reach. A tag-line was placed perpendicular to flow across the stream, stretching to the bankfull width (Orth 1983). At each cross-section, maximum depth across the tag-line was found with an engineer's measurement rod. Flood-prone width was then calculated by multiplying maximum depth by 2 (U.S. Forest Service Pacific Northwest Region 1997). Another tag-line was stretched to the flood-prone width and marked with pins. Height measurements from the ground up to the flood-prone width tag-line was measured in metrics across the stream.

Macroinvertebrate Sampling

Three systematic point samples were taken from each reach at the beginning (mid June), end (mid Sept), and 1 month (late Oct) after the mining season. The reach was divided into 3 equal sections going across and down the study site; placement of samples varied inside a section according to Fig. 5. The sample in the most downstream section was located in the area within 1/3 of the distance from the bank.

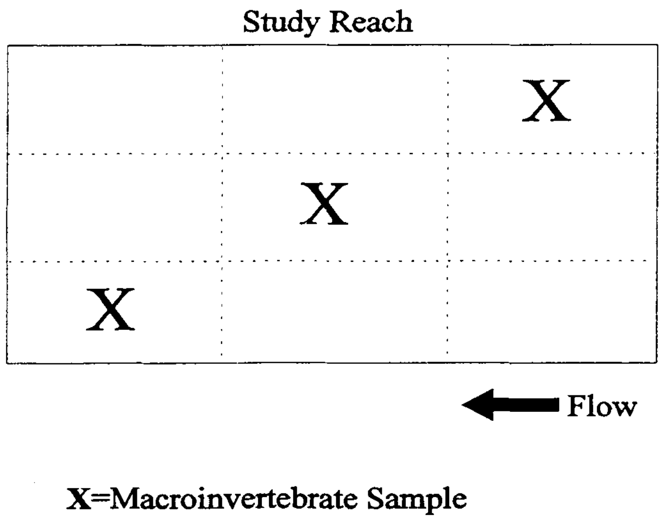

Figure 5. Illustration of macroinvertebrate sample locations within each study reach.

I used a modified Surber sampler with Nitex 280 micron mesh netting in a 0.09 m^2 frame to collect benthic aquatic insects. The procedure used followed Platts et. al. (1983). Each sampling location was approached from downstream and the collecting net placed into position as quickly as possible to reduce the potential for escape by macroinvertebrates. The bottom frame of the net was pressed tightly against the stream bottom, avoiding contamination from outside the sample area. Larger rocks were lifted, scrubbed at the mouth of the net opening, and removed from the sampler. The remaining sediment was thoroughly disturbed to a standard depth of 50 mm by repeatedly stirring and digging. The top of the net was tipped downstream until a 45° degree angle was formed with the streambed and the sampler was quickly removed from the water. The net was dipped several times in the stream to wash the contents to the bottom, using care not to submerge the net opening. The net and its seams were carefully checked for any adhering specimens.

Samples were sieved through a 500 micron mesh and preserved in whirl packs containing 95% ethanol. Samples for each reach were pooled and total organisms counted. Specimens were identified to the taxonomic level of genus where possible (tribe for Chironomidae) and assigned to functional feeding groups as described by Cummins and Merritt (1996). Density was calculated as number of insects per m^2.

Species diversity was measured using the Shannon-Weiner Index (Magurran 1988, Platts et. al. 1983). This index was used because it accounts for relative abundances of the different taxa, it is relatively independent of sample size, and it produces dimensionless values which are independent of the unit of measurement (Platts et. al. 1983). Although Shannon's index takes into account the evenness of the abundances of species (Magurran 1988), a separate additional measure of evenness (e') is calculated by taking the ratio of observed diversity to maximum diversity. This evenness measure is constrained between 0 and 1.0 with 1.0 indicating all species are equally abundant (Magurran 1988).

Change in relative abundance of the dominant taxa was tabulated and the means and variances determined for each site at each sampling period. Percent dominant taxa is the percent contribution of the most numerous taxa present. It's assumed in a stressed benthic community one or a few tolerant taxa will dominate the community. An ANOVA with a Bonferroni adjustment of =0.0167 was conducted to test the means of density, taxa richness, diversity, and functional feeding group abundance for each sampling period. The functional feeding group method of analysis establishes linkages to basic aquatic food resource categories (CPOM, FPOM, periphyton, and prey) (Cummins and Merritt 1996). The Bonferroni correction factor is based on Student's t statistic and adjusts the observed significance level for the fact that multiple comparisons are made (Norman & Streiner 1994), in this case June to Sept, Sept to Oct, and June to Oct. I set a more stringent alpha based on my number of comparisons, recognizing that the probability of making a Type I error on any one comparison is 0.05.

A Rank-sum test was performed to detect significant differences between treatment and control at each sampling period for density, taxa richness, diversity, and functional feeding groups. The Rank-sum test is a resistant alternative to two sample t-test (Ramsey and Schafer 1994).

RESULTS

Amount of Area Disturbed

The smallest treatment reach area of the study sites was Taylor (57.2 m^2) (Table 1). However, it had the highest percent area dredged (31.2%). The Pergeson site had the highest treatment reach area (118.87 m^2), the greatest volume removed from the resulting dredged pools (19.37 m^3) but only about half of the fraction of area dredged as was dredged on Taylor (Table 2). Blue Jay and Sucker were equivalent in area but varied in percent area dredged and size/volume of dredge pool. Sucker was the only site that had two dredged pools.

Table 1. Dimensions of dredged pools for each claim one month after the mining season on Siskiyou National Forest, OR, 1996.

	Study Site			
	Watershed size = 175 ha	**Watershed size = 620 ha**	**Watershed size = 300 ha**	
Dimensions	Taylor	Sucker	Pergeson	Blue
Length	7.47 m (24.5 ft)	3.35 m (11 ft) 3.05 m (10 ft)	6.1 m (20 ft)	3.66 m (12 ft)
Width	2.44 m (8 ft)	1.83 m (6 ft) 2.44 m (8 ft)	2.74 m (9 ft)	1.83 m (6 ft)
Depth	.85 m (2.8 ft)	1.16 m (3.8 ft) 0.73 m (2.4 ft)	1.16 m (3.8 ft)	0.30 m (1 ft)

Table 2. Area of 15 m treatment reach, percent area of treatment reach dredged, and volume of dredged pool.

	Treatment Area (m^2)	% Area Dredged	Pool Volume (m^3)
Blue Jay	77.73	8.6	2.04
Pergeson	118.87	14.1	19.37
Sucker	77.73	17.4	12.54
Taylor	57.2	31.2	15.23
Mean	*82.88*	*17.83*	*12.3*

Pools created by the suction dredges were not greater than 1.16 m deep and averaged 2.26 m in width. Dredge pool depth averaged 0.84 and the dredged area averaged 13.7 m^2 (17.8% of treatment area). Amount of material removed varied, from 2.04 to 19.37 m^3.

Substrate Distribution

Substrate within the dredge hole was altered to either bedrock, large cobbles, or small boulders. Originally the area to be dredged consisted of small cobble over large cobble, with the exception of Taylor which consisted of small cobble and large gravel. Dredge tailings were located below the dredge holes. They consisted of material too large to pass through a 10.2 cm diameter nozzle.

Distribution of substrate showed a shift from beginning of the mining season to 1 month after the mining season (Fig. 6).

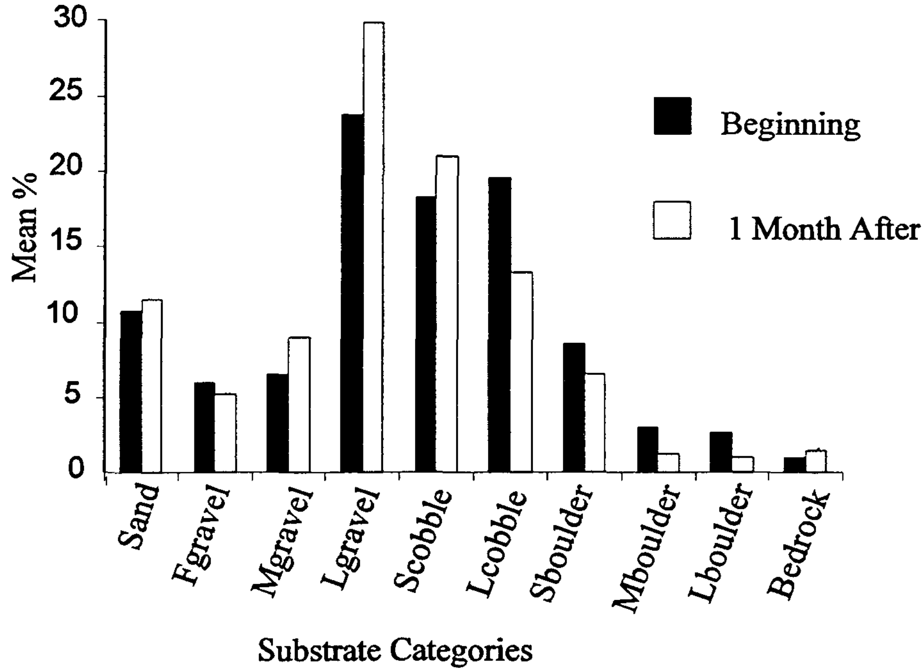

Figure 6. Substrate distribution within initial treatment reaches at the beginning and one month after the mining season.

These results cover the full original length of the initial treatment reach which was 30 m long. Substrate sampling had taken place before the resulting dredge pattern which was concentrated in the lower half of the initial reach length. Large gravel, small cobble, and large cobble dominated throughout the study period. The proportion of large gravel and small cobble increased one month after the mining season, whereas large cobble decreased. However, the two-sample Kolmogorov-

Smirnov test on substrate distribution for beginning and one month after the mining season was not significant ($p > 0.05$). In addition, there was no significant difference ($p>0.05$; one-tailed *t*-test) between control and treatment areas in the proportion of fines (< 8 mm) one month after the mining season.

Cross-sections

Only the first cross-section placed at the downstream end of Taylor treatment reach captured a change in stream bottom after one mining season. Dredging activity resulted in a 0.48 m depth increase compared to the area above the dredging activity on Taylor treatment reach (Fig. 7). This particular dredged area, as well as the other dredged areas, immediately filled up with substrate following the winter spate.

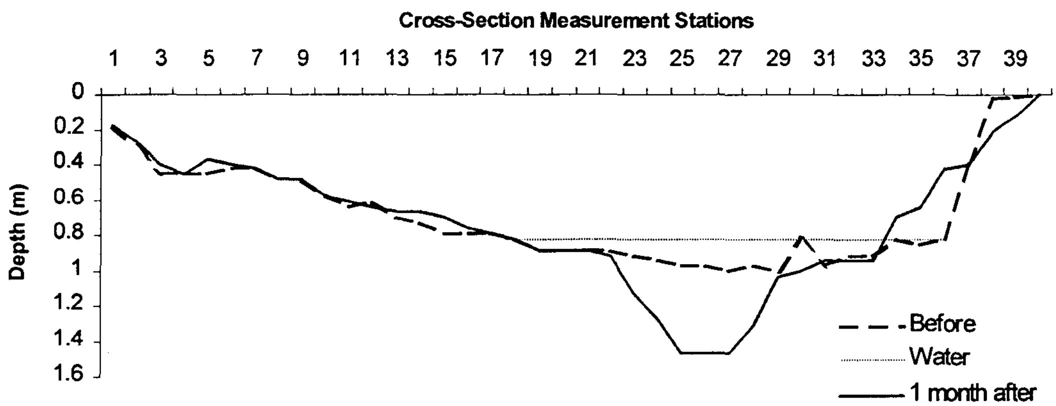

Figure 7. Cross-section on Taylor study treatment area, Taylor Creek, Josephine Co., Siskiyou National Forest, OR, 1996.

Macroinvertebrate Density

There were no statistical differences ($p > 0.05$) in the mean density of macroinvertebrates between control and treatment groups in any sampling period (Fig. 8, Table 3).

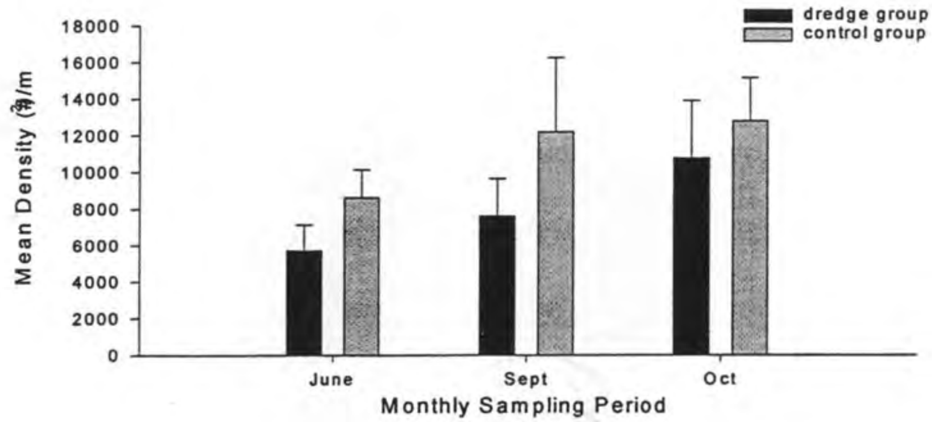

Figure 8. Mean densities (+SE) of benthic macroinvertebrates in treatment and control groups at the beginning (June), at the end (Sept), and one month (Oct) following the 1996 mining season on Siskiyou National Forest, OR.

Table 3. Diversity indices and percent functional group composition for treatment and control areas, Josephine Co., Siskiyou National Forest, OR, 1996. S = Taxa richness; e' = equitability index; H' = Shannon-Weiner diversity index. June=Beginning of mining season, Sept=End of mining season, Oct=one month after mining season.

Time	*Study Area*	*(#/m²) Density*	*S*	*e'*	*H'*	Percent (does not include values for "unknown" category)				
						Predators	Shredders	Scrapers	Gatherers	Filterers
					Blue Jay Claim					
June	treatment	3983.8	39	.692	2.54	8.11	4.86	11.62	63.51	7.84
	control	10723.5	54	.688	2.74	13.66	4.22	25.30	44.37	8.23
Sept	treatment	10637	39	.610	2.24	5.97	52.62	7.19	11.04	21.86
	control	8462.5	41	.662	2.46	9.16	44.91	7.13	25.06	8.02
Oct	treatment	20132.2	59	.571	2.33	5.83	60.10	8.82	19.36	2.99
	control	19723.4	59	.595	2.43	5.02	52.13	7.04	25.60	8.79
					Pergeson Claim					
June	treatment	2767.6	45	.864	3.29	29.96	11.28	12.06	28.01	8.95
	control	6912.6	57	.734	2.97	38.63	10.75	6.54	25.07	13.24
Sept	treatment	11465.8	41	.654	2.43	10.05	40.75	1.5	18.88	25.82
	control	24373.5	47	.501	1.93	6.45	60.47	0.93	13.56	16.92

Table 3. (Continued)

Time	Study Area	(#/m²) Density	*S*	*e'*	*H'*	Percent (does not include values for "unknown" category)				
						Predators	Shredders	Scrapers	Gatherers	Filterers
					Pergeson Claim (Continued)					
Oct	treatment	8128.8	43	.588	2.21	5.43	61.59	1.86	21.45	8.74
	control	10152.5	43	.577	2.17	7.21	63.73	2.86	11.98	12.72
					Sucker Claim					
June	treatment	8882.2	44	.642	2.43	8.49	1.82	16.36	64.72	7.15
	control	11605.5	54	.703	2.80	8.63	5.66	23.19	55.10	4.73
Sept	treatment	3370	26	.487	1.59	3.83	2.55	5.12	21.09	66.77
	control	7289.1	39	.724	2.65	7.39	12.26	33.37	29.54	16.84
Oct	treatment	7580.2	50	.705	2.76	6.40	2.84	17.33	63.49	9.09
	control	9646.9	39	.694	2.54	3.91	2.90	20.76	63.05	8.93

Table 3. (Continued)

Time	*Study Area*	*(#/m²) Density*	*S*	*e'*	*H'*	Percent (does not include values for "unknown" category)				
						Predators	Shredders	Scrapers	Gatherers	Filterers
					Taylor Claim					
June	treatment	7224.4	45	.798	3.04	28.32	1.34	21.61	29.06	9.69
	control	5178.6	45	.814	3.10	21.62	1.46	22.45	36.80	6.86
Sept	treatment	4941.8	42	.763	2.85	19.61	8.28	17.43	16.55	35.51
	control	8558.9	51	.751	2.95	14.09	17.86	15.35	20.25	29.68
Oct	treatment	7160.1	49	.773	3.01	15.95	4.36	33.98	38.94	4.21
	control	11508.9	48	.798	3.09	18.43	12.72	26.11	31.25	9.07

Shannon-Weiner (H′) and Equitability (e′)

There were no statistical differences ($p>0.05$) in mean Shannon-Weiner or equitability indices (evenness) between the treatment and control areas at any sampling date (Fig. 9A and 9B, respectively). There is suggestive but inconclusive evidence that mean taxa richness in treatment areas were significantly lower than the control areas at the beginning of the mining season (43.25 and 52.5, respectively) (one sided p-value = 0.06; from a Rank-sum test) (Fig. 9C). Mean taxa richness in treatment areas increased from 37.0 at the end of the mining season to 50.25 one month after the season, however, the increase was not significant (one sided p-value 0.03 > Bonferroni adjustment p-value 0.01).

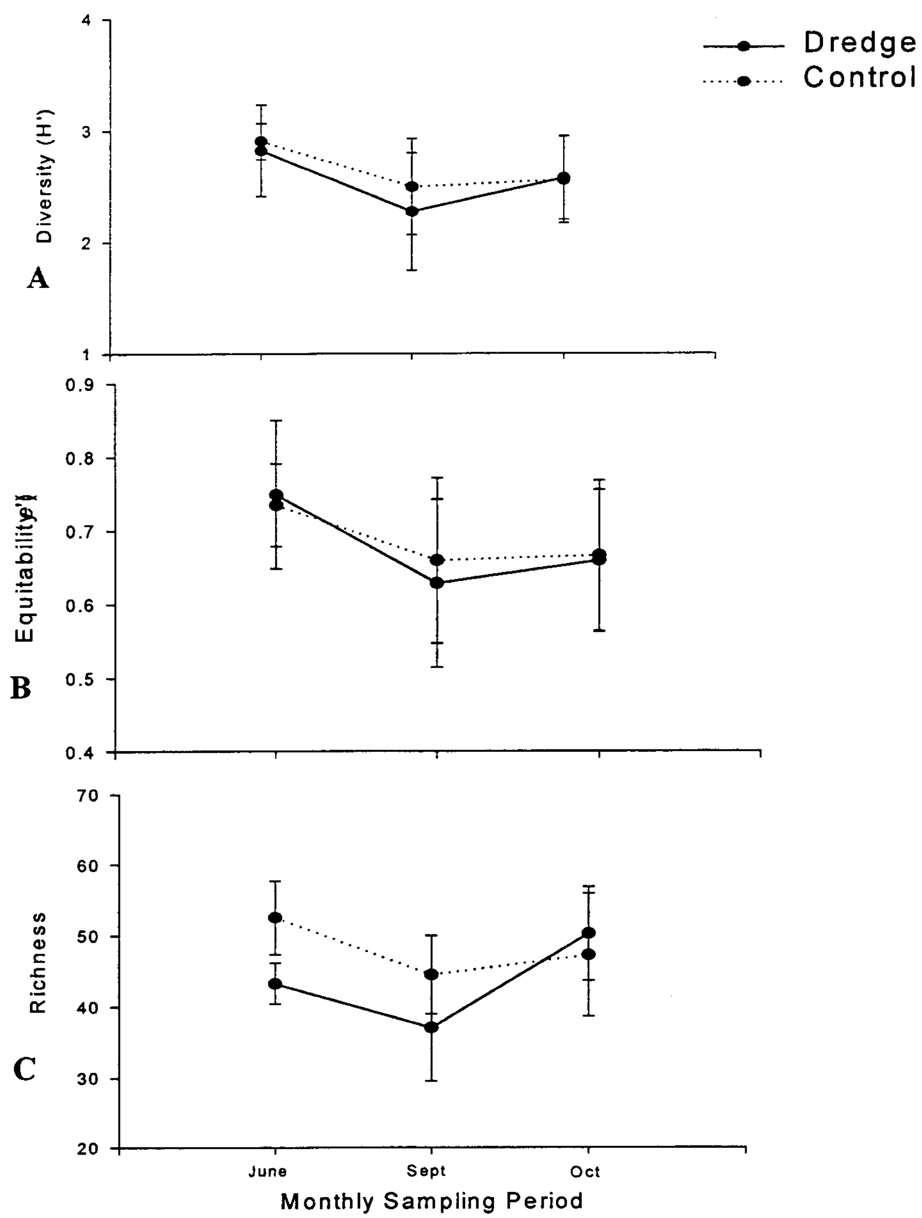

Figure 9. Means levels (+SE) of macroinvertebrate diversity (A), equitability (B), and taxa richness (C) at the beginning, end, and one month after the mining season on Siskiyou National Forest, OR, 1996.

Functional Feeding Groups

In the treatment areas, mean abundance of collector-filterers significantly increased from the beginning to end of the mining season (473.78 to 2322.68/m^2, respectively) and decreased to 575.98/m^2 one month after the season (analysis of variance F-test p-value 0.0004 < Bonferroni adjustment p-value 0.017) (Fig. 10A). There was no significant difference ($p>0.05$) between control and treatment areas in mean abundance of collector-filterers at any sampling period. There are no statistical differences ($p>0.05$) in the mean abundances of collector-gatherers, predators, scrapers, and shredders between the control and treatment areas at any sampling date or throughout the sampling period (Fig. 10B-E).

The pattern between non-collector filterers (collector-gatherers, predators, and scrapers) and collector-filterers is of particular interest. At the end of the mining season the pattern of collector-filterers reflects a large increase while collector-gatherers, predators, scrapers, and shredders show the opposite. Taxa that contributed to the increase in collector-filterers at the end of the mining season were Simuliids and Tanytarsini.

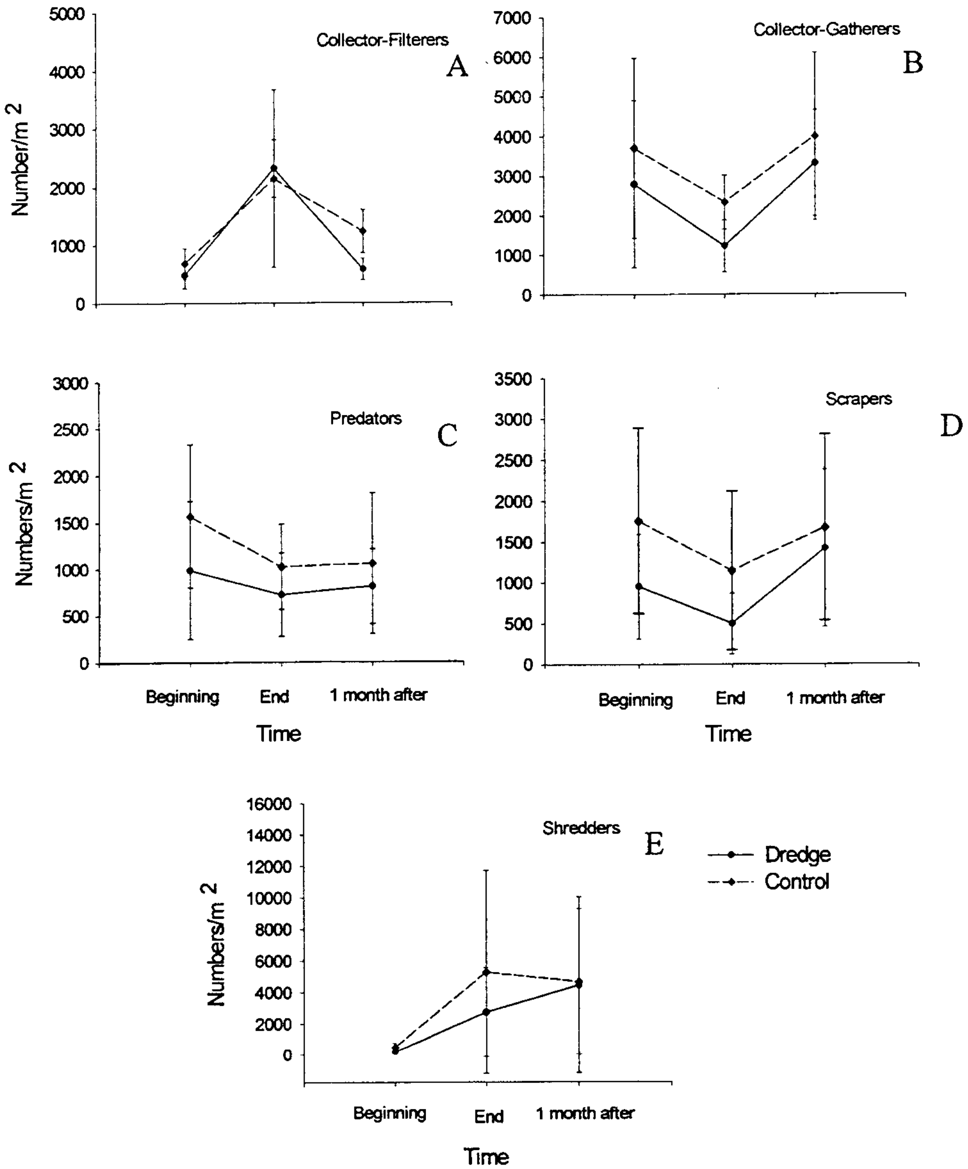

Figure 10. Mean densities (+SE) of collector-filterers (A), collector-gatherers (B), predators (C), scrapers (D), and shredders (E) for treatment and control areas at the beginning, end, and one month after the 1996 mining season, Siskiyou National Forest, OR, 1996.

Community Composition

The average proportion of Ephemeroptera and Trichoptera in both treatment and control areas compared to the beginning of the mining season were not significantly different ($p<0.05$) (Fig. 11).

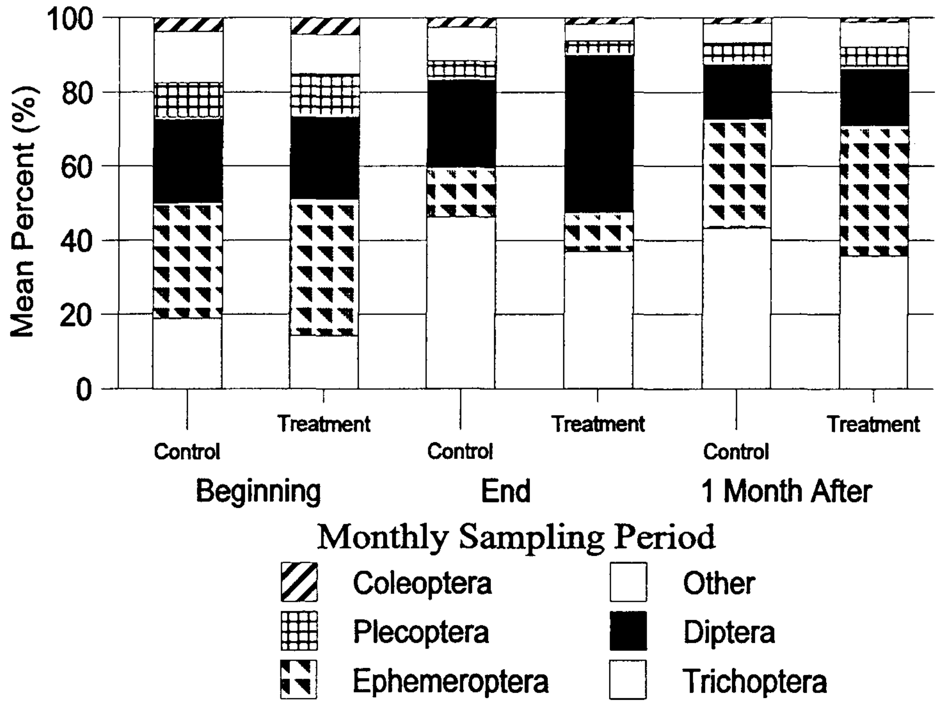

Figure 11. Mean proportion of orders of macroinvertebrates in treatment and control areas throughout the sampling period (Beginning=June, End=Sept, one Month After=Oct).

There was an apparent difference in species dominance at Taylor Creek compared to Sucker and Althouse Creeks. At the beginning of the mining season *Calineuria* spp. and *Drunella* spp. were the dominant organisms in the Taylor treatment site whereas the Ephemeropteran *Baetis* spp. dominated the other treatment sites and 2 control sites (Table 4).

Table 4. Proportions of dominant taxa in treatment and control areas, 1996.

		BEGINNING (JUNE)		
STUDY SITE	**TREATMENT**	**%**	**CONTROL**	**%**
Blue Jay	*Baetis* spp.	28.1	*Baetis* spp.	22.4
	Orthocladiinae	21.6	*Glossosoma* spp.	21.3
Pergeson	*Baetis* spp.	11.7	Acari	19.9
	Acari	11.3	*Baetis* spp.	17.6
Sucker	*Baetis* spp.	38.6	Orthocladiinae	23.9
	Orthocladiinae	9.5	*Baetis* spp.	17.9
Taylor	*Calineuria* spp.	9.5	*Baetis* spp.	13.7
	Drunella spp.	9.2	*Glossosoma* spp.	10.0
	MEAN DENSITY	57145/m^2	MEAN DENSITY	8605/m^2
		END (SEPTEMBER)		
Blue Jay	*Micrasema* spp.	44.0	*Micrasema* spp.	39.9
	Simuliidae	12.6	*Rhithrogena* spp.	9.5
Pergeson	*Lepidostoma* spp.	25.7	*Lepidostoma* spp.	51.8
	Tanytarsini	17.4	Tanytarsini	13.9
Sucker	Simuliidae	63.9	*Glossosoma* spp.	27.6
	Epeorus spp.	7.7	Tanytarsini	10.8
Taylor	Tanytarsini	26.1	Tanytarsini	27.9
	Glossosoma spp.	12.2	*Micrasema* spp.	9.6
	MEAN DENSITY	7604/m^2	MEAN DENSITY	12171/m^2

Table 4. (Continued)

	1 MONTH AFTER (OCTOBER)			
STUDY SITE	TREATMENT	%	CONTROL	%
Blue Jay	*Micrasema* spp.	47.8	*Micrasema* spp.	41.5
	Lepidostoma spp.	10.3	Orthocladiinae	8.5
Pergeson	*Lepidostoma* spp.	43.4	*Micrasema* spp.	32.8
	Micrasema spp.	14.4	*Lepidostoma* spp.	29.4
Sucker	*Baetis* spp.	27.6	*Baetis* spp.	21.1
	Ephemerella spp.	11.9	*Ephemerella* spp.	14.3
Taylor	Heptageniidae spp.	22.6	Heptageniidae spp.	16.3
	Oligochaeta	11.7	*Micrasema* spp.	9.6
	MEAN DENSITY	10750/m^2	MEAN DENSITY	12758/m^2

Trichopteran *Glossosoma* spp. was dominant only in control areas at Blue Jay and Taylor at the beginning of the mining season. At the end of the mining season *Glossosoma* spp. dominated in the Taylor treatment and Sucker control areas. Trichopterans *Lepidostoma* spp. and *Micrasema* spp. dominated Blue Jay and Pergeson, which are both located on Althouse Creek, at the end and one month after the mining season.

The proportion of Dipterans in the treatment area nearly doubled from 23.7 to 42.3% at the end of the mining season, but there was no significant difference ($p<0.05$). Dominant organisms in the order Diptera that contributed to the increase in proportion at the end of the mining season were Simuliidae and Tanytarsini.

Chironomids in Orthocladiinae dominated at the beginning of the mining season in both treatment and control areas at Sucker Creek, while Tanytarsini dominated at the end of the mining season in Taylor Creek, Pergeson site on Althouse Creek, and Sucker Creek's control area.

The similarities in taxa between sites at the beginning of the mining season were primarily based on *Baetis* spp. dominance. At the end of the mining season, taxa were more different from each other with respect to dominance. One month after the mining season taxa at Pergeson and Blue Jay on Althouse Creeks were very similar, while Sucker and Taylor Creeks were distinctive as separate streams.

The statistical power of my work (α=0.05) based on my sample size (N) and means for the different macroinvertebrate variables in June, September, and October varied from 0.05 to 0.70 (Table 5).

Table 5. Statistical power of this study and future sample sizes (N) required for different macroinvertebrate variables in order to detect significant differences between treatment and control areas ($\alpha = 0.01$, $\alpha = 0.05$).

Variable	Difference in Means ($\mu_0 - \mu_1$)	Sample size required $\beta = 0.20$, Power = 0.80		Statistical Power of this study based on my results N=4, α=0.05
		α= 0.01	α= 0.05	
JUNE (Beginning of Mining Season)				
Density(LOG)	0.4600	44	23	0.1719
Taxa Richness	9.25	9	5	0.6967

Table 5. (Continued)

Predators(LOG)	0.5906	47	25	0.1445
Scrapers(LOG)	0.5982	80	43	0.1099
Collector-Gatherers(LOG)	0.36145	180	96	0.0746
Collector-Filterers(LOG)	0.38073	69	36	0.1217
September (End of the Mining Season)				
Density(LOG)	0.46154	67	36	0.1240
Taxa Richness	7.5	33	18	0.2234
Predators(LOG)	0.5392	90	48	0.0941
Scrapers(LOG)	0.77583	66	35	0.1252
Collector-Gatherers(LOG)	0.72763	14	7	0.5016
Collector-Filterers(LOG)	0.28417	179	95	0.0655
October (1 Month After the Mining Season)				
Density(LOG)	0.22938	140	74	0.0822
Taxa Richness	3.0	280	148	0.0654
Predators(LOG)	0.17583	548	290	0.0577
Scrapers(LOG)	0.26058	825	436	0.0551
Collector-Gatherers(LOG)	0.09687	1619	856	0.0521
Collector-Filterers(LOG)	0.77985	9	5	0.7340

This means my chances of concluding there was a difference between treatment and control sample means given my sample size (N=4) varied from 5 to 70%, if there was a difference.

A β of 0.20 means there is a 20% chance of concluding that no difference exists when in fact it does (making a Type II Error), and an 80% chance of concluding there is a difference when in fact there is one (Power=1-β). Statistical power increases when sample size increases. When the significance level decreases from 0.05 to 0.01, sample sizes required to detect a significant difference between treatment and control is nearly doubled.

In this study for example, I would need at least 23 samples (N) in June to detect a significant difference at the 0.05 level for density, 36 in September, and 74 in October. Whereas, for taxa richness I would need at least 5 samples in June, 18 in September, and 148 in October.

The decrease in size of treatment area from 30 to 15 m, decreased the number of macroinvertebrate samples resulting in a small sample size with high variability. Based on variances and differences in means, Table 5 expresses the statistical power of this study and sample sizes needed in the future to detect significant differences between treatment and control areas at alpha levels 0.01 and 0.05, with a power of 80%.

DISCUSSION

This study found no differences in measures of macroinvertebrate density and diversity and substrate composition between sites with and without dredge mining. It appears that the recovery of macroinvertebrates in this study was relatively quick. There were no detectable differences in density between treatment and control areas although numbers of macroinvertebrates increased throughout the study period. There were local reductions in benthic invertebrate abundances and proportions in each of my study sites, but reductions were not significant. The effects of dredging on aquatic insects may have changed taxa richness at the beginning of the mining season when some level of activity had already taken place. However, at the end of the mining season richness was not statistically different but lower in both treatment and control. Neither Thomas (1985) nor Harvey (1986) were able to detect differences in the abundance of invertebrates 10 m or more downstream of dredged areas versus abundances at upstream control sites. Both found that the immediate impacts of dredging on insect abundance was limited to the area dredged.

Other studies found direct and indirect effects of suction dredge mining, such as sedimentation and changes in species diversity of macroinvertebrates (Griffith and Andrews 1981, Pearson and Jones 1975, Somer and Hassler 1992, Thomas 1985). Somer and Hassler (1992) found differences in macroinvertebrate assemblage composition but not overall abundance when they measured colonization of artificial substrates upstream and downstream of active dredges. Complete embeddedness of larger substrate by fine sediment reduces benthic invertebrate abundance and species richness. However, abundance and species composition of benthic invertebrates can be restored on tailings 4 - 6 weeks after dredging (Griffith and Andrews 1981, Thomas 1985, Harvey 1986).

At the beginning of the mining season following two weeks of dredging, taxa richness in the treatment areas was lower than in the control areas. This may result from the immediate dislodgement of existing macroinvertebrates upon dredging. One month after the mining season, taxa richness increased probably because of available habitat (larger substrate sizes). Thomas (1985) found that the number of insects in a dredged area increased one month after dredging indicating that most aquatic insects find dredged areas to be suitable habitat.

In this study, the proportion of orders represented in treatment and control areas were more similar at the beginning and one month after the mining season, than at the end. The large percentage of Dipterans at the end of the mining season is reflective of the abundance in collector-filterers, mainly Simuliidae by 63.9%. This may be because collector-filterers require exposed cobbles or boulders for net construction (Ward 1992). These were not abundant one month after the mining season because of the settling of smaller particles during low-flow. There were more clean rock surfaces at the end of the mining season that provided suitable areas for attachment by collector-filterers, such as Simuliidae and Tanytarsini.

When dredgers remove substrate too big to pass through the suction intake pipe, the rock surfaces are wiped clean in the process and new rock surface is exposed within the dredged hole. In northern California, filterers decreased below dredging sites and filled samplers that were free of siltation, resulting in gatherers and filterers being significantly higher below than above dredges (Somer and Hassler 1992).

In this study, the dominant taxon at dredged sites at the beginning of the mining season was *Baetis* spp. Recolonization by *Baetis* spp. (Ephemeropteran) may have taken place rapidly within the dredged area at the beginning of the mining season. One month after mining, the Sucker Creek study reach was dominated by *Baetis* spp. Somer and Hassler's (1992) results indicated that the gatherer *Baetis* spp. showed a positive relation with sediment. However, Harvey (1986) found that the abundance of *Baetis* spp. after dredging in the North Fork of the American River was not altered. Results of those studies are likely due to the tolerance of *Baetis* spp. to silty substrates and their rapid recolonization abilities (Brittain 1982).

Recolonization of dredged sites by macroinvertebrates appeared to be relatively rapid. Insect drift is the major means of colonizing both natural and altered streams (Ward 1992). Drift is influenced by the available insect species, as well as substrate type, current, velocity, and other stream characteristics (Luedtke and Brusven 1976). Benthic invertebrates can rapidly recolonize small patches of new or disturbed substrate in streams (Mackay 1992). Ephemeropterans are often among the first macroinvertebrates to colonize virgin habitat because of their winged adult stage and a propensity for drift as nymphs (Brittain 1982). A freshly dredged pool is virgin habitat for Ephemeropterans, which may be why *Baetis* spp. was the dominant taxon at the beginning of the mining season.

Most intentional drift is confined to periods of darkness and the amount of intentional drift during the day is probably small compared with accidental dislodgment and drift associated with changes in life cycle events (Rader 1997). Dredging takes place during the middle of the day and may increase the rate of drift. There may be a constant level of recolonization every night during the mining season until total recolonization can take place once the mining season is over.

Although changes in substrate distribution were not statistically significant, observed changes may have been large enough to allow a macroinvertebrate response. There was an increase in substrate size within the category of large gravel (16 - 64 mm) and small cobble (64 - 128 mm) one month after the end of the mining season. This may have facilitated recolonization of dredged areas primarily by collectors because of potential increases in available habitat with the increase in large gravel and small cobble.

Taylor Creek had a smaller average substrate size at the beginning of the mining season than the other sites. However, fines were not abundant enough to limit the presence of *Calineuria* and *Drunella*. The presence of the predaceous stonefly *Calineuria* in the Taylor Creek treatment area could be the result of greater availability of and accessibility to prey organisms on small substrate, such as *Baetis* spp. and chironomids. Harvey (1982) found increased numbers of *Calineuria* spp. below dredging sites and suggested that the fine sediments from dredging may cover hiding places and render prey more accessible to predators.

Changes in Taylor Creek as a result of dredging may have altered habitat suitability for *Drunella* spp. *Drunella* spp. are generally intolerant of fine sediment, require high oxygen tensions, and are sensitive to high winter scour (Wisseman 1996). *Drunella* taxa is also a large, slow developing, non-drifting mayfly that is attracted to clean surfaces.

One explanation for the difference in taxa found in Taylor Creek treatment area compared to the other sites is the condition of the watershed and the level of dredging activity that had taken place at the time sampling was taken. Sucker and Althouse Creeks have a much higher density of dredging activity than Taylor and a larger amount of stream side slides.

Even though at the end of the mining season Taylor Creek had the largest percent area dredged (31.2%), the presence of *Glossosoma* spp. was a good indication of habitat quality at the sampling location. Glossosomatids are relatively intolerant scrapers that are typical components of montane streams and rivers (Wisseman 1996). They can rapidly build numbers over the warm season and are quite capable of taking advantage of clean substrate with plenty of diatoms. They also do poorly where fine sediment smothers rock surfaces or filamentous algae leaves no exposed rock surfaces.

The increase of Trichopterans (*Lepidostoma* spp., *Micrasema* spp., and *Glossosoma* spp.) for all sites at the end and one month after the mining season suggests that colonization results more likely from colonization dynamics than dredging impacts. Both *Lepidostoma* spp. and *Micrasema* spp. can move into new areas rapidly. They tend to aggregate in areas where there is a good amount of detrital material. The majority of *Lepidostoma* spp. and *Micrasema* spp. found in samples were early instars. The small caddisfly taxa, panel-case *Lepidostoma* spp., will often be found in streams where all other caddis shredders have disappeared (Wisseman 1996), or where there is a good amount of detrital material. This is a faster growing taxa that can complete its life cycle by mid-fall, before winter storms push most of the course particulate organic matter out of streams. Peak numbers are in September (end of the mining season). The scraper *Micrasema* spp. may have hatched above the dredged area and moved downstream where rock surfaces had fresh diatom growth or there was plenty of entrained detritus due to the larger exposed rock surfaces. *Glossosoma* spp. were dominant in Blue Jay and Taylor control areas at the beginning of the mining season, and in the Taylor treatment area at the end of the mining season. The large proportion of Heptageniids and *Epeorus* spp. found in the study samples for Taylor Creek were early instars, which may be more a seasonal response rather than a dredging impact.

Sucker Creek, like Taylor, had different taxa at the end of the mining season and one month after. At the end of the mining season Simuliidae and *Epeorus* spp. dominated the treatment area, and *Glossosoma* spp. and Tanytarsini the control. Simuliidae are a normal component of almost all montane streams. The large proportion of Simuliidae at the end of the mining season may have been facilitated by the exposed larger substrate in the Sucker treatment area. Generally, high densities of these larvae are usually associated with disturbed or enriched streams and tend to aggregate new exposed areas (Wisseman 1996).

Tailings from the dredging activity at each study site were displaced by the 1997 winter flows, and dredge holes were not visible by the beginning of the next mining season. Dredged holes are usually short-lived because they tend to be filled with substrate during high flows and can also be filled by sediments mobilized by upstream dredging (Thomas 1985, Harvey 1986).

Dredging in areas that have an extensive mining history may impede recovery of already damaged areas. Repeated disturbance of already disturbed areas does not allow a system to recover. Althouse Creek has been channelized approximately 3 m down within the Pergeson mining claim as evidenced by streambank height (pers. obs.). Early mining activities damaged stream and riparian habitat. They removed large wood from the stream channel, removed trees from riparian areas, and excavated the floodplain (U.S. Forest Service 1996). The Sucker Creek treatment reach still shows scars of past hydraulic mining in the riparian area and holds gravel bars twice the size that it did 20 years ago (U.S. Forest Service 1995). Today, these gravel bars function as terraces and have reduced the floodplain along the stream. Much of the riparian vegetation along Sucker Creek was scoured and large volumes of sediment were delivered during the 1964 flood. In addition, past timber harvest activities (both Forest Service and mining related) involved considerable disturbance by tractor logging through streams, total removal of riparian vegetation, and sidecast road construction (U.S. Forest Service 1995). Although Taylor Creek parallels a Forest Service road, the stream is well shaded by riparian vegetation (U.S. Forest Service 1999). Riparian conditions are more intact compared to Althouse and Sucker Creeks.

Even though none of the miners in this study dredged outside the wetted perimeter, they did dredge along the stream margin which may still artificially deepen the channel and inadvertently prohibit armoring of the riparian root layer. Loss of roots decreases bank stability and may result in streams becoming shallower and wider.

CONCLUSION

Lack of significant differences between control and treatment reaches does not allow one to conclude that there were no impacts on benthic macroinvertebrates from a 4-inch (10.16 cm) suction dredge on Althouse Creek, Sucker Creek, and Taylor Creek. Results from this study suggest that 4-inch (10.16 cm) suction dredge mining operations had a minimal impact on benthic macroinvertebrates and their physical habitats of the four claim areas studied. The limited mining activity within the originally proposed treatment reach (30 m) probably influenced results of this study. The decrease in size of treatment area decreased the number of macroinvertebrate samples. This reduced the sample number and increased variability among samples. Consequently, the power to detect any difference was reduced.

Macroinvertebrates show a general response to watershed conditions. The dominant proportions of *Baetis* spp. at the beginning of the mining season and Simuliidae at the end of the mining season in treatment areas, may be reflective of the quality of habitat and tolerance level by the local benthic community as a result of dredging. The study streams were different from each other in size and general watershed conditions. Taylor Creek was the smallest of streams and had a more intact riparian area. Sucker and Althouse Creek's riparian conditions are slowly recovering from historical mining methods. The substrate size is generally larger in both Sucker and Althouse Creeks. The increase of Trichoptera for all sites at the end and one month after the mining season may show colonization trends resulting more from colonization dynamics than dredging impacts.

Future studies of the effects of dredge mining should use in short-comings of this study to improve chances of obtaining defensible results.

It was difficult for me to detect significant differences in the macroinvertebrate measurements because even under natural conditions there is a low probability of detecting differences in invertebrate abundance because of high spatial variability (Ward 1992). My suggestion for future studies would be to concentrate on changes in the physical environment (i.e., longer period of study, multiple dredges, substrate distributions/stability) and the evaluation of general conditions of the watershed (i.e. history of watershed, riparian areas). Changes in the physical environment ultimately affect the structure of a community because they influence habitat quantity and quality, food type and availability, and predator-prey relations.

Sample sizes required to detect significant differences between control and treatment areas at 0.05 level will vary on which type of variable would be tested and depend on the season sampling would take place. A low number of macroinvertebrate samples would require a larger number of study sites. Increasing the sample size would increase power.

Based on previous studies, effects of suction dredge mining on invertebrates generally appear to be temporary and site-specific affecting abundance, taxa richness, and community composition. However, consideration to what the condition of the sites were prior to implementation of the research may not have been considered. It may be that studies like these need more than 1 year (mining season) to evaluate true impacts of an activity that will persist until the 1872 mining law is reviewed or updated. Until then, agencies and natural resource managers will be questioning the true impacts of dredging on river ecosystems.

Although invertebrates may be able to recolonize dredged areas relatively quickly, the question of which species recolonizes is just as important. Invertebrate communities in streams in southern Oregon that are actively dredged every year may be actually recovering at a slow rate due to historical hydraulic mining methods. Perhaps the impacts from suction dredging will be fully understood if studies approach the problem at a watershed scale and centers on the cumulative effects with an emphasis on what taxa are present. In addition, streams with no current instream dredging activity should be used as controls. Future dredging studies should focus at a much larger scale rather than at a single dredge operation. Basins that hold historical and active mining claims should be looked at as a whole with each sub-basin reviewed for it's functioning benthic community.

Today's challenges for the gold dredger and permitting agencies is to demonstrate a model of compatibility with other land uses, and to recognize how their activities (i.e., dredging, permiting process, monitoring) affect the streams, surrounding ecosystems, and the public. Increased awareness of the potential effects of suction dredging on aquatic ecosystems and increased scrutiny of miner's activities are especially needed in areas where there are listed species and water quality limited streams.

LITERATURE CITED

Bevenger, G. S. and R. King. 1995. A pebble count procedure for assessing watershed cumulative effects. USDA For. Serv. Res. RM-RP-319.

Brittain, J. E. 1982. Biology of mayflies. Annual review of entomology. Annual Reviews Inc. Palo Alto, California. **27**:119-147.

Brooks, H. C. and L. Ramp. 1968. Gold and Silver in Oregon. State of Oregon Dept of Geology and Mineral Industries. Bulletin 61. Salem, Oregon.

California Department of Fish and Game. 1993. Adoption of regulations for suction dredge mining. Draft Environmental Impact Report.

Cooley, Mike. 1998. Recreation, Lands, and Minerals Staff. Siskiyou National Forest. Grants Pass, Oregon.

Cummins, K. W., and G. H. Lauff. 1969. The influence of substrate particle size on the microdistribution of stream macrobenthos. Hydrobiologia. **34**:145-181.

Cummins, K. W. and R. W. Merritt. (editors). 1996. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Company. Dubuque, Iowa.

Gibbons, J. D. 1971. The general two-sample problem, Ch. 7 *in* Nonparametric Statistical Inference. McGraw Hill Book Co.

Griffith, J. S., and D. A. Andrews. 1981. Effects of a small suction dredge on fishes and aquatic invertebrates in Idaho streams. N. Am. J. Fish. Man. **1**:21-28.

Harvey, B. C. 1982. Effect of suction dredge mining on fish and invertebrates in California foothill streams. Masters Thesis. Univ. of California. Davis, California.

Harvey, B. C. 1986. Effects of suction gold dredging on fish and invertebrates in two California streams. N. Am. J. Fish. Man. **6**:401-409.

Harvey, B. C. and T. E. Lisle. 1998. Effects of suction dredging on streams: a review and an evaluation strategy. Fisheries **23**(8):8-17.

Hassler, T. J., W. L. Somer, and G. R. Stern. 1986. Impacts of suction dredge mining on anadromous fish, invertebrates, and habitat in Canyon Creek, California. California Cooperative Fishery Research Unit, U. S. Fish and Wildlife Service, Final Report.

King, R. and J. Potyondy. 1993. Statistically testing wolman pebble counts: changes in percent fines. Stream Notes. Stream Systems Techonological Center. Fort Collins, Colorado. October.

Luedtke, R. J., and M. A. Brusven. 1976. Effects of sand sedimentation on colonization of stream insects. J. Fish. Res. Board Can. **33**:1881-1886.

Mackay, R. J. 1992. Colonization by lotic macroinvertebrates: A review of processes and patterns. Can. J. Fish. Aquat. Sci. **49**:617-628.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press. Princeton, New Jersey.

Norman, G. R. and D. L. Streiner. 1994. Biostatistics: the bare essentials. Mosby-Year Book, Inc. St. Louis, Missouri.

Orr, E. L., Orr W. N. and Baldwin E. M. 1992. 4th ed. Geology of Oregon. Kendall/Hunt Publishing Company. Dubuque, Iowa.

Orth, D. J. 1983. Aquatic habitat measurements, Page 61 *in* L. A. Nielson and D. L. Johnson, editors. Fisheries techniques. Southern Printing Company, Inc. Blacksburg, Virginia.

Pearson, R. G., and N. V. Jones. 1975. The effects of dredging operations on the benthic community of a chalk stream. Biology Conservation **8**:273-278.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA For. Serv. Gen. Tech. Rep. INT-138. Ogden, Utah.

Rader, R. B. 1997. A functional classification of the drift: traits that influence invertebrate availability to salmonids. Can. J. Fish. Aquat. Sci. **54**:1211-1234.

Rabeni, C. F., and G. W. Minshall. 1977. Factors affecting microdistribution of stream benthic insects. Oikos **29**:33-43.

Ramsey, F. and D. Schafer. 1994. The statistical sleuth: a second course in statistical data analysis. Dept. of Statistics Oregon State University. Corvallis, Oregon.

Somer, W. L., and T. J. Hassler. 1992. Effects of suction dredge gold mining on benthic invertebrates in a northern California stream. N. Amer. J. Fish. Man. **12**:244-252.

Thomas, V. G. 1985. Experimentally determined impacts of a small, suction gold dredge on a Montana stream. N. Amer. J. Fish. Man. **5**:480-488.

U.S. Forest Service, Pacific Northwest Region. 1995. Grayback/Sucker Watershed Analysis, Version 1.0. Siskiyou National Forest. Grants Pass, Oregon.

U.S. Forest Service, Pacific Northwest Region. 1997. Stream inventory handbook level I & II, Version 9.7.

U.S. Forest Service, Siskiyou National Forest. 1999. Taylor Creek 1998 Level II stream inventory. Grants Pass, Oregon. Portland, Oregon.

Ward, J.V. 1992. Aquatic Insect Ecology. Biology and Habitat. John Wiley & Sons, Inc. Toronto, Ontario.

Wentworth, C. K. 1922. A scale of grade and class terms for clastic sediments. J. Geol. **30**:377-392.

Wisseman, B. 1996. Interpretive Manual: Benthic invertebrate biomonitoring and bioassessment in western montane streams. ABA, Inc. Corvallis, Oregon.

Wright, K. K. and J. L. Li. 1998. Effects of recreational activities on the distribution of Disosmoecus gilvipes in a mountain stream. J. N. Am. Benthol. Soc. **17**(4):535-543.

Zar, J. H. 1974. Biostatistical analysis. 2nd ed. Prentice Hall. Englewood Cliffs, New Jersey.

APPENDIX

Table A.1. Mean proportions of modified substrate size categories based on the Wentworth Scale (Wentworth 1922) at the beginning and one month after the mining season, 1996. N=4

Size Class	Size Range (mm)	Beginning	One month after
Sand	0 - 2	10.75	11.5
Fine Gravel	2 - 8	6.0	5.25
Medium Gravel	8 - 16	6.5	9.0
Large Gravel	16 - 64	23.75	29.75
Small Cobble	64 - 28	18.25	21.0
Large Cobble	128 - 256	19.5	13.25
Small Boulder	256 - 512	8.5	6.5
Medium Boulder	512 - 1024	3.0	1.25
Large Boulder	>1024	2.75	1.0
Bedrock	Bedrock	1.0	1.5

Table A.2. Means, variances, and std. deviations for different variables with N=4.

Variable	Means		Variances		Std Deviations	
	Treatment	Control	Treatment	Control	Treatment	Control
June (Beginning of Mining Season)						
Density(LOG)	8.54819	9.0082	0.28774	0.144327	0.536414	0.379904
Taxa Richness	43.25	52.5	8.25	27.0	2.87228	5.19615
Predators(LOG)	6.68664	7.27725	0.569595	0.192273	0.754715	0.43849
Scrapers(LOG)	6.64592	7.24413	0.61994	0.725349	0.787363	0.851674
C-Gatherers(LOG)	7.69884	8.06029	0.677467	0.427016	0.823084	0.653465
C-Filterers(LOG)	6.06509	6.44582	0.265363	0.200088	0.515134	0.447312
September (End of Mining Season)						
Density(LOG)	8.81184	9.27338	0.355725	0.309966	0.596427	0.556746
Taxa Richness	37.0	44.5	55.3333	30.3333	7.43864	5.50757
Predators(LOG)	6.31026	6.84928	0.995462	0.224644	0.997729	0.473966
Scrapers(LOG)	5.92424	6.70007	0.802614	1.05294	0.895887	1.02613
C-Gatherers(LOG)	7.00527	7.7239	0.246903	0.073759	0.496893	0.271587
C-Filterers(LOG)	7.733338	7.44921	0.045789	0.632045	0.213986	0.795013
October (1 Month After the Mining Season)						
Density(LOG)	9.1807	9.41008	0.239127	0.107678	0.489006	0.328144
Taxa Richness	50.25	47.25	43.5833	74.9167	6.60177	8.65544
Predators(LOG)	6.59584	6.77167	0.281678	0.513294	0.530734	0.716445
Scrapers(LOG)	6.86909	7.12967	1.58851	1.04326	1.26036	1.0214
C-Gatherers(LOG)	8.03604	8.13291	0.19596	0.518026	0.442674	0.719741
C-Filterers(LOG)	6.30293	7.08278	0.161983	0.089920	0.402471	0.299867

Table A.3. List of taxa collected from 4 study sites on Siskiyou National Forest, OR, 1996. Total taxa = 144.

ORDER (or other taxon)	FAMILY	GENUS
EPHEMEROPTERA	Ameletidae	*Ameletus*
	Baetidae	*Acentrella*
	Baetidae	*Baetis*
	Baetidae	*Diphetor*
	Baetidae	*Procloeon*
	Baetidae	Unknown
	Ephemerillidae	*Attenella*
	Ephemerillidae	*Caudatella*
	Ephemerillidae	*Drunella*
	Ephemerillidae	*Ephemerella*
	Ephemerillidae	*Eurylophella*
	Ephemerillidae	*Serratella*
	Ephemerillidae	*Timpanoga*
	Ephemerillidae	Unknown
	Heptageniidae	*Cinygma*
	Heptageniidae	*Cinygmula*
	Heptageniidae	*Epeorus*
	Heptageniidae	*Ironodes*
	Heptageniidae	*Leucrocuta*
	Heptageniidae	*Nixe*
	Heptageniidae	*Rhithrogena*
	Heptageniidae	Unknown
	Leptophlebiidae	*Paraleptophlebia*
	Leptophlebiidae	Unknown

Table A.3. (continued)

ORDER (or other taxon)	FAMILY	GENUS
PLECOPTERA	Capniidae	Unknown
	Chloroperlidae	*Kathroperla*
	Chloroperlidae	*Paraperla*
PLECOPTERA cont'd	Chloroperlidae	*Sweltsa*
	Chloroperlidae	Unknown
	Leuctridae	Unknown
	Nemouridae	*Malenka*
	Nemouridae	Unknown
	Nemouridae	*Visoka*
	Nemouridae	*Zapada*
	Peltoperlidae	*Yoraperla*
	Perlidae	*Calineuria*
	Perlidae	*Doroneuria*
	Perlidae	*Hesperoperla*
	Perlidae	Unknown
	Perlodidae	*Cultus*
	Perlodidae	*Megarcys*
	Perlodidae	*Rickera*
	Perlodidae	*Skwala*
	Perlodidae	Unknown
	Pteronarcyidae	*Pteronarcys*
TRICHOPTERA	Brachycentridae	*Micrasema*
	Calamoceratidae	*Heteroplectron*
	Glossosomatidae	*Agapetus*
	Glossosomatidae	*Glossosoma*

Table A.3. (continued)

ORDER (or other taxon)	FAMILY	GENUS
	Glossosomatidae	Unknown
	Hydropsychidae	*Arctopsyche*
	Hydropsychidae	*Cheumatopsyche*
	Hydropsychidae	*Hydropsyche*
	Hydropsychidae	*Parapsyche*
	Hydropsychidae	Unknown
TRICHOPTERA cont'd	Hydropsychoidae	*Wormaldia*
	Hydroptilidae	*Hydroptila*
	Lepidostomatidae	*Lepidostoma*
	Leptoceridae	*Mystacides*
	Limnephilidae	*Dicosmoecus*
	Limnephilidae	*Ecclisomyia*
	Limnephilidae	*Hydatophylax*
	Limnephilidae	*Onocosmoecus*
	Limnephilidae	Unknown
	Polycentropodidae	*Polycentropus*
	Psychomyiidae	*Psychomyia*
	Rhyacophiloidae	*Rhyacophila*
	Sericostomatidae	*Gumaga*
	Uenoidae	*Neophylax*
COLEOPTERA	Dytiscidae	Unknown
	Elmidae	*Ampumixis*
	Elmidae	*Cleptelmis*
	Elmidae	*Dubiraphia*
	Elmidae	*Heterlimnius*

Table A.3. (continued)

ORDER (or other taxon)	FAMILY	GENUS
	Elmidae	*Lara*
	Elmidae	*Microcylloepus*
	Elmidae	*Narpus*
	Elmidae	*Optioservus*
	Elmidae	*Ordobrevia*
	Elmidae	*Rhizelmis*
	Elmidae	*Zaitzevia*
	Eubriinae	*Acneus*
	Gyrinidae	Unknown
COLEOPTERA cont'd	Hydrophilidae	Unknown
	Psephenidae	*Eubrianax*
DIPTERA	Athericidae	*Atherix*
	Blephariceridae	Unknown
	Ceratopogonidae	Ceratopogoninae
	Ceratopogonidae	Forcipomyiinae
	Dixidae	*Dixa*
	Empididae	*Chelifera*
	Empididae	*Clinocera*
	Empididae	*Oreogeton*
	Empididae	Unkown
	Empididae	*Wiedemannia*
	Nematocera	Unknown
	Pelecorhynchidae	*Glutops*
	Psychodidae	*Maruina*
	Psychodidae	*Pericoma*

Table A.3. (continued)

ORDER (or other taxon)	**FAMILY**	**GENUS**
	Ptychopteridae	Unknown
	Simuliidae	Unknown
	Tipulidae	*Antocha*
	Tipulidae	*Cryptolabis*
	Tipulidae	*Dicranota*
	Tipulidae	*Hesperoconopa*
	Tipulidae	*Hexatoma*
	Tipulidae	*Limnophila*
	Tipulidae	*Limonia*
	Tipulidae	*Rhabdomastix*
	Tipulidae	Unknown
	Chironomidae	Chironominae
DIPTERA cont'd	Chironomidae	Chironomini
	Chironomidae	Tanypodinae
	Chironomidae	Tanytarsini
	Chironomidae	Diamesini
	Chironomidae	Cricotopus
	Chironomidae	Orthocladiinae
	Chironomidae	Unknown
MEGALOPTERA	Corydalidae	Unknown
ODONATA	Gomphidae	Unknown
OTHER	Acari	
	Copepoda	
	Juga	
	Nematoda	

Table A.3. (continued)

ORDER (or other taxon)	FAMILY	GENUS
	Oligochaeta	
	Ostracoda	
	Turbellaria	