The Macro benthos of
Burnout Creek & James Canyon Creek,
Tributaries to Electric Lake,
Huntington Creek Drainage.
Spring 2001

Prepared by

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November 2001

INTRODUCTION

Our previous report noted the importance of benthic invertebrate surveys and their use in monitoring the aquatic environment (Shiozawa 2000). Seasonal surveys are sometimes useful to identify the effect of any seasonal bias that may exist. This report elaborates on the analysis presented in our previous report and that of a second set of samples taken in the spring of 2001. This will help generate a more robust picture of the environmental state of James Canyon Creek and Burnout Creek.

PURPOSE

This subsequent benthic-sampling study broadens the base-line information established by the previous fall's samples at Burnout Creek and James Canyon Creek and gives a broader estimation of the invertebrate densities present in these regions.

METHODS

Both Burnout Creek and James Canyon Creek were sampled on June 20, 2001. The same benthic sites were sampled in the Fall of the previous year: 162 meters (528 feet) above the reservoir on both streams.

Coinciding with methods used in 2000, quantitative samples were taken with a modified box sampler (Shiozawa 1986) composed of a net mesh of 253 microns. The three samples taken at each stream were field preserved in ethyl alcohol and returned to the laboratory for processing. The samples were sorted in an illuminated pan and identified; small specimens and those of questionable identity were examined under magnification; identification was to the lowest possible taxonomic level using the keys of Merritt and Cummins (1994). The mean and standard deviation are calculated for each taxon and the mean values were used to determine the density per square meter. Standing crop was estimated from wet weights of total invertebrates collected at each station.

Calculations of the USFS Biotic Condition Index (Winget and Mangum 1979) were again completed using the abundances of the benthic taxa to generate the dominance weighted community tolerant quotient (CTQd). The predicted community tolerant quotient (CTQp) was calculated using water chemistry data provided in Winget (1972) for the Huntington Creek drainage.

Cluster analysis was run using the Bray-Curtis dissimilarity index with the UPGM clustering algorithm. Data from both sampling periods (Fall 2000 and Spring 2001) and both streams were combined in the analysis.

RESULTS AND DISCUSSION

Burnout Creek contained 41 taxa (including larvae and adults and unidentifiable immature insects as separate taxa). Larval Chironomids (Diptera: Chironomidae), Ostracods (Crustacea: Ostracoda) and larval *Heterlimnius* (Coleoptera: Elmidae) are the most abundant taxa. Taxa in moderate numbers were *Baetis* (Ephemeroptera: Baetidae), Oligochaets (Annelida: Oligochaeta), Planeria (Class,Turbellaria: Planeriidae) Chironomidae pupae. The remaining taxa are in low abundance (*see Table 2)*. James Canyon Creek had a total of 39 taxa (including larvae and adults and unidentifiable immature insects as separate taxa). The dominant taxa are larval Chironomids, *Drunella grandis* (Ephemerillidae: Ephemeroptera), and *Neothrema alicia* (Trichoptera: Limniphilidae). *Baetis*, ostracods, Planeria, early instar Plecoptera (immature-unidentifiable), and larval Ryacophila (Trichoptera: Hydropsychidae) all occur in moderate numbers (*Table 3*).

While density estimates for the previous fall exhibited a substantial difference between creeks, (James Canyon was 2.75 times higher than Burnout Creek), the spring difference was minimal. Total density at Burnout Creek was 384,010 per square meter, while in James Canyon Creek it was slightly less at 335,500 organisms per square meter (*Tables 2 and 3*). Biomass for Burnout Creek was estimated at 348.48 grams per square meter considerably higher than for the first sampling period at 103.74 grams per square meter. For James Canyon Creek biomass was 273.9 grams per square meter, close to the biomass numbers of the previous fall (272.118 grams per square meter; *Table 1*).

The variance to mean ratios were examined to evaluate the number of taxa demonstrating a contagious distribution (Elliott 1977). As discussed in the previous report, a Chi Square value of 8 or above indicates that the taxa is contagiously distributed. Thirteen taxa in both Burnout Creek and James Canyon Creek were contagiously distributed. The remaining taxa in each stream followed a Poisson distribution. As with the fall samples, the conclusion reached from these values is that abundant taxa are contagiously distributed. The total densities were also examined and both Burnout Creek (Chi sq. = 1204.03) and James Canyon Creek (Chi sq. = 1022.04) are highly contagious in distribution.

The Biotic Condition Index (BCI) for this year was also calculated. The predicted community tolerant quotient (CTQp) was still the same with a value of 80. However, the CTQa for this year at Burnout Creek was 60.77, and for James Canyon Creek it was 72.00. Both values are based on the ratings for individual invertebrate taxa found in Table 4. The **BCI values for Burnout Creek was calculated at 131.64**, while **BCI for James Canyon Creek was 111.11**. Again, like the previous fall, both streams are in excellent condition, according to this index.

Four clusters are readily apparent from the cluster analysis (Figure 1). One of these contains only one station, James Canyon Creek 2, Oct. 2000. Two clusters include just 2 samples each, and are only marginally similar to each other, these are Burnout Creek, Oct. 2000, samples 2 and 3 in one, and Burnout Creek 1,Oct. 2000 with James Canyon Creek 2, June 2000 in the other.

The October 2000 samples from Burnout Creek were very dissimilar to one another. The James Canyon Creek samples were also dissimilar to one another at the 40% dissimilarity level. In contrast all of the spring samples were less that 40% dissimilar to one another with the exception of one sample from James Canyon Creek, J2 June01, which was quite dissimilar to the others. This separation appears to be influenced by low numbers of Chironomid larvae in the James Canyon 2 sample. From these samples, it appears that a seasonal signal does exist, but it appears to be characterized by higher variability during the fall and lower variability in the spring. The cluster analysis does not indicate any clear segregation between James Canyon Creek and Burnout Creek. The difference between samples is as great as it is between streams.

We therefore conclude that the differences between the sites for the two sampling periods do not show any distinct trends. Neither the sampling stations, nor the sampling dates appear to make a significant difference in the interpretation of the data. The results of the fall 2001 samples will be useful in helping evaluate this information more completely.

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Figure 1. Cluster analysis: Fall 2000 and Spring 2001 Benthic Samples for Burnout(B) and James Canyon (J) Creeks

Bray-Curtis Dissimilarity Index

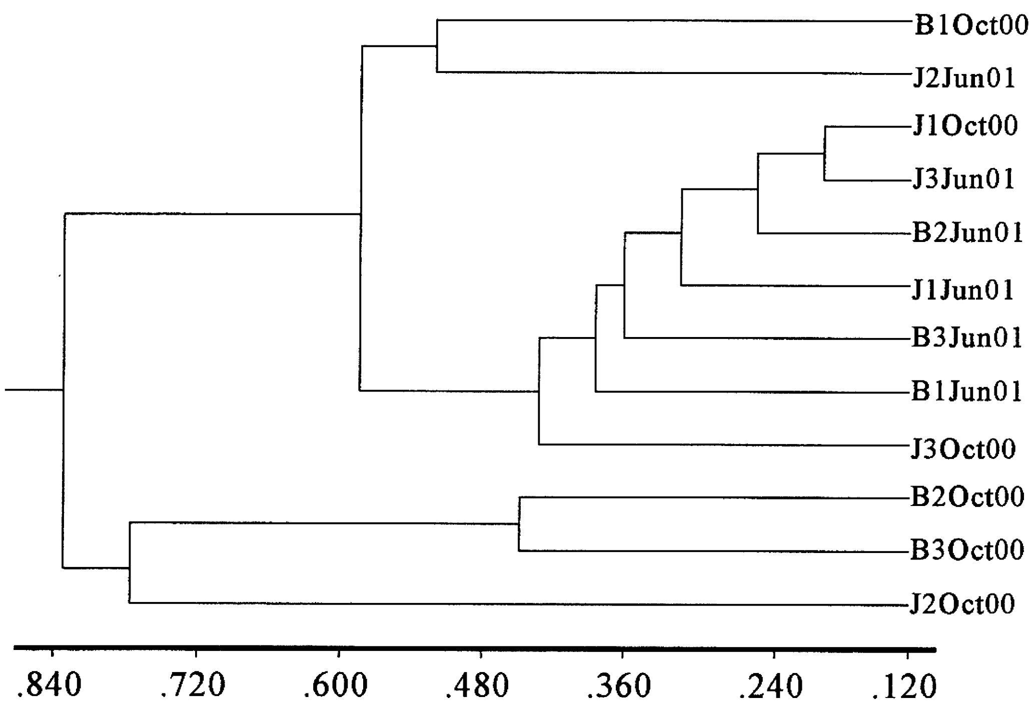

Table 1. Mean biomass per meter square, June 2001

Stream	Sample1	Sample2	Sample3	Mean	Mb/m2
Burnout	2.02 g	0.67 g	0.48 g	1.06	348.48 g
James Canyon	1.16 g	0.72 g	0.62 g	0.83 g	273.90 g

Table 2. June, 2001 Summary Statistics for Burnout Creek

	Burnout Creek	1	2	3	mean	sd	chi sq	#/m2
Ephemeroptera	*Baetis sp.*	14	43	37	31.33	15.31	14.96	10,340
	Cinygmula	0	0	1	0.33	0.58	2.00	110
	Drunella grandis	0	0	2	0.67	1.15	4.00	220
	Ephemerella sp.	2	0	0	0.67	1.15	4.00	220
	Paraleptophlebia sp.	2	1	1	1.33	0.58	0.50	440
Plecoptera	*Early instar plecoptera*	1	1	0	0.67	0.58	1.00	220
	Isoperla sp.	0	0	1	0.33	0.58	2.00	110
	Skwala parallela	0	0	1	0.33	0.58	2.00	110
	Zapada	0	1	0	0.33	0.58	2.00	110
Trichoptera	*Brachycentrus echo*	0	0	1	0.33	0.58	2.00	110
	(Brachycentridae) Amiocentrus	0	0	1	0.33	0.58	2.00	110
	(Brachycentridae) Micrasema	0	10	3	4.33	5.13	12.15	1,430
	Dicosmoecus	1	0	0	0.33	0.58	2.00	110
	Lepidostoma sp.	5	0	2	2.33	2.52	5.43	770
	(Limniphilidae)*Neothremma alicia*	1	4	3	2.67	1.53	1.75	880
	*(*Limniphilidae*)Oligoplebodes*	0	7	13	6.67	6.51	12.70	2,200
	*(*Limniphilidae*)Platycentropus*	0	0	1	0.33	0.58	2.00	110
	Rhyacophila (larva)	2	6	2	3.33	2.31	3.20	1100
Coeleoptera	*Heterlimnius* (larva)	105	23	152	93.33	65.29	91.34	30,800
	Heterlimnius (adult)	1	1	3	1.67	1.15	1.60	550
	Hydrophiloidea	0	0	1	0.33	0.58	2.00	110
Diptera	*Antocha monticola*	1	14	0	5.00	7.81	24.40	1,650
	Ceratopogonidae	2	0	0	0.67	1.15	4.00	220
	Chelifera	3	9	0	4.00	4.58	10.50	1320
	Chironomidae (larva)	525	760	886	723.7	183.22	92.78	238,810
	Chironomidae (pupa)	19	7	22	16.00	7.94	7.88	5280
	Chironomidae (adult)	0	0	1	0.33	0.58	2.00	110
	Dicranota	1	0	0	0.33	0.58	2.00	110
	Simulium sp.	0	1	2	1.00	1.00	2.00	330
	Simulium (pupa)	1	0	2	1.00	1.00	2.00	330
	Simulium (adult)	0	0	1	0.33	0.58	2.00	110
	(Stratiomyidae) Caloparyphus	1	0	1	0.67	0.58	1.00	220
	(Tipulidae) Antocha pupa	0	2	0	0.67	1.15	4.00	220
	(Tipulidae) *Tipula*	2	1	0	1.00	1.00	2.00	330
Crustacea	*Cladocera*	0	0	49	16.33	28.29	98.00	5,390
	Ostracoda	51	13	449	171.0	241.50	682.15	56,430
Arachnid	*Hydracarina*	5	1	14	6.67	6.66	13.30	2,200
Mollusca	*Sphaerium sp.*	10	0	26	12.00	13.11	28.67	3,960
Collembola	*Non-specific*	0	0	2	0.67	1.15	4.00	220
Misc.	*Oligochaeta*	18	46	25	29.67	14.57	14.31	9,790
	Planariidae	11	8	43	20.67	19.40	36.42	6,820
TOTAL		784	959	1,748	1,163.67	644.26	1,204.03	384,010

Table 3. June, 2001 Summary Statistics for James Canyon Creek

	James Canyon Creek	1	2	3	mean	sd	chi sq	#/m2
Ephemeroptera	*Baetis sp.*	53	27	22	34.00	16.64	16.29	11,220
	Cinygmula	23	7	8	12.67	8.96	12.68	4180
	Drunella grandis	45	40	17	34.00	14.93	13.12	11,220
	Ephemerella sp.	1	0	1	0.67	0.58	1.00	220
	Rhithrogena sp.	2	3	0	1.67	1.53	2.80	550
Plecoptera	*Early instar plecoptera*	76	3	8	29.00	40.78	114.69	9,570
	Paraperla fontinalis	1	0	0	0.33	0.58	2.00	110
	Skwala parallela	10	0	31	13.67	15.82	36.63	4,510
	Sweltza sp.	0	1	0	0.33	0.58	2.00	110
	Zapada	0	11	0	3.67	6.35	22.00	1,210
Trichoptera	*Brachycentrus echo*	17	0	0	5.67	9.81	34.00	1,870
	Early in. hydropsychidae	0	1	0	0.33	0.58	2.00	110
	Lepidostoma sp.	0	3	0	1.00	1.73	6.00	330
	(Limniphilidae) Neothremma alicia	70	57	10	45.67	31.56	43.64	15,070
	(Limniphilidae)*Oligoplebodes*	31	3	2	12.00	16.46	45.17	3,960
	Rhyacophila (larva)	43	23	13	26.33	15.28	17.72	8,690
	Rhyacophila (pupa)	0	3	0	1.00	1.73	6.00	330
Coeleoptera	*Heterlimnius* (larva)	13	4	2	6.33	5.86	10.84	2,090
	Heterlimnius (adult)	0	2	0	0.67	1.15	4.00	220
	Staphylinidae	1	0	0	0.33	0.58	2.00	110
Diptera	*Ceratopogonidae*	2	3	1	2.00	1.00	1.00	660
	Chelifera	5	2	1	2.67	2.08	3.25	880
	Chironomidae (larva)	683	306	1052	680.33	373.01	409.02	224,510
	Chironomidae (pupa)	21	15	9	15.00	6.00	4.80	4,950
	Dixidae dixa	0	1	0	0.33	0.58	2.00	110
	Simulium sp.	1	0	0	0.33	0.58	2.00	110
	(Stratiomyidae) Caloparyphus	0	3	2	1.67	1.53	2.80	550
	(Tipulidae) Limnophila	2	0	0	0.67	1.15	4.00	220
	(Tipulidae) *Tipula*	1	0	0	0.33	0.58	2.00	110
	Trichoclinocera	1	0	0	0.33	0.58	2.00	110
	(Empididae) Hemerodromia	1	0	0	0.33	0.58	2.00	110
	(Empididae) Wiedemania	4	0	5	3.00	2.65	4.67	990
Crustacea	*Cladocera*	5	0	0	1.67	2.89	10.00	550
	Ostracoda	9	4	72	28.33	37.90	101.39	9,350
Arachnid	*Hydracarina*	6	0	4	3.33	3.06	5.60	1,100
Mollusca	*Sphaerium sp.*	3	13	19	11.67	8.08	11.20	3,850
Collembola	*Non-specific*	4	0	1	1.67	2.08	5.20	550
Misc.	*Oligochaeta*	8	3	8	6.33	2.89	2.63	2,090
	Planariidae	58	10	14	27.33	26.63	51.90	9,020
TOTAL		1,200	548	1,302	1,016.67	665.33	1,022.04	335,500

Table 4. Biotic Condition Index values for taxa collected, June 2001

	James Canyon Creek			Burnout Creek	
Ephemeroptera	Baetis sp.	72	Ephemeroptera	Baetis sp.	72
	Cinygmula	21		Cinygmula	21
	Drunella grandis	24		Drunella grandis	24
	Ephemerella sp.	48		Ephemerella sp.	48
	Rhithrogena sp.	21		Paraleptophlebia sp.	24
Plecoptera	Early instar plecoptera	108	Plecoptera	Early instar plecoptera	108
	Paraperla fontinalis	24		Isoperla sp.	48
	Skwala parallela	18		Skwala parallela	18
	Sweltza sp.	24		Zapada	16
	Zapada	16	Trichoptera	Brachycentrus echo	24
Trichoptera	Brachycentrus echo	24		(Brachycentridae) Amiocentrus	24
	Early in. hydropsychidae	108		(Brachycentridae) Micrasema	24
	Lepidostoma sp.	18		Dicosmoecus	24
	(Limniphilidae)Neothremma	8		Lepidostoma sp.	18
	(Limniphilidae)Oligophlebodes	24		(Limniphilidae) Neothremma	8
	Rhyacophila (larva)(pupa)	18		(Limniphilidae)Oligophlebodes	24
Coeleoptera	Heterlimnius (larva)(adult)	108		Rhyacophila (larva)	18
Diptera	Ceratopogonidae	108	Coeleoptera	Heterlimnius (larva)(adult)	108
	Chelifera	108		Hydrophilidea	72
	Chironomidae (larva)(pupa)	108	Diptera	Antocha monticola	24
	Dixidae dixa	108		Ceratopogonidae	108
	Simulium sp.	108		Chelifera	108
	(Stratiomyidae) Caloparyphus	108		Chironomidae (larva)(pupa)(adult)	108
	(Tipulidae) Limnophila	72		Dicranota	24
	(Tipulidae) Tipula	36		Simulium sp.(pupa)(adult)	108
	Trichoclinocera	108		(Stratiomyidae) Caloparyphus	108
	(Empididae) Hemerodromia	108		(Tipulidae) Antocha pupa	24
	(Empididae) Wiedemania	108		(Tipulidae) Tipula	36
Crustacea	Cladocera	108	Crustacea	Cladocera	108
	Ostracoda	108		Ostracoda	108
Arachnid	Hydracarina	108	Arachnid	Hydracarina	108
Mollusca	Sphaerium sp.	108	Mollusca	Sphaerium sp.	108
Collembola	Non-specific	108	Collembola	Non-specific	108
Misc.	Oligochaeta	108	Misc.	Oligochaeta	108
	Planariidae	108		Planariidae	108

The Benthos of Bordinghouse & Eccles Creeks and the Impact of Increased Water Discharge Into Eccles Creek in 2001

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February 2002

The Benthos of Boardinghouse and Eccles Creeks and the Impact of Increased Water Discharge into Eccles Creek in 2001

Introduction

This project was undertaken to compare the benthic invertebrates in Eccles Creek and Boardinghouse Creek near Scofield, Utah. Eccles Creek has recently been subject to an increase in discharge resulting from mining operations. In August of 2001 water entering the Skyline Mine increased significantly resulting in the need for emergency discharge of the water to prevent mine flooding. The water was diverted into Eccles Creek. The discharge in Eccles Creek increased from 1000 gpm to 4100 gpm. The increased discharge has the stream flowing at approximately bank full levels. The state of Utah is requires continual monitoring of various water chemistry parameters within the stream to determine potential impacts on the system. This survey was completed for Canyon Fuel Company in an attempt to evaluate the potential impacts of increased water discharges in Eccles Creek as well as provide some comments about specific parameters of existing water chemistry data on the stream's benthic invertebrates. Figures 1 and 2 shows Bordinghouse and Eccles Creeks and also provides a visual impression about the flow differences between the creeks at the time of sampling.

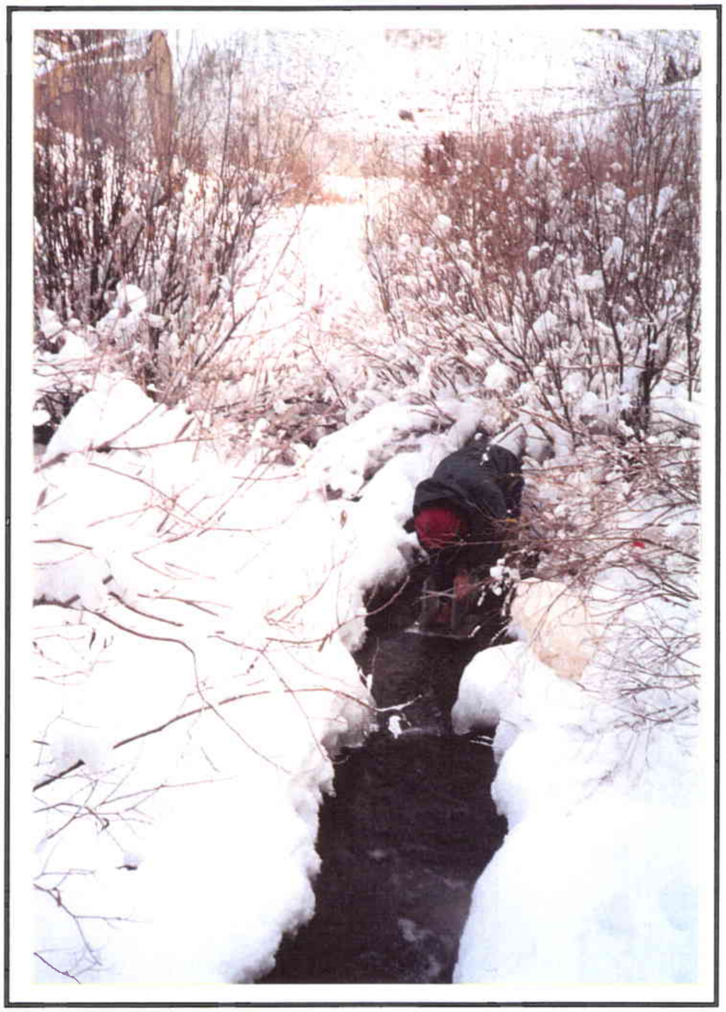

Figure 1: Sampling in Bordinghouse Creek

Figure 2: Sampling in Eccles Creek

Methods

Quantitative samples were taken on November 24, 2001. Four samples were taken at each stream. Samples were collected upstream at intervals separated by approximately 20 to 30 m. Samples were taken in areas with rubble or cobble substrates to insure that similar substrates were examined. Samples were located in the center of the stream channel to insure that the sample sites had been submerged continuously throughout the year. A box sampler was used to collect the samples. The substrate was stirred to a depth of approximately 5 cm. All rocks within the area of the sampler were removed and individually washed to insure quantitative removal of the invertebrates.

The samples were concentrated on a screen with a mesh of 64 microns and field preserved in ethyl alcohol. Samples were sorted in a pan illuminated from below. Small and questionable specimens were examined under magnification. Specimens were identified to the lowest possible taxonomic level using the keys of Merritt and Cummins (1996). The mean and standard deviation was calculated for each taxon and the mean values were used to determine the density per square meter.

Results

Boardinghouse Creek had low discharge and the samples were taken in water less than 15 to 20 cm deep. Much of the stream bed was cemented together with a calcareous marl. This reduces the available interstitial space for the invertebrates, but allows the development of an extensive epilithic community. Eccles Creek, as expected, had significantly greater discharge, and the mid-stream samples were taken in water approximately 30 to 40 cm deep. The substrate in this stream was uncompacted and relatively well sorted (i.e. sand, pea gravel, gravel, and rubble tended to be segregated by the fall velocity of the stream). In many locations the stream was flowing over grasses that had apparently been growing on the stream bank prior to the increase in discharge. Particles of coal were found in the samples from Eccles Creek, intermixed with the gravels and sands.

A total of 34 taxa, typical for the area (Winget 1972), were identified from the two streams. However, while Boardinghouse Creek contained 33 of the 34 taxa, only 5 taxa were collected from Eccles Creek (Table 1). The five taxa from Eccles Creek were *Baetis*, *Hydropsyche*, *Pedicia*, chironomids, and Ostracods. The total density of invertebrates from Boardinghouse Creek was on the order of 35,500 organisms per square meter. The majority of the organisms were *Baetis* mayflies, in densities of over 20,000 per square meter. Second in abundance were chironomids (4000/square meter), followed by the caddisfly Neothremma (3400/square meter). Eccles Creek, in contrast, has a total density estimate of 61 per square meter. *Hydropsyche* was the most abundant taxa at Eccles Creek, being present at a density of 45 per square meter. This, like the total number of taxa in Eccles Creek, is significantly lower than that of Boardinghouse Creek.

The Biotic Condition Index (Winget and Mangum 1979) was also used to generate information about the condition of the two streams. Water chemistry for Eccles Creek was provided by EarthFax Engineering (2001). We utilized the upstream chemical conditions for Eccles Creek to estimate the conditions of Boardinghouse Creek since we did not have water chemistry data from Boardinghouse. The following estimates were used for alkalinity and sulfate levels: Boardinghouse Creek alkalinity estimated at 190 mg/l and sulfate estimated at 15 mg/l. Eccles Creek alkalinity recorded levels at 264 mg/l and sulfate estimated at 49 mg/l. The gradient in Boardinghouse is approximately 3.0 and in Eccles Creek it is approximately 3.3. The Boardinghouse Creek substrate, because of the tendency for the stream bed to be cemented together, was treated as boulder and rubble substrate. The combination of alkalinity, sulfate, and substrate classification generated an expected CTQp of 51 for Boardinghouse Creek (Winget and Mangum 1979). Eccles Creek had a number of well sorted substrates, including sand, gravel, boulder and rubble. With its combination of physical properties, it had an expected CTQp of 80 (Winget and Mangum 1979). The CTQa values for Boardinghouse Creek and Eccles Creek respectively were 93.6 and 59.7. The standard BCI for Boardinghouse Creek is 85.4 and that for Eccles Creek is 85.5 (Table 2).

Discussion

No data exist for the pre-emergency discharge invertebrate community in Eccles Creek, so we can only surmise that the benthos would have been similar to that of Boardinghouse Creek before August of 2001. However, Eccles Creek is confined to the southern side of the canyon by a roadway, and thus is adjacent to stands of conifers and the north facing slope of the canyon. This makes it subject to more shading than Boardinghouse Creek, which is more centrally located in its canyon and has an open overhead canopy. The high amount of marl precipitation in Boardinghouse Creek is a function of sunlight and algal growth. The shaded Eccles Creek would have had much less in-stream primary production prior to the emergency discharge, and thus may have supported a different community type.

The extremely low total number of taxa in Eccles Creek, however, indicate that a major impact has occurred on the stream ecosystem. Even if this system had fewer taxa than Boardinghouse Creek, the presence of just 5 taxa, as found in our samples, would not be expected. Further, densities in Eccles Creek were less than 1/500th of the densities in Boardinghouse Creek. This magnitude of difference is again highly unlikely, even when considering the physical differences in the settings of the two streams.

Based on the BCI indices alone, the two streams are about equal relative to their expected community values; the CTQa's for both streams are close to 85% of the predicted. These values suggest that both streams are marginally within the index range one would expect, given each stream's gradient, substrate, and water chemistry (alkalinity and sulfate). However, the CTQa values for the two streams are 59.7 and 93.6 respectively (Table 2). A CTQa value of less than 65 and a BCI value of less than 85 classifies the stream as high quality. A CTQa value of greater than 80 and a BCI value greater than 70 is considered to be indicative of either a need for water quality improvement or both habitat and water quality improvement (Winget and Mangum 1979).

In this case the physical parameters of Eccles Creek had already predicted (CTQp = 80; table 2) that it was in need for either habitat or water quality improvement. The interpretation of the BCI index data requires several cautions. First, the value is completely independent of the density of individual taxa. If some species are in high densities and others are in low densities, the index is not affected. This is a present-absence index. Second, the index is based on a mean of the index values assigned to each of the taxa present. Thus if only a few taxa are found in the system it is possible that they will can give a mean in the same range as a stream with 50 taxa. Thus within stream comparisons, based on repeated sampling periods at the same site, are the most reliable. Still, these results suggest that Eccles Creek is impacted and that Boardinghouse Creek is in relatively good condition.

The impact in Eccles Creek may be due to high discharge or chemical contamination, or both. Unseasonably high discharges can induce major changes in stream communities. Scouring floods, especially when occurring out of phase with normal flood events can significantly reduce the density of invertebrates (Williams and Hynes 1976). Eccles Creek was flowing at or slightly above bankfull when sampled, as indicated by inundated patches of grass and other terrestrial vegetation that would otherwise have been part of the riparian vegetation. Apparently the stream has been at that level since the emergency release has been in effect (EarthFax Engineering, 2001). The majority of the sediment transport and rearrangement by streams takes place at the bankfull stage (Leopold 1994), and for this reason bankfull flows, which usually occur in the frequency of once every one to two years (Leopold et. al.1964), are considered to maintain the stream geomorphology (Gordon et. al.1992). That does not mean that continual maintenance of stream geomorphology translates directly into no impact.

Bankfull discharges are responsible for the downstream migration of meanders in streams. The high flows will scour pools, changing them from depositional to erosional environments and in the process move the outside bend of meanders further downstream. These flows also rearrange the materials in riffles, which become the depositional region of the stream. Rocks scoured by the high velocity water in the pool, or swept into the pool from upstream, will be deposited as the water leaves the pool at the meander bend and slows (Leopold et. al.1964, Gordon et. al.1992). Because the deposition of material is a function of current velocity, the deposits are graded, with the largest particles (boulder, rubble) being deposited first and as velocity decreases the particles grade into increasing smaller sizes. These flows act to reset (maintain) the system by sorting sediments that otherwise tend to become embedded in silt and sand during low water periods. In that sense floods are considered a necessary part of the maintenance of natural stream ecosystems.

Under normal conditions aquatic invertebrate life cycles are adapted to the relatively predictable seasonal dynamics of the stream in which they reside. Variables such as the timing of runoff and annual changes in water temperature are predictable in their timing and intensity. Flooding during normally low water periods or elevated temperatures during normally cold water periods can be extremely detrimental to the invertebrate community. Suspended sands, swept up and carried by high water can physically abrade attached invertebrate taxa (e.g. *Brachycentrus*, *Hydropsyche*, and simullids; Waters 1995). Bedload, those particles too large to be suspended, but which are rolled and bounced downstream by high discharge, mechanically crush interstitial and epilithic benthic invertebrates. Elevated temperatures can induce emergence of insects at times when ambient air temperatures will not allow their survival.

The emergency discharge in Eccles Creek has acted as an extended spate. Much longer in duration than the normal spring runoff, and also beginning eight months out of phase with the natural occurrence of bankfull discharge. The presence of uncompacted, well sorted sediments in the stream bed suggests that this could be a major factor in the reduction of the invertebrate community. Water temperatures were also detectably elevated in the Eccles Creek relative to Boardinghouse Creek, although we did not take temperature readings while sampling. With prolonged sustained bankfull discharge the stream can be expected to increase its erosion at meander bends, widen its channel, and to down cut to bedrock. This can be exacerbated during spring runoff because the new maintenance discharge will be approximately twice what it has normally been.

The invertebrate community may recover if high discharge is the main factor that has eliminated the benthos. If the stream discharge stays high and water temperatures remain elevated the resulting community will likely be much lower in diversity, consisting of species that can successfully complete their life cycles under the moderated temperature regimens and higher discharge in the stream. The invertebrate community will be living under thermal conditions analogous to those below reservoirs. Reservoirs tend to moderate downstream temperatures, making the water warmer than normal in the winter and cooler than normal in the summer. But the species that normally make tailwater systems productive rely heavily on primary productivity of the reservoir upstream. In the case of Eccles Creek no such source of energy input will exist, and the food base will likely be detrital based. This makes the ultimate community changes, if recovery takes place, difficult to predict.

The water chemistry data (EarthFax Engineering 2001; Table 5) includes another set of factors that should be considered. The discharge from the mines (CS-12 and CS-14), list levels of heavy metals and cyanide that are potentially greater than that tolerable by aquatic organisms. For example both invertebrates and fish are very sensitive to copper. The concentrations in Eccles Creek may be below acute toxicity levels, but fish can detect and will avoid copper salts at levels less than 0.05 to 0.02 mg/l (Sprague 1964, Kleerekoper et. al. 1972). The alkalinity of the water in Eccles Creek may reduce the available copper cations (reduce toxicity), but the report does not provide the level of precision necessary to determine if these compounds are above lethal thresholds in the discharge water, nor are the concentrations downstream given. All that is required for a toxin to impact the community is a single slug flow that exceeds the lethal dosage, and the community will be gone. We cannot rule out this possibility with the data gathered.

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Table 1: Sample data and total invertebrates per square meter.

	Eccles Creek					Boardinghouse Creek				
Taxa	1	2	3	4	#/ m^2	1	2	3	4	#/ m^2
Ephemeroptera										
Baetis	0	0	1	0	**8**	1018	761	347	560	**20,348**
Cinygmula	0	0	0	0	**0**	8	4	0	12	**182**
Drunella sp.	0	0	0	0	**0**	4	0	1	0	**39**
Drunellla dodsei	0	0	0	0	**0**	1	0	1	0	**15**
Seratella	0	0	0	0	**0**	0	3	5	18	**197**
Ephemerella	0	0	0	0	**0**	1	3	1	0	**39**
Paraleptophlebia	0	0	0	0	**0**	3	6	1	2	**83**
Plecoptera										
Early instar Plecoptera	0	0	0	0	**0**	14	10	10	15	**371**
Malenka californica	0	0	0	0	**0**	46	48	127	50	**2,053**
Isoperla	0	0	0	0	**0**	0	0	3	0	**23**
Zapada	0	0	0	0	**0**	5	0	3	1	**68**
Trichoptera										
Brachycentrus	0	0	0	0	**0**	0	2	0	0	**15**
Micrasema	0	0	0	0	**0**	5	30	17	9	**462**
Dicosmecus	0	0	0	0	**0**	0	7	0	0	**53**
Arctopsyche	0	0	0	0	**0**	1	2	11	0	**106**
Hydropsyche	0	0	4	2	**45**	2	0	0	0	**15**
Neothremma alica	0	0	0	0	**0**	50	67	187	144	**3,394**
Oligoplebodes	0	0	0	0	**0**	18	14	14	7	**402**
Rhyacophila	0	0	0	0	**0**	9	5	16	12	**318**
Coleoptera										

Heterlimnus	0	0	0	0	**0**	2	4	16	4	**197**
Diptera										
Ceratopogonidae	0	0	0	0	**0**	0	0	0	1	**8**
Chironomidae	1	0	0	0	**8**	89	185	170	93	**4,068**
Empidae *Chelifera*	0	0	0	0	**0**	1	2	0	0	**23**
Simuliidae *Simulium*	0	0	0	0	**0**	22	25	22	31	**758**
Tipulidae *Dicranota*	0	0	0	0	**0**	1	0	0	0	**8**
Tipulidae *Limnophila*	0	0	0	0	**0**	1	1	0	0	**15**
Tipulidae *Tipula*	0	0	0	0	**0**	0	1	0	1	**15**
Tipulidae *Pedicea*	1	0	0	0	**8**	0	0	0	0	**0**
Collembola	0	0	0	0	**0**	0	1	2	0	**23**
Ostracoda	1	0	1	0	**16**	0	2	1	0	**23**
Hydracarina	0	0	0	0	**0**	9	8	6	11	**258**
Mollusca: Sphaerium	0	0	0	0	**0**	17	24	11	4	**424**
Oligochaeta	0	0	0	0	**0**	39	36	19	7	**765**
Tricladida Planariidae	0	0	0	0	**0**	38	26	24	18	**803**
totals	**2**	**0**	**4**	**2**	**61**	**1404**	**1277**	**1015**	**100 0**	**35,576**

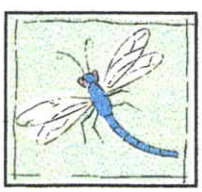
Table 2: Tolerance quotients and biotic condition index values.

	Eccles Creek	Boardinghouse Creek	Ideal stream (combined species list)
Taxa	**TQ**	**TQ**	**TQ**
Ephemeroptera			
Baetis	**72**	**72**	**72**
Cinygmula	**0**	**21**	**21**
Drunella sp.	**0**	**48**	**48**
Drunellla dodsei	**0**	**4**	**4**
Seratella	**0**	**48**	**48**
Ephemerella	**0**	**48**	**48**
Paraleptophlebia	**0**	**24**	**24**
Plecoptera			
Early instar Plecoptera	**0**	**36**	**36**
Malenka californica	**0**	**36**	**36**
Isoperla	**0**	**48**	**48**
Zapada	**0**	**16**	**16**
Trichoptera			
Brachycentrus	**0**	**24**	**24**
Micrasema	**0**	**24**	**24**
Dicosmecus	**0**	**24**	**24**
Arctopsyche	**0**	**18**	**18**
Hydropsyche	**108**	**108**	**108**
Neothremma alica	**0**	**8**	**8**
Oligoplebodes	**0**	**24**	**24**
Rhyacophila	**0**	**18**	**18**

Coleoptera			
Heterlimnus	**0**	**108**	**108**
Diptera			
Ceratopogonidae	**0**	**108**	**108**
Chironomidae	**108**	**108**	**108**
Empidae *Chelifera*	**0**	**108**	**108**
Simuliidae *Simulium*	**0**	**108**	**108**
Tipulidae *Dicranota*	**0**	**24**	**24**
Tipulidae *Limnophila*	**0**	**72**	**72**
Tipulidae *Tipula*	**0**	**36**	**36**
Tipulidae *Pedicea*	**72**	**0**	**72**
Collembola	**0**	**108**	**108**
Ostracoda	**108**	**108**	**108**
Hydracarina	**0**	**108**	**108**
Mollusca: Sphaerium	**0**	**108**	**108**
Oligochaeta	**0**	**108**	**108**
Tricladida Planariidae	**0**	**108**	**108**
totals	**468**	**1969**	**2041**
n	**5**	**33**	**34**
CTQa	**93.6**	**59.7**	**60.0**
CTQp	**80**	**51**	**60**
BCI = CTQp / CTQa X 100	**85.5**	**85.4**	
BCI based on combined species (column 3) as CTQp	**64.1**	**100.5**	

ECCLES CREEK
BENTHIC INVERTEBRATE
MONITORING

JUNE 2004



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December 2006

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INTRODUCTION

In August, 2001, an aquifer tapped by Skyline Mine near Scofield, UT, was discharged into Eccles Creek. The discharge maintained the stream at approximately bank-full levels until a diversion was completed to transfer part of the water into Electric Lake. The increased discharge had the potential to impact the stream benthic community, and this report summarizes the results of monitoring in Eccles Creek for spring, 2004.

Eccles Creek has been sampled intermittently since 1979 (Shiozawa 2003), and this report uses some of the previous data as estimates of baseline community structure. The samples taken in June, 2004, represent the sixth series taken from the stream following increased discharge. This project was undertaken for Canyon Fuel Company with the objective of determining the impact of the increased flows on the stream community.

METHODS

Quantitative samples from Eccles Creek were taken from the same locations sampled in July and October, 2002, and June and October, 2003. The three stations in Eccles Creek were designated as (1) above South Fork (EC-2: N 39^0 40.970', W 111.11.579', 8406 feet elevation), (2) Eccles Creek at Whisky Canyon (EC-4: N 39^0 40.908', W 111.10.747', 8234 feet elevation), and (3) Lower Eccles Creek (EC-5: N 39^0 41.001', W 111.10.031', 8074 feet elevation). Five replicate samples were taken per station. All samples were taken from locations in the stream where rubble or cobble substrates were present to reduce variability induced by habitats dominated by silt and sand sediments. A box sampler with a net mesh of 250 microns was used to collect the samples. The substrate was stirred to a depth of approximately five cm. All rocks within the area of the sampler were removed and individually washed to insure quantitative collection of the invertebrates. The samples were concentrated on a 64 micron mesh screen and field preserved in ethyl alcohol. A GPS unit was used to both locate and record the positions of the sample stations.

In the laboratory, the samples were sorted in pans illuminated from underneath. After visually sorting and removing invertebrates from a sample, the sample residue was concentrated, and then sub-sampled with a Stempel pipette. The sample residue was concentrated to a volume of 200 ml, and five 2 ml subsamples were processed under magnification with a dissecting scope. Invertebrates were identified to the lowest possible taxonomic level using the keys of Merritt and Cummins (1996). The mean density per subsample was used to project the total density of organisms in the sample residue. These data were then added to the total invertebrate count from the visual sorting of the sample. The data from all five samples were used to determine the density of taxa per square meter at each station. Mean biomass estimates were also generated so that trends in standing crop could be documented.

Analyses included comparisons of the number of taxa and mean densities in the June, 2004, samples with those generated from samples taken October, 2003; June, 2003; October, 2002; November, 2001 (Shiozawa 2002a); July, 2002 (Shiozawa 2002c);1979 (Winget 1980); and 1992 (Ecosystems Research Institute,1992). These comparisons allow a general evaluation of changes that have occurred since the increased discharge of water into the stream channel from the mine and help place the results in perspective relative to other perturbations and baseline conditions.

The community tolerance quotient (CTQ; Winget and Mangum 1979) was used to gain insight into the condition of the stream relative to idealized system predicted from slope, water chemistry, and substrate. Water chemistry for Eccles Creek was provided by EarthFax Engineering (2001). The following estimates were used for alkalinity and sulfate levels: Eccles Creek alkalinity recorded levels at 264 mg/l and sulfate estimated at 49 mg/l. The gradient in Eccles Creek is approximately 3.3%. With its combination of physical properties, it had a predicted community tolerance quotient (CTQp) of 80 (Winget and Mangum 1979). The biotic condition index was used to further interpret the data generated with this procedure.

Diversity was calculated for the stations using the Shannon-Weiner index (Pieliou 1977). This allows a general comparison among sample stations and dates. Diversity indices take the number of taxa and their individual densities into account generating a single value for each station. The greater the number of species or taxa and generally the more even the distribution of densities among taxa, the higher the index value. Finally, the data were clustered with the UPGMA algorithm using the Bray-Curtis measure of dissimilarity (Poole 1974, Krebs 1989). The NTSYSpc package was utilized to generate the cluster dendrograms (Rolf 2000).

RESULTS AND DISCUSSION

Number of Taxa

A total of 25 taxa, were collected from Eccles Creek in the spring, 2004, samples. The total number of taxa is more than have been collected in any of the post mine discharge samples to date. In comparison, just five taxa (*Baetis*, *Hydropsyche*, *Pedicia*, chironomids, and ostracods) were collected from Eccles Creek in the 2001 sampling series. In the spring, 2004, samples, ten taxa were collected in station EC2, 14 taxa in EC4, and 21 taxa in EC5 (Table 1). The baseline 1979 samples (Winget 1980) had up to 42 taxa at a station, although the spring, 1979, samples recorded between 27 to 38 taxa per station with 35 taxa at EC4 and 38 at EC 5. No samples were taken at station EC2 that spring.

The number of taxa in stations EC2 and EC4 in spring, 2004, were similar to the number collected in the early 1990s (Ecosystems Research Institute, 1992). If the stream was to be considered as recovered to the pre-mining level, the number of taxa would need to increase substantially especially in the upper station. The number of taxa in Eccles Creek, between the impacts of the early 1990s and the increased discharge in 2001, is unknown. However, studies in the 1980s documented the impact of the road (Shiozawa 2002b), so it is reasonable to assume that just prior to the increased

Table 1. Number of taxa collected from Eccles Creek.

	Winget, 1980		Ecosystems Research Institute, 1992			Shiozawa, 2002a	Shiozawa, 2002c	Shiozawa, 2003	Shiozawa & Hansen, 2004	Shiozawa & Kauwe, 2005	This Report
Sampling Date	May-June, 1979	Aug., 1979	June, 1990	Oct., 1990	Sept., 1991	Nov., 2001	July, 2002	Oct., 2002	June, 2003	Oct., 2003	June, 2004
South Fork tributary above mine, upper site (USF2)			20	11							
South Fork tributary above mine (USF)			12	9	21						
Middle Fork tributary above mine (UMF)			14	18							
Eccles Creek below mine (EC1)			4	2							
Eccles Creek above south Fork (EC2)		42	6		6		6	11	11	5	10
South Fork Eccles Creek (SF)	36	35	12								
Eccles Creek below South Fork (EC3)	27	30									
Eccles Creek at Whisky Canyon (EC4)	35	37	7	17	15	6	14	7	9	13	14
Lower Eccles Creek (EC5)	38	21	12	13/11	14		6	11	9	11	21

discharge of 2001, between 21 to 33 taxa were in the system. This would suggest that station EC5 could be near the recovery level for number of taxa in the June, 2004, samples. However, both stations EC2 and EC4 still need to have substantial increases in the number of taxa.

Total Density Comparisons

The total density (Table 2) of invertebrates in the June, 2004, sampling series was 60809/m^2, ten-fold higher than obtained in June, 2003, when the average was 6670/m^2. This is due to chironomids and oligochaetes especially in EC4 and EC5. The total density for June, 2004, is also higher than both the July, 2002, (Shiozawa 2002c) and the 1990 (Ecosystems Research Institute, 1992) estimates and are within the high range (except for EC2) of the densities recorded in 1979. As noted in previous reports (Shiozawa 2002c, 2003), the invertebrate densities should increase to 15000/m^2 or higher, if total numbers were to approximate the baseline condition. Based upon that measure, parts of the stream have now recovered, although EC2 appears to still require a 50% increase in total density.

Taxa Specific Densities

While total densities can give a quick picture of the state of the stream system, they can also be misleading if the component taxa are not considered. High densities of relatively few taxa are common in stressed or polluted systems, because under such conditions a few tolerant taxa are able to monopolize resources in an environment with reduced predation and competition.

Baetis increased in abundance in the June, 2004, samples (Table 3) from a low of 1151/m^2 in EC2 to over 8300/m^2 in EC5. This group was absent or rare in the June, 2003, sampling series (Shiozawa and Hansen 2004). In the July, 2002, samples (Shiozawa 2002c), *Baetis* densities were moderate at 242/m^2, 491/m^2, and 200/m^2 in EC2, EC4, and EC5 respectively. The October, 2002, samples showed *Baetis* absent at EC2, about the same density at EC4 (400/m^2), and higher at EC5 (1297/m^2). In the June, 2003, samples only six *Baetis* per square meter were found at EC4, and none were present at EC2 or EC5. The densities in EC2, EC4, and EC5 respectively in June, 2004, were 1151, 2624, and 8302 per square meter. This indicates that the baetid mayflies are now doing well. The basis for their recovery is not known, but it could be associated with increased precipitation in spring, 2004, possibly changing chemical conditions in the stream and increasing the flushing of detritus into the stream.

The mayfly *Cinygmula* was essentially absent in all stations in June, 2004. In June, 2003, it was in moderate densities in the upstream site (EC2) at 230/m^2, but rare or absent in the middle (EC4) and lower (EC5) sites. This genus was also absent in the fall, 2002, samples but was in low densities at stations EC2 and EC4 in July, 2002. *Cinygmula* is characteristic of relatively high quality stream systems being a scraper-gatherer, feeding on algae and detritus on the surface of rocks. Prior to the construction of the road, this genus reached densities of over 8000/m^2 in late summer, although spring and early summer densities were around 1000/m^2 in the middle and upper reaches of Eccles Creek (Shiozawa 2002b).

Table 2. Total invertebrate densities per square meter for selected studies on Eccles Creek.

	Winget, 1980		Ecosystems Research Institute, 1992			Shiozawa, 2002a	Shiozawa, 2002c	Shiozawa, 2003	Shiozawa &Hansen, 2004	Shiozawa & Kauwe, 2005	This Report
Sampling Date	May-June, 1979	Aug., 1979	June, 1990	Oct., 1990	Sept., 1991	Nov., 2001	July, 2002	Oct., 2002	June, 2003	Oct., 2003	June, 2004
South Fork tributary above mine, upper site (USF2)			1089	528							
South Fork tributary above mine (USF)			1144	216	2455						
Middle Fork tributary above mine (UMF)			1503	3812							
Eccles Creek below mine (EC1)			164	16							
Eccles Creek above south Fork (EC2)		73181	267		89		3703	1260	6265	1267	10865
South Fork Eccles Creek (SF)	9321	17773	1356								
Eccles Creek below South Fork (EC3)	18093	23247									
Eccles Creek at Whisky Canyon (EC4)	11634	25273	1719	3928	1419	61	8757	1491	10351	5004	73950
Lower Eccles Creek (EC5)	18661	2526	2212	4104/ 2863	1468		4927	2879	3387	16919	97614

Table 3. June, 2004, sample data and invertebrates per square meter.

	Eccles Creek above South Fork (EC2)						Eccles Creek Whisky Canyon (EC4)						Lower Eccles Creek (EC5)					
Taxa	1	2	3	4	5	**#/m²**	1	2	3	4	5	**#/m²**	1	2	3	4	5	**#/m²**
Ephemeroptera: *Baetis*	70	11	93	6	10	**1151**	8	70	60	51	244	**2624**	468	44	418	368	72	**8302**
Ephemeroptera: *Cinygmula*	0	1	0	0	1	**12**	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Ephemeroptera: *Epeorus*	0	0	0	0	0	**0**	0	0	0	1	0	**6**	0	0	0	0	0	**0**
Plecoptera: early instar	0	0	0	0	0	**0**	0	0	0	0	0	**0**	39	0	0	0	0	**236**
Plecoptera: *Diura knowltoni*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	1	0	0	0	**6**
Plecoptera: *Hesperoperla pacifica*	0	0	0	0	0	**0**	0	1	0	0	0	**6**	0	0	0	0	0	**0**
Plecoptera: *Isoperla*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	3	0	0	0	**18**
Plecoptera: *Perlomyia utahensis*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0	0	1	1	**12**
Plecoptera: *Zapada*	0	0	0	0	1	**6**	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Trichoptera: *Brachycentrus*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	1	0	0	0	**6**
Trichoptera: *Dicomoescus*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0	0	1	0	**6**
Trichoptera: *Hesperophylax*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0	1	0	0	**6**
Trichoptera: *Hydropsyche*	0	0	0	0	0	**0**	0	9	0	0	3	**73**	0	33	0	0	0	**200**
Trichoptera: *Hydropsyche* pupae	0	0	0	0	0	**0**	0	13	0	2	7	**133**	0	0	0	0	0	**0**
Trichoptera: *Hydroptila*	0	0	0	0	0	**0**	0	2	0	3	1	**36**	1	0	0	0	0	**6**
Trichoptera: *Ochrotricia*	0	0	0	0	1	**6**	1	33	0	53	132	**1327**	4	48	315	590	5	**5830**
Trichoptera: *Neothremma*	0	0	0	0	1	**6**	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Trichoptera: *Rhycophila*	6	1	3	1	0	**67**	0	0	0	1	0	**6**	0	0	0	0	0	**0**
Trichoptera: pupae	3	0	1	0	0	**24**	0	5	0	0	3	**48**	0	3	0	1	0	**24**
Coleoptera: Dytiscidae	0	0	0	0	0	**0**	0	0	0	1	0	**6**	0	0	0	0	0	**0**
Coleoptera: *Optioservus*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0	0	0	1	**6**
Diptera: Caloparyphus	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0	30	1	0	**188**

Diptera: Chironomidae larva	332	122	147	376	23	**6060**	212	608	212	810	1172	**18265**	1458	868	1407	1197	590	**33451**
Diptera: Chironomidae pupae	1	34	0	1	0	**218**	3	6	0	20	35	**388**	16	12	19	20	35	**618**
Diptera: Ceratopogonidae	0	0	0	0	0	**0**	0	0	0	0	0	**0**	32	0	0	0	0	**194**
Diptera: *Hemerodromia*	0	0	0	0	0	**0**	0	1	0	0	0	**6**	0	0	1	0	0	**6**
Diptera: *Hemerodromia* pupae	0	0	1	0	0	**6**	2	2	0	3	3	**61**	0	3	4	1	2	**61**
Diptera: *Simulium*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	14	0	0	0	0	**85**
Copepoda	30	0	30	0	0	**364**	30	30	0	60	0	**727**	0	90	150	270	0	**3091**
Ostracoda	0	0	0	0	0	**0**	30	30	0	0	90	**909**	0	0	120	570	60	**4545**
Hydracarina	0	0	0	0	1	**6**	0	0	0	0	30	**182**	0	2	1	1	0	**24**
Oligochaeta	61	31	151	181	61	**2939**	909	1032	2104	2323	1712	**48965**	438	1582	1990	97	1161	**37378**
Totals:	503	200	426	565	98	**10865**	1195	1872	2376	3328	3432	**73950**	2620	2817	4618	4122	1931	**97614**

The hydroptilid caddisfly, *Ochrotricha* (a micro-cadddisfly), was absent from both the upstream (EC2) and downstream (EC5) sites in June, 2003, but was abundant in EC4. In June, 2004, it was essentially absent in the upstream site, EC2, where a density of just six per square meter was recorded. However, it was abundant in both EC4 (1327/m^2) and EC5 (5830/m^2). Densities were high in several samples (these were mostly detected in subsamples). These insects attach to the surface of rocks and woody debris and feed on algae growing on the surface of the substrate. This taxon is tolerant to stressful conditions and their feeding behavior, utilizing algae on the surface of rocks, means they are not reliant on continual detritus input and deposition. The substrate at station EC2, while highly armored, should have contained enough epilithic algae to support these caddisflies. So their absence as that station is not clear.

Hydropsyche was also absent at station EC2 in the spring, 2004, sample series. It was absent in this site in spring, 2003, as well, and in July, 2002, it was found at about 18/m2, 73/m^2, 200/m^2 in 2004. This genus was the dominant benthic macroinvertebrate in the October, 2002, samples (1030/m^2, 1024/m^2, 1321/m^2 at stations EC2, EC4, and EC5 respectively). This difference could be due to temporal changes (seasonal emergence) or a lack of food for filter feeders because of the high flushing induced by the increased flows. The July, 2002, samples had densities of 18/, 1027/m^2, and 494/m^2 at stations EC2, EC4, and EC5 respectively. While lower densities may be characteristic during the early summer, a complete absence of individuals of this genus appears to be unlikely. This implies that other changes in the environment have a role in the disappearance of this group from the stations.

Chironomids were the dominant taxon in the June, 2004, samples. They showed significant increases over the June, 2003, densities being present at station EC2 at 6060/m^2 compared to the 2003 density of 3837/m^2. Station EC4 had chironomid larvae at 18265/m^2 compared to 7042/m^2 in June, 2003, and 33451/m^2 compared to 2424/m^2 in June, 2003, at station EC5 (Table 3). This family has undergone a dramatic increase in density. Midges are quite opportunistic and can disperse readily. In the absence of high densities of other taxa, they can develop very high densities. We did not identify the midges below the family level, but it is certain that the chironomid community included grazers and predators. The numbers at station EC2 did not have the high increases seen at stations EC4 and EC5.

Oligochaetes were the other taxa to show dramatic increases in density being 2939/m^2, 48965/m^2, and 37378/m^2 in stations EC2, EC4, and EC5 respectively. Their higher densities in the two downstream sites reflect the increased abundance of interstitial sediments. Oligochaetes are deposit feeders, burrowing into sand and other depositional microhabitats. The scarcity of such deposits at station EC2 is likely related to their lower densities at that station. Both Copepoda, 364/m^2, 727/m^2, and 3091/m^2 at stations EC2, EC4, and EC5 respectively, and Ostracoda 0/m^2, 909/m^2, and 4545/m^2 at stations EC2, EC4, and EC5 respectively also reflect the differences between station EC2 and the other two stations.

As with the spring, 2003, samples, the total densities of invertebrates in Eccles Creek in June, 2004, and the higher number of taxa at each site suggest that the stream is undergoing a recovery. But the major recovery seems to be occurring in the lower two stations, and EC2 appears to be responding quite differently to the continued mine discharge into the stream. In June, 2003, the two aquatic insects that showed increases, *Cinygmula* and *Ochrotricha*, are grazers. The two that were lost from the system, *Baetis* and *Hydropsyche*, fed more heavily on detrital food sources. The resurgence of the two detrital feeders suggests that detrital input and/or retention has increased. This could be associated with the termination of the extended drought and the flushing of allochthnous detritus into the stream system. Thus, increased runoff may have neutralized the impact of the continual scouring and armoring of the streambed by the mine water input.

Biomass

Total biomass for each site (Table 4) was determined. Such estimates allow insight into the actual partitioning of energy stored in the living system at different locations and time periods. As with the June, 2003, samples, the June, 2004, samples showed that both the middle (EC4) and lower (EC5) sites have the highest standing crop. Just as in June and October, 2003, the lowest station (EC5) was just half of the middle station (EC4) biomass. The biomass in the middle station was double what it was the previous fall. In contrast, the biomass estimate for EC2 was actually lower than it was the previous June suggesting at best no change in the community condition or possibly a reduction in the benthos at that station. When the June, 2003, biomass estimates are compared to the October, 2002, samples, the June, 2003, biomass estimates were about half of the October, 2002, biomass estimates. The June, 2004, biomass estimates in station EC2 were again about half of the previous fall's biomass. But both stations EC4 and EC5 were much higher than the fall, 2003, estimates being about two and one and a half times higher respectively.

Table 4. Biomass comparisons, October, 2002, through June, 2004.

	Upper Eccles (EC2)				Middle Eccles (EC4)				Lower Eccles (EC5)			
Sample	Oct., 2002	June, 2003	Oct., 2003	June, 2004	Oct., 2002	June, 2003	Oct., 2003	June 2004	Oct., 2002	June, 2003	Oct., 2003	June, 2004
1	0.58 g	0.13 g	0.23 g	0.26g	0.24 g	0.14 g	1.39 g	0.10g	0.21 g	0.14 g	0.41 g	0.23g
2	0.34 g	0.31 g	0.13 g	0.10g	0.40 g	0.10 g	0.59 g	4.38g	0.04 g	0.07 g	0.19 g	0.71g
3	0.07 g	0.05 g	0.06 g	0.06g	0.27 g	0.06 g	0.50 g	0.18	0.40 g	0.01 g	0.37 g	.057g
4	0.31 g	0.04 g	0.28 g	0.06g	0.05 g	0.12 g	0.19 g	0.33g	0.43 g	0.05 g	0.64 g	1.07g
5	0.29 g	0.11 g	0.33 g	0.05g	0.07 g	0.24 g	0.43 g	1.06g	0.10 g	0.10 g	0.03 g	0.62g
Total	1.59 g	0.64 g	1.03 g	0.53 g	1.03 g	0.66 g	3.11 g	6.05 g	1.18 g	0.37 g	1.64 g	2.69 g
per m^2	9.64 g/m^2	3.88 g/m^2	6.24 g/m^2	3.21 g/m^2	6.24 g/m^2	4.00 g/m^2	18.82 g/m^2	36.66 g/m^2	7.15 g/m^2	2.24 g/m^2	9.95 g/m^2	16.28 g/m^2

Biotic Condition Index

Community tolerance quotients are a part of the biotic condition index developed by Winget and Mangum (1979). The community tolerance quotients are of two types, the actual community tolerance quotient, CTQa, and the predicted community tolerance quotient, CTQp. The predicted community tolerance quotient is based on water chemistry, substrate, and gradient and was determined to be 80 using the directions in Winget and Mangum (1979). CTQa values are a simple arithmetic mean of pre-assigned index values for the taxa present at a given station. The CTQa indices for the June, 2004, samples and an idealized stream, based on a combination of taxa collected from Boardinghouse Creek in November, 2001, and all taxa collected in Eccles Creek from 2001-2004 are given in Table 5. Generally, CTQa values less than 65 represent high quality waters while those between 65 and 80 represent situations with moderate to high quality water. CTQa values greater than 80 represent low water quality or stressed systems. The June, 2004, CTQa values were 82.72, 91.4, and 87.91 at stations EC2, EC4, and EC5 respectively. All are greater than 80, thus indicating water quality problems with Eccles Creek. However, in June, 2003, these stations had CTQa values of 86.8, 94.3, and 96.9 and in July, 2002, these same stations had CTQa values of 99, 52, and 66 (Table 6). It, therefore, appears that the three stations are still undergoing changes in their CTQa values and that the only consistent site is EC2 which has given readings of poor water quality since the initial 2002 sampling. The general trends of all three stations showed an increase in stress from October, 2002, to June, 2003, with a decrease in fall, 2003, and then an increase in stress level in June, 2004. This indicates that significant problems still exist with Eccles Creek, especially station EC2, and confirms the changes detected with individual taxa and biomass.

Table 5. Tolerance quotients.

Eccles Creek; June, 2004 Taxa	above South Fork (EC2)	at Whisky Canyon (EC4)	Lower Eccles (EC5)	Ideal stream (species list, including Boarding-house Creek)
Ephemeroptera: Baetidae: Baetis	72	72	72	72
Ephemeroptera: Ephemerellidae: *Drunella sp.*	0	0	0	48
Ephemeroptera: Ephemerellidae: *Drunella dodsei*	0	0	0	4
Ephemeroptera: Ephemerellidae: *Seratella*	0	0	0	48
Ephemeroptera: Ephemerellidae: *Ephemerella*	0	0	48	48
Ephemeroptera: Heptageniidae: *Cinygmula*	48	0	0	21
Ephemeroptera: Heptageniidae: *Epeorus*	0	21	0	21
Ephemeroptera : Leptophlebidae: *Paraleptophlebia*	0	0	0	24
Plecoptera early instar	0	0	36	36

Plecoptera: Leuctridae: *Perlomyia utahensis*	0	0	18	18
Plecoptera: Nemouridae: *Malenka californica*	0	0	0	36
Plecoptera: Nemouridae: *Zapada*	16	0	0	16
Plecoptera: Perlididae: *Hesperoperla pacifica*	0	18	0	18
Plecoptera: Perlodidae: *Diura knowltoni*	0	0	24	24
Plecoptera: Perlodidae: *Skwalla parallela*	0	0	0	18
Plecoptera: Perlodidae: *Isoperla*	0	0	48	48
Trichoptera: pupae	108	108	108	108
Trichoptera: Brachycentridae: *Brachycentrus*	0	0	24	24
Trichoptera: Brachycentridae: *Micrasema*	0	0	0	24
Trichoptera: Hydropsychidae: *Arctopsyche*	0	0	0	18
Trichoptera: Hydropsychidae: *Hydropsyche*	0	108	108	108
Trichoptera: Hydroptilidae: *Hydroptila*	0	108	108	108
Trichoptera: Hydroptilidae: *Ochrotricia*	108	108	108	108
Trichoptera: Limnephilidae: *Dicosmecus*	0	0	24	24
Trichoptera: Limnephilidae: *Hesperophylax*	0	0	108	108
Trichoptera: Psychomyiidae: *Tinodes*	0	0	0	108
Trichoptera: Rhyacophilidae: *Rhyacophila*	18	0	0	18
Trichoptera: Uenoidae: *Neothremma alica*	0	0	0	8
Trichoptera: Uenoidae: *Oligoplebodes*	0	0	0	24
Coleoptera: Dytiscidae	0	72	0	72
Coleoptera: Elmidae: *Optioservus*	0	0	108	108
Coleoptera: Haliplidae: *Peltodytes*	0	0	0	54
Diptera: Ceratopogonidae	0	0	108	108
Diptera: Chironomidae	108	108	108	108
Diptera: Empididae: *Chelifera*	0	0	0	108
Diptera: Empididae: *Hemerodromia*	108	108	108	108
Diptera: Simuliidae: *Simulium*	0	0	108	108
Diptera: Stratiomyidae: *Allognasa*	0	0	0	108

Diptera: Stratiomyidae: *Caloparyphus*	0	0	108	108
Diptera: Tipulidae: *Dicranota*	0	0	0	24
Diptera: Tipulidae: *Limnophila*	0	0	0	72
Diptera: Tipulidae: *Tipula*	0	0	0	36
Diptera: Tipulidae: *Pedicea*	0	0	0	72
Diptera: Tipulidae: *Antocha*	0	0	0	24
Collembola	0	0	0	108
Hemiptera: Saldidae	0	0	0	108
Acari: Hydracarnia	108	108	108	108
Ostracoda	0	108	108	108
Copepoda	108	108	108	108
Cladocera	0	0	0	108
Mollusca: Gastropoda: *Gyraulus*	0	0	0	108
Mollusca: Spharidae: *Sphaerium*	0	0	0	108
Oligochaeta	108	108	108	108
Tricladida: Planariidae	0	0	0	108
Nematoda	0	108	108	108
Total	910	1371	2022	3694
n	11	15	23	55
CTQa	82.72	91.4	87.91	67.16

Comparisons of Community Tolerance Quotient and Biotic Comparison Indices

CTQa values for Eccles Creek can be compared from the 1979, 1990, and 2000 time periods. These values detected the impact in the 1990s in three stations below the mine (EC1, EC2, and EC4; Table 6), when the stations recorded increases in the CTQa values from the 50s and 60s to the 60s and 70s. The 1990 spill did not reach the lowest station, EC5, which maintained its CTQa in the 50s range. Beginning in 2001, the average CTQa for the stream jumped to 94 and stayed above 70 in 2002, and in June, 2003, it was again near 94 but fell to 78 in the fall of that year. In June, 2004, it increased to 87. Based on the CTQa values, the mine discharge has had a more intense impact on the stream than did the 1990 detergent spill, and between 2001 and June, 2004, the number of clean water taxa has decreased substantially in both EC4 and EC5.

Table 6. CTQa and BCI values for selected studies on Eccles Creek.

	Winget, 1980		Ecosystems Research Institute, 1992			Shiozawa, 2002a	Shiozawa, 2002c	Shiozawa, 2003	Shiozawa &Hansen, 2004	Shiozawa, 2005	This Report
Sampling Date	May-June, 1979	Aug., 1979	June, 1990	Oct., 1990	Sept., 1991	Nov., 2001	July, 2002	Oct., 2002	June, 2003	Oct., 2003	June, 2004
	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI	CTQa /BCI
South Fork tributary above mine, upper site (USF2)			59/133	53/151							
South Fork tributary above mine (USF)			49/163	59/136	45/178						
Middle Fork tributary above mine (UMF)			54/148	49/163							
Eccles Creek below mine (EC1)			67/119	108/74							
Eccles Creek above south Fork (EC2)		65/123			73/110		99/81	86/93	87/92	88/91	83/97
South Fork Eccles Creek (SF)	59/136	64/125	55/145								
Eccles Creek below South Fork (EC3)	65/123	55/145									
Eccles Creek at Whisky Canyon (EC4)	62/127	61/131	69/116	70/114	63/127	94/85	52/154	69/116	94/79	76/105	91/88
Lower Eccles Creek (EC5)	59/136	74/108	53/151	55/145 57/140	58/138		66/121	69/116	97/82	71/112	88/91
Average	62/131	64/126	59/140	64/132	60/138	94/85	72/119	75/108	93/86	78/102	87/92

The biotic condition index (BCI) is simply CTQp/CTQa X 100. This measure, according to Winget and Mangum (1979), can be used in conjunction with CTQa to generate a broader interpretation of the state of the stream system. Ideally, if all predictors are accurate, a pristine system will have a BCI of 100 (CTQp = CTQa). BCI values below 100 represent a condition where fewer clean water taxa than predicted are present and thus indicate a reduction in the quality of the habitat. Any BCI value above 100 represents communities whose clean water taxa are in greater abundance than predicted. In 32 of the 43 sample stations presented in this report (Table 6), the BCI was over 100. None of the stations sampled in June, 2004, had a BCI value above 100, although two stations, EC4 and C5, had values over 100 in fall, 2003. The BCI values generated in previous studies of Eccles Creek indicate that the CTQp is systematically biased in its prediction of the expected average community tolerance quotient. However, that implies that a BCI value less than 90 is a strong indication of problems in the system. In general, stations EC4 and EC5 have fluctuating BCI values tending to have higher values (more clean water taxa) in the fall and fewer clean water taxa in the spring. However, it also appears that the trend is one of increasing BCI index readings each year. This indicates that the community, rather than recovering, is still deteriorating in condition.

CTQp values are likely to induce a systematic error into the computation. The interpretation given in Winget and Mangum (1979) cannot be assumed to have consistent properties when compared across streams. Further, the CTQa values are based on the average index from just those taxa that are present, and all taxa are weighted equally regardless of differences in abundance. A site could conceivably have just a single individual and nothing else. For example, one specimen of *Neothremma* would give the sample a CTQa of eight. One *Neothremma* and 5000 chironomids would have a CTQa of 58 while 5000 chironomids would have a CTQa of 108. For these reasons, the CTQa and BCI values cannot be relied upon as stand alone indicators of stream condition.

Diversity Index

Diversity indices are a way of combing both number of taxa and relative densities into a single measurement. High diversity index values indicate more taxa and a greater number of individuals per taxon. Low diversity values generally reflect a depauperate fauna in both species and somewhat in numbers. The baseline stations (the 1979 samples, Table 7) had diversity values ranging between about 1.96 and 3.5. The areas impacted in 1990-1991 had diversities values around one. But in September, 1991, the values fell to around 0.5. However, in that same sample series, the Upper South Fork had a diversity of 0.7 considerably lower than in the previous year.

Diversity values from 2001-2002 were below 1.0 for all sampled stations. In June, 2003, the diversity index value exceeded 1.0 at station EC2, and the diversity value has stayed above 1.1 since then. Station EC4 exceeded a diversity index value of 1.0 in October, 2003, but the long-term trend appears to be hovering just below the 1.0 level with the June, 2004, value at 0.982. Station EC5 has had its diversity value fluctuating below that of station EC4 until the June, 2003, sample period when it had the highest diversity value (1.147) recorded in the post discharge period. It appears that a slight recovery may be underway in the downstream-most station, EC5. However, the diversity values are significantly below those of the reference conditions established in the 1970s. Both

Table 8. Diversity indices, based on natural logs, for selected studies on Eccles Creek.

	Winget, 1980		Ecosystems Research Institute, 1992			Shiozawa, 2002a	Shiozawa, 2002c	Shiozawa, 2003	Shiozawa & Hansen 2004	Shiozawa, 2005	This Report
Sampling Date	May-June, 1979	Aug., 1979	June, 1990	Oct., 1990	Sept., 1991	Nov., 2001	July, 2002	Oct., 2002	June, 2003	Oct., 2003	June, 2004
South Fork tributary above mine, upper site (USF2)			1.63	1.9							
South Fork tributary above mine (USF)			1.72	1.9	0.702						
Middle Fork tributary above mine (UMF)			1.66	1.9							
Eccles Creek below mine (EC1)			1.06	0.7							
Eccles Creek above south Fork (EC2)		1.964	1.58		0.400		0.398	0.836	1.314	1.190	1.165
South Fork Eccles Creek (SF)	3.510	3.322	1.62								
Eccles Creek below South Fork (EC3)	2.450	2.743									
Eccles Creek at Whisky Canyon (EC4)	2.450	3.060	1.22	1.6	0.666	0.757	0.957	0.835	0.955	1.432	0.982
Lower Eccles Creek (EC5)	2.280	2.590	1.24	1.8/ 1.4	0.416		0.829	0.341	0.789	0.750	1.474

stations EC4 and EC5 would need to have diversity indices in the 2.5 to 3.5 range. Station EC2 would only need to double its index value to return to the pre-development conditions.

Cluster Analysis

The final analysis utilized in this study was clustering. This approach generates a visual representation of the relationships among samples based upon their similarity or dissimilarity to one another. The dissimilarity index utilized in this study considers both quantitative counts of individuals within each taxon and their relative densities. The cluster results (Figure 1) separate the majority of the spring-summer samples, including all of the reference samples, into one cluster while the fall samples are part of a second cluster. The exceptions are eight spring samples taken in the 1990s and one sample taken in fall, 2003, at station EC5. The 1990 samples occur in the fall cluster but show a high dissimilarity to other members of the fall grouping. The fall, 2003, samples from EC5 placed that station in the spring-summer samples with it being most similar to the 1979 reference samples. The overall separation of spring-summer samples from the fall samples illustrates very clearly the effect of seasonality.

The spring, 2004, samples joined the spring-summer cluster as was expected. Station EC2 for the spring, 2004, clustered most tightly with station EC4 from both 2002 and 2003 suggesting that the community at the upstream-most sampling site (EC2) may be converging toward a structure similar to that previously seen in EC4. Station EC4 was well scoured immediately after the increase in discharge into the stream. However, both EC4 and EC5 in spring, 2004, combined to form a separate cluster joining basally to the spring-summer cluster. While these sites were most similar to the spring-summer cluster, they joined at a dissimilarity level above 0.8 which is very divergent. This indicates that while they retain some of the seasonal signal, their community structure is becoming more divergent rather than converging with the baseline data from the late 1970s. Thus, the cluster analysis indicates that the stream is still far from its original condition and the lower stations appear to be in a transitional state, but to where is not clear.

CONCLUSIONS

Eccles Creek in June, 2004, still showed significant impacts from the increased inflow of water. The number of taxa had increased beyond that recorded in previous sampling periods since the increase in discharge, but the number of taxa was still just 40% to 55% of the total number recorded per station in the 1979 samples. Stations EC2 and EC4 appear to be the ones that have recovered the least. Total densities of invertebrates for all stations had increased dramatically especially the two downstream stations, EC4 and EC5. Their increases exceeded what would be expected in an unimpacted system, but high densities in low diversity systems is common when a system has been impacted.

Baetis returned in numbers in the spring, 2004, samples at all stations and at densities that imply it is doing well. However, the grazer, *Cinygmula*, became rare suggesting that something impacted this taxon perhaps either food availability or recruitment. The causal factors are not known. Another grazer, *Ochrotricha*, was essentially absent at Station EC2 but had good densities at stations EC4 and EC5. The downstream abundance of *Ochrotricha*, which utilizes the same general food type as *Cinygmula*, suggests that *Cinygmula* may have been more limited by recruitment failure rather than by a lack of food. The net spinning caddisfly, *Hydropsyche*, was absent at Station EC2 and in low densities relative to previous years at the other two stations. Its distribution was similar to that of *Ochrotricha*. Chironomids and oligochaetes increased at all stations but were most abundant at stations EC4 and EC5. Their numbers reflect the better conditions at these two downstream stations.

Biomass estimates did not increase in station EC2 from the previous spring sample period. However, both EC4 and EC5 did have significant increases again reflecting the improved conditions at those two stations. The CTQa indices indicated that the taxa composition at all three stations tended to have relatively fewer clean water taxa. Station EC2 has been relatively consistent in its CTQa ranging between 99 and 83 from 2002 to this sample series. It may have improved slightly from the initial sample in July, 2002. EC4 and EC5 both appear to have gotten worse as time progressed. Both had CTQa values in the high 50s and low 60s in July, 2002, but in this last series, their CTQa values were about 90. When the CTQa was adjusted for the physical parameters in the stream, station EC2 had consistently lower BCI values than expected. Stations EC4 and EC5 both had fluctuating BCI values tending to meet the expected score during the fall sampling period and then having lower BCI scores than predicted during the spring sampling periods. However, their BCI values appear to be on an upward trend indicating decreasing quality.

In contrast to the CTQa and BCI indices, the diversity of station EC2 appears to have slightly improved since the initial sampling in 2002. Its diversity level is still much lower than we would expect in an unimpacted stream, but the increase in diversity is generally interpreted as a positive indicator of change. Station EC4 does not appear to have changed much, but EC5 may have improved considerably from winter, 2003, to spring, 2004. All stations still need substantial increases in their diversity indices before they could be considered recovered.

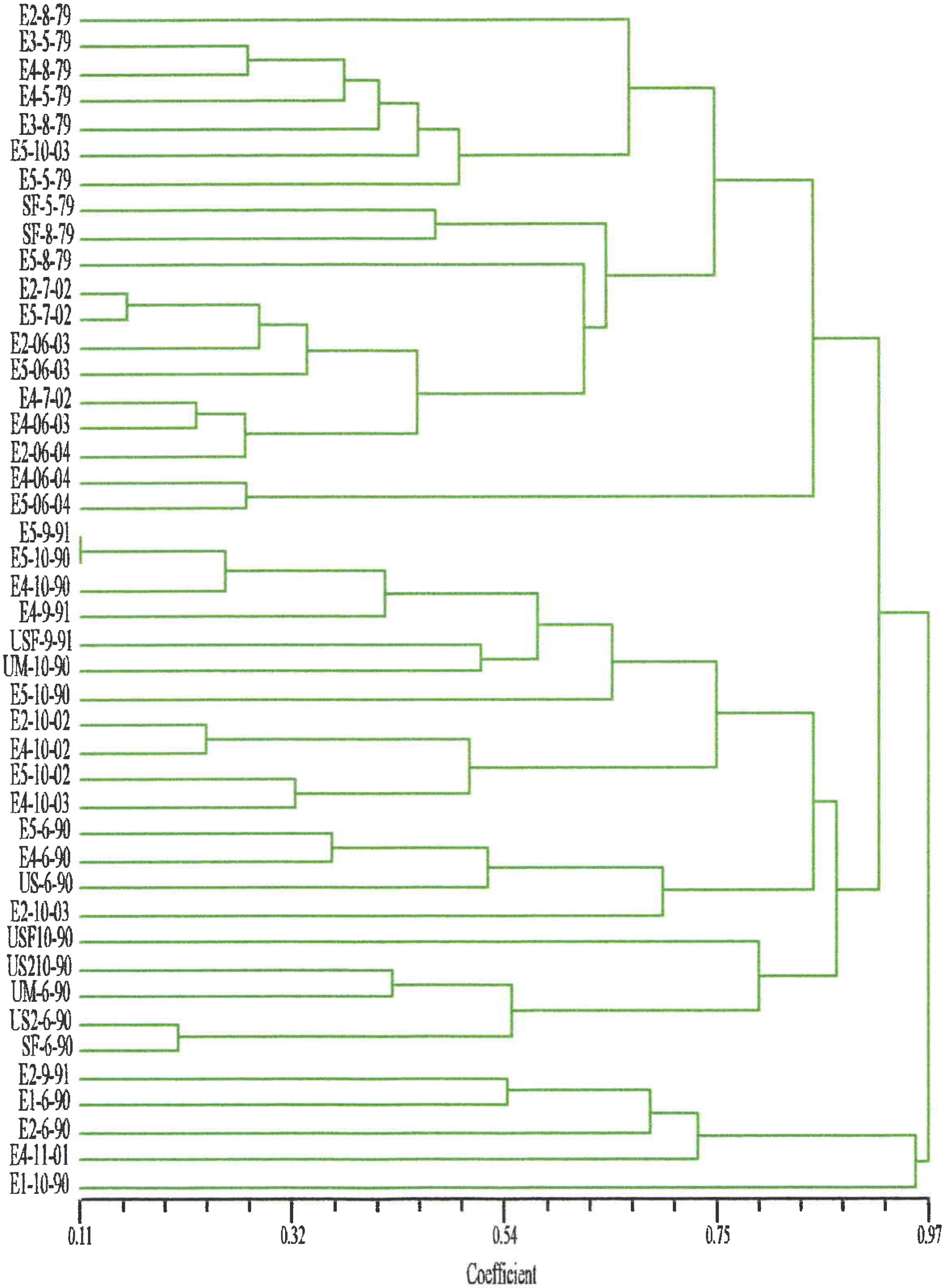
The cluster analysis indicated that the upstream most station, EC2, was becoming more similar to station EC4 in previous spring samples. However, both EC4 and EC5 for the June, 2004, sampling series had a significant increase in dissimilarity between their community structure and the spring samples taken in previous years. These two stations cluster out together, with a dissimilarity less than 0.30 between each other, and they are part of the spring-summer cluster, but their cluster was also over 80% dissimilar from the other spring-summer stations. That high dissimilarity suggests that the two stations are on a separate trajectory taking them farther away from the baseline spring-summer community structure documented in the 1970s.

In spring, 2004, the community again had detritivores as a significant component especially in the downstream two stations where both midges and oligochaetes were abundant. This may be associated with increased runoff into the system which would increase allochthnous detritus input. However, the upstream most station, EC2, showed the effects of the armoring of the sediment through the continued high flows. The armored substrate then tends to be cemented together by the precipitation of carbonates. The carbonate precipitate has cemented the rubble and even woody debris into a solid stream bed that is incapable of retaining particulate organic matter and which also severely limits interstitial habitat for stream invertebrates. This marl or tufa streambed may have existed prior to the increased discharge since it has been observed in other nearby unimpacted streams (Shiozawa personal observation), but in those cases, the marl is much lower in extent and loose sediments form a veneer over the encrusted substrate. In those systems, sediments input from side drainages and the riparian appear to be in a quasi-equilibrium with stream export.

In Eccles Creek, the sustained high flow tends to rapidly flush sediment out of the stream channel especially in the upper-most reaches where the inflowing mine water is the most sediment starved. It does appear that some of the sediments are accumulating in the downstream stations especially EC5. The retention of the sediments may be in part assisted by beaver activity, which often favors the retention of fine sediments, and these foster increases in taxa that burrow into fine substrates such as chironomids and oligochaetes. Other taxa, especially stoneflies, which require higher interstitial oxygen tensions associated with coarse sediments, will be excluded from such habitats. Conditions now suggest that the high carbonate content of the water is also important. As the water degasses carbon dioxide in the turbulent upper reaches of the stream, the loss of carbonic acid shifts the stream to a more basic pH. This favors calcium carbonate precipitation and a cementing of the substrate. This amplifies the problem of low sediment retention.

As emphasized in previous reports (Shiozawa 2002a, b, c), the benthic community in Eccles Creek is unlikely to return to the structure that existed in 1979 unless the sustained discharge is eliminated. The higher flushing rate relative to the input of allochthonous detritus will tend to prevent the re-establishment of the 1979 community structure, especially in the upper reaches of the stream. It may be possible for the lower reaches, especially EC5 to mover closer to the 1979 standard, since the lower reaches should be able to accumulate detritus flushed from upstream.

Figure 1. UPGMA cluster dendrogram of relationships among stations and dates sampled.



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AN ASSESSMENT OF THE MACROINVERTEBRATES *of* ECCLES CREEK *in* OCTOBER, 2004

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March 2007

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INTRODUCTION

In August, 2001, an aquifer tapped by Skyline Mine, near Scofield, UT, significantly increased the discharge of water from the mine into Eccles Creek. The discharge maintained the stream at approximately bank full levels. This report summarizes results of monitoring of the benthic invertebrate community in Eccles Creek for fall, 2004. It also includes summaries of previous data to maintain the context for comparative purposes and a multivariate analysis of all available benthic data for Eccles Creek collected through 2004. The samples taken in fall, 2004, represent the seventh series taken from the stream following the increased discharge. This project was undertaken for Canyon Fuel Company with the objective of determining the impact of the increased flows on the stream community.

METHODS

Quantitative samples were taken from Eccles Creek in October, 2004. The three stations sampled were Eccles Creek above South Fork (EC2: N 39^0 40.970', W 111.11.579', 8,406 feet elevation), Eccles Creek at Whisky Canyon (EC-4: N 39^0 40.908', W 111.10.747', 8,234 feet elevation), and Lower Eccles Creek (EC-5: N 39^0 41.001', W 111.10.031', 8,074 feet elevation). These three stations have been sampled intermittently since 1979 (Shiozawa 2003). The samples were taken from the same locations sampled in July and October, 2002; June and October, 2003; and June, 2004. Five replicate samples were taken per station. All samples were taken from locations in the stream where rubble or cobble substrates were present. A box sampler with a net mesh of 250 microns was used to collect the samples. The substrate was stirred to a depth of approximately 5 cm whenever possible. In some cases, the streambed could only be brushed. All rocks within the area of the sampler were removed and individually washed to insure quantitative collection of the invertebrates. The samples were concentrated on a screen with a mesh of 64 microns and field preserved in ethyl alcohol. A GPS unit was used to both record and locate the positions of the sample stations.

In the laboratory, the samples were sorted in illuminated pans. All invertebrates were removed and identified to the lowest possible taxonomic level using the keys of Merritt and Cummins (1996). The visually sorted samples were then subsampled by suspending the residual sample in a volume of 200 ml of water. Five 2 ml subsamples were then removed and processed under magnification with a dissecting scope. The mean density per subsample was used to project the total density of organisms remaining in the sample after it was visually sorted. These projections were added to the total count from the visual sorting. The data were then used to determine the density of taxa per square meter. Mean biomass estimates based on wet weights of invertebrates were also generated so that trends in standing crop could be documented.

Analyses included comparisons of the number of taxa and mean densities in the October, 2004, samples with those generated from samples taken June, 2004; October, 2003; June, 2003; October, 2002; November 24, 2001 (Shiozawa 2002a); and July 2, 2002 (Shiozawa 2002c) and with samples taken in 1979 (Winget 1980) and 1992 (Ecosystems Research Institute1992). These comparisons allow a general evaluation of changes that have occurred since the increased discharge of water into the stream channel from the mine and help place the results in perspective relative to other perturbations and baseline conditions.

The community tolerance quotient (CTQ; Winget and Mangum 1979) was used to gain insight into the condition of the stream relative to an idealized system predicted from slope, water chemistry, and substrate. Water chemistry for Eccles Creek was provided by EarthFax Engineering (2001). The following estimates were used for alkalinity and sulfate levels: Eccles Creek alkalinity recorded levels at 264 mg/l and sulfate estimated at 49 mg/l. The gradient in Eccles Creek is approximately 3.3%. With its combination of physical properties, it had a predicted community tolerance quotient (CTQp) of 80 (Winget and Mangum 1979). The Biotic Condition Index was used to further interpret the data generated with this procedure.

Diversity was calculated for the stations using the Shannon-Weiner index (Pieliou 1977). This allows a general comparison among sample stations and dates. Diversity indices take the number of taxa and their individual densities into account generating a single value for each station. The greater the number of species or taxa and generally the more even the distribution of densities between taxa, the higher the index value.

The data were clustered with the UPGMA algorithm using the Bray-Curtis measure of dissimilarity (Poole 1974, Krebs 1989). The NTSYSpc package was utilized to generate the cluster dendrograms (Rolf 2000). As a final analysis, the entire data set was examined with an ordination technique, detrended correspondence analysis (Braak and Smilauer 2002). This was accomplished with a reduced data set of 44 taxa. Taxa that were rare in frequency or total abundance were eliminated from the analysis. A log X+1 transformation was applied to the data to reduce the effect of high densities. This procedure is used mainly as an exploratory method so that general trends in the sampling stations can be graphically appraised.

RESULTS AND DISCUSSION

<u>Number of Taxa</u>

Twenty-six taxa were collected from Eccles Creek in the fall, 2004 samples, an increase of five taxa over fall, 2003. This is the highest number of taxa collected since this sample series began in 2001. Excluding two categories (unidentified plecopterans and chironomid pupae), seven taxa were collected in EC2, 16 in EC5, and 24 taxa in EC4 (Table 1). The total number of taxa is more than collected in the spring, 2003, and the 23 taxa collected in October, 2002. The taxa increase occurred mainly in the dipterans, but shifts in rare taxa in the Plecoptera and Trichoptera also occurred. The increase is significantly higher than the five taxa (*Baetis*, *Hydropsyche*, *Pedicia*, chironomids, and ostracods) gathered from Eccles Creek in the 2001 sampling series. In comparison to other October data, the October, 2004 samples had the highest recorded number of taxa in EC4 and EC5, but the number of taxa at station EC2 fell below the average collected from 2002 through 2004. Station EC5 had numbers of taxa comparable with the fall samples taken in 1979 (Winget 1980) and was double that seen in the fall samples in 1990-1991 (Ecosystems Research Institute 1992). Both stations, EC2 and EC4, are still substantially below the baseline number of taxa collected in 1979. Based on this measure alone, station EC5 could be considered to have recovered to pre-mining conditions, but the other two stations have not. But as noted in previous reports, the sustained high discharge does not favor retention of detritus, and thus, it is unlikely that in the long term, the stream can recover without a reduction in flow or an increase in loose, coarse material in the streambed. During sampling, it has been obvious that most of the habitat in EC2 and much of the habitat in EC4 is scoured to bedrock and has larger rubble cemented onto the substrate. The cementing appears to be a combination of carbonate precipitation and some iron deposition, a function of pH changes with degassing of carbon dioxide and the infusion of oxygen into what may be anoxic water entering the stream. These processes do not leave much interstitial space for invertebrates and thus eliminates or reduces those taxa that require such habitat.

Total Density Comparisons

Total density (Table 2) of invertebrates in stations EC4 and EC5 in October, 2004 was higher than those recorded in the baseline studies in 1979. In contrast, station EC2 densities were less than 1/16th of the 1979 level. The EC2 data reflect the reduced habitat available for colonization in that reach of the stream system, but it should be noted that the numbers are considerably higher than in the previous fall samples. The high densities in the other two stations, EC4 and EC5, are also much greater than in previous fall samples. And it appears that a pattern of high spring and low fall densities predominates at the three stations with the exception of station EC5 where the pattern was reversed in 2003. This general pattern is partly due to seasonal changes in community structure. Early instars of many invertebrates can pass through a 250 micron mesh net, and chironomids often overwinter in early instars (e.g. Shiozawa and Barnes1977). By June, they would have grown to a size that could be more readily collected by the sampler.

Based on total densities, both EC4 and EC5 are exceeding pre-impact numbers. If density alone were a function of recovery, and if higher numbers denote greater recovery, then those two stations could be considered to have recovered. However, as noted below, in stressed systems, a few taxa often dominate the community and can easily inflate the density of the community.

Taxa Specific Densities

While total densities can give a quick picture of the state of the stream system, they can also be misleading if the component taxa are not considered. High densities of relatively few taxa are common in stressed or polluted systems, because under such conditions a few tolerant taxa are able to monopolize resources in an environment with reduced predation and competition.

Baetis were absent or rare in the June, 2003 sampling series. In the July, 2002, samples (Shiozawa 2002c), *Baetis* densities were moderate at $242/m^2$, $491/m^2$, and $200/m^2$ in EC2, EC4, and EC5,

Table 1. Number of taxa collected from Eccles Creek.

	Winget 1980		Ecosystems Research Institute 1992			Shiozawa 2002a	Shiozawa 2002c	Shiozawa 2003	Shiozawa & Hansen 2004	Shiozawa 2005	Shiozawa 2005	this report
Sampling date	May-June 1979	Aug 1979	June 1990	Oct 1990	Sept 1991	Nov 2001	July 2002	Oct 2002	June 2003	Oct 2003	June 2004	Oct 2004
South Fork tributary above mine, upper site (USF2)			20	11								
South Fork tributary above mine (USF)	30		12	9	21							
Middle Fork tributary above mine (UMF)	29		14	18								
Eccles Creek below mine (EC1)			4	2								
Eccles Creek above south Fork (EC2)	35	42	6		6		6	11	11	5	10	7
South Fork Eccles Creek (SF)	36	35	12									
Eccles Creek below South Fork (EC3)	27	30										
Eccles Creek at Whisky Canyon (EC4)	35	37	7	17	15	6	14	7	9	13	14	16
Lower Eccles Creek (EC5)	38	21	12	13/11	14		6	11	9	11	21	24

Table 2. Total invertebrate densities per square meter for selected studies on Eccles Creek.

	Winget 1980		Ecosystems Research Institute 1992			Shiozawa 2002a	Shiozawa 2002c	Shiozawa 2003	Shiozawa & Hansen 2004	Shiozawa 2005	Shiozawa 2005	this report
Sampling date	May-June 1979	Aug 1979	June 1990	Oct 1990	Sept 1991	Nov 2001	July 2002	Oct 2002	June 2003	Oct 2003	June 2004	Oct 2004
South Fork tributary above mine, upper site (USF2)			1,089	528								
South Fork tributary above mine (USF)	10,179		1,144	216	2,455							
Middle Fork tributary above mine (UMF)	7,447		1,503	3,812								
Eccles Creek below mine (EC1)			164	16								
Eccles Creek above South Fork (EC2)	12,341	73,181	267		89		3,703	1,260	6,265	1,267	10,865	4,339
South Fork Eccles Creek (SF)	9,321	17,773	1,356									
Eccles Creek below South Fork (EC3)	18,093	23,247										
Eccles Creek at Whisky Canyon (EC4)	11,634	25,273	1,719	3,928	1 419	61	8,757	1,491	10,351	5,004	73,950	38,093
Lower Eccles Creek (EC5)	18,661	2,526	2,212	4,104/ 2,863	1,468		4,927	2,879	3,387	16,919	97,614	65,206

respectively. The October, 2002 samples showed *Baetis* absent at EC2, about the same density at EC4 (400/m^2) and higher at EC5 (1,297/m^2). Yet in the June, 2003, samples, only six *Baetis* per square meter were found at EC4, and none were present at EC2 or EC5. However, by the following sample period, the fall, 2003, *Baetis* density had rebounded in stations EC4 and EC5 with 2448/m^2 and 13,835/m^2. None were collected in station EC2. By spring, 2004, *Baetis* was again collected at station EC2 where a density of 1,151/m^2 was recorded. During that same sampling period, station EC4 had *Baetis* densities of 2,362/m^2, almost identical with the previous fall, and the downstream station EC5 had a density estimate of 8,302/m^2, a third less than recorded in the previous fall samples. In fall, 2004, *Baetis* density at station EC2 was estimated at 1,151/m^2 (Table 3), identical with the estimate for spring, 2004. While the mean density estimate is identical for the two seasons, the densities per sample were not, with the spring samples showing a more clumped distribution than was found in the fall samples. In fall, 2004, station EC4 had 18,392/m^2, and the lower station, EC5, had 44,341/m^2. Both of these stations had a significant increase in *Baetis* indicating that whatever caused the decrease of *Baetis* in 2003 may have been a transient perturbation. Nevertheless, the failure of *Baetis* to increase at station EC2 may signify that the scouring and armoring of the streambed in the upper portions of Eccles Creek is still not favorable to the taxon.

The mayfly, *Cinygmula,* was not collected in this sample series (Table 3). In spring, 2003, it was in moderate densities in the upstream site (EC2*)* with a density of 230/m^2 but rare or absent in the middle (EC4) and lower (EC5) sites. This genus was also absent in the fall, 2002 samples but was in very low densities at stations EC2 and EC4 in July, 2002, and was in moderate densities (182/m^2) in station EC4 in fall, 2003. In spring, 2004, it was only found at station EC2 in low density (12/m^2). *Cinygmula* is characteristic of relatively high quality systems. It is a scraper-gatherer feeding on algae and detritus on the surface of rocks. Prior to the construction of the road, this genus reached densities of over 8,000 per square meter in late summer, although spring and early summer densities were around 1,000 per square meter in the middle and upper reaches of Eccles Creek (Shiozawa 2002b). The lack of this taxon indicates that it has not adapted to the changes induced by or accompanying the increased flow even though it utilizes rock surfaces for feeding and the entire streambed in station EC2 should be available for its use.

The hydroptilid caddisfly, *Ochrotricha* (a micro-caddisfly), was absent in the fall, 2004, samples, yet at station EC5 in spring, 2004, its density was 5,830/m^2, and at station EC4, it was collected at 1,327/m^2. Hydroptilla caddisflies were collected at 55/m^2 from station EC5 in fall, 2004. These insects attach to the surface of rocks and woody debris and feed on algae growing on the surface of the substrate.

Hydropsyche was absent at station EC2 but occurred at stations EC4 and EC5 at densities of 897/m^2 and 212/m^2 respectively (Table 3). This is in contrast with 73/m^2 and 199/m^2 at those two stations in spring, 2004. In the previous fall samples (2003), *Hydropsyche* was collected at 394/m^2, 1,245/m^2, and 242/m^2 from stations EC2, EC4, and EC5 respectively. *Hydropsyche*, like *Baetis*, was not collected in the spring, 2003, sample series but had been the dominant benthic macroinvertebrate in the October, 2002, samples (1,030/m^2, 1,024/m^2, 1,321/m^2 at stations EC2, EC4, and EC5 respectively). This indicates that the loss of hydropsychids in spring, 2003, was likely a result of an

Table 3. October, 2004, sample data and invertebrates per square meter.

	Eccles Creek above South Fork (EC2)						Eccles Creek Whisky Canyon (EC4)						
Taxa	1	2	3	4	5	**#/m²**	1	2	3	4	5	**#/m²**	1
Ephemeroptera: *Baetis*	32	32	32	34	60	**1151**	665	759	425	460	726	**18392**	1154
Ephemeroptera: early instar*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	60
Plecoptera: early instar*	0	0	0	1	0	**6**	0	0	30	0	0	**182**	31
Plecoptera: *Malenka californica*	0	0	0	1	0	**6**	0	0	0	0	0	**0**	0
Trichoptera: *Brachycentrus*	0	0	0	0	0	**0**	0	1	1	1	0	**18**	1
Trichoptera: *Hydropsyche*	0	0	0	0	0	**0**	63	19	11	32	23	**897**	0
Trichoptera: *Hydroptila*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	4
Trichoptera: *Rhycophila*	0	0	0	0	0	**0**	0	0	0	0	2	**12**	0
Trichoptera: pupae*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Coleoptera: Dytiscidae	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Coleoptera: *Heterlimnius* (adult)	0	0	0	0	0	**0**	0	0	0	0	0	**0**	2
Coleoptera: *Heterlimnius* (larvae)	0	0	0	0	0	**0**	0	0	0	0	0	**0**	1
Coleoptera: *Optioservus* (adult)	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Coleoptera: *Optioservus* (larvae)	0	0	0	0	0	**0**	0	0	0	2	0	**12**	30
Diptera: *Antocha*	0	0	1	0	0	**6**	2	1	1	1	0	**30**	2
Diptera: Caloparyphus	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Diptera: *Chelifera*	0	0	0	30	0	**182**	30	90	60	0	30	**1273**	0
Diptera: Chironomidae larva	31	0	0	2	0	**200**	98	102	7	160	90	**2769**	126
Diptera: Chironomidae pupae	0	0	0	0	0	**0**	0	0	1	1	0	**12**	0
Diptera: *Dicranota*	0	0	1	0	0	**6**	0	0	0	0	1	**6**	4
Diptera: *Euparyphus*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Diptera: *Limnophora*	0	0	0	0	0	**0**	0	0	0	1	0	**6**	0
Diptera: *Limnophila*	0	0	0	0	0	**0**	0	0	1	0	0	**6**	0
Diptera: *Hemerodromia*	0	0	0	0	0	**0**	0	1	0	0	0	**6**	0
Diptera: *Simulium*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Diptera: *Tipula*	0	0	0	0	0	**0**	1	0	1	0	0	**12**	1
Crustacea: Copepoda	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Crustacea: Ostracoda	0	0	0	0	0	**0**	0	0	0	0	0	**0**	30
Arachnida: Hydracarina	0	0	0	0	0	**0**	1	0	30	0	0	**188**	31
Mollusca: *Gyrulus*	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0
Mollusca: *Sphaerium*	0	0	0	0	0	**0**	0	0	1	0	0	**6**	0
Annelida: Oligochaeta	212	121	0	96	30	**2782**	666	723	226	584	152	**14247**	337
Nematoda	0	0	0	0	0	**0**	0	0	0	1	2	**18**	0
Totals:	275	153	34	164	90	**4338**	1526	1696	795	1243	1026	**38903**	1814

unknown perturbation that affected the stream in the winter/spring of 2003. The fall, 2004 numbers are little changed from the fall, 2003 densities at stations EC4 and EC5, but *Hydropsyche* was not collected from station EC2 during the spring and fall sampling periods in 2004. The absence of individuals of this genus at station EC2 in 2004, while it was present in the fall, 2003, implies that changes in the environment at that station may have reduced recruitment onto the substrate. Chironomids, in October, 2004, numbered 200/m^2, 2,769/m^2, and 5,363/m^2 in stations EC2, EC4, and EC5, respectively. In the previous October samples (2003), they numbered 479/m^2, 642/m^2, and 1,036/m^2 at the same three stations. The fall, 2004 density was down in station EC2 but was up in both of the lower stations. In contrast, the June, 2004 density estimates of 6,060/m^2, 18,265/m^2, and 33,451/m^2 were highest recorded in the sample series. This supports a seasonal fluctuation in numbers of midges within the system but also suggests that the seasonal trend overlays another trend where midge numbers may be increasing especially in the downstream two stations.

Oligochaetes also show a trend of increasing abundance over time along with a seasonal abundance signal. In June, 2002, they numbered 79/m^2, 654/m^2, and 576/m^2 in stations EC2, EC4, and EC5 respectively. In fall, 2002, the numbers fell to 79/m^2, 0/m^2, and 0/m^2 at the same three sites. The following year, in spring, 2003, the density estimates were 442/m^2, 879/m^2, and 103/m^2, slightly higher at stations EC2 and EC4 than the previous spring. But again in fall, 2003, the densities at stations EC2 and EC4 had declined to 24/m^2 and 24/m^2. Station EC5, however, increased to 1,079/m^2. By spring, 2004, the densities of oligochaetes in all stations increased especially in the two downstream stations. Their spring, 2004 densities were 2,939/m^2, 48,965/m^2, and 37,378/m^2 in EC2, EC4, and EC5 respectively. By fall, 2004, the numbers had declined at stations EC4 and EC5 to 14,247/m^2 and 8,514/m^2, respectively. Station EC2, with 2,782/m^2, was only slightly lower than the spring, 2004, estimates. Oligochaetes are deposit feeders burrowing into sand depositional microhabitats. Their increasing abundance may reflect both an increase in sand habitat (at the expense of silt habitats) as well as an ongoing population increase as the system recovers from the initial impact of the higher stream flow.

Once seasonal fluctuations are considered, it is apparent that *Baetis,* chironomids, and oligochaetes have all shown increases in the later sampling periods especially in the downstream two stations. This suggests an adaptation of the community to the increased flows. However, *Hydropsyche* decreased from peak October, 2002 densities and was missing at the upper station, EC2. This could indicate physical changes, which would be expected to be ongoing, as the streambed continues to armor itself with the increased discharge. Future successional changes in the stream community could parallel the dynamics of station EC2 as the armoring induced by sediment starvation continues to extend downstream.

Biomass

Total biomass estimates for each site (Table 4) give insight into the storage of energy in the living system at different time periods. The most information comes by comparing both the trends of each station with the others. Upper Eccles Creek, station EC2, had the highest biomass in October, 2002, and all stations showed a 35% to 70% decrease in biomass in the following spring. By fall, 2003,

Table 4. Biomass comparisons October, 2002, through October, 2004.

	Upper Eccles (EC2)					Middle Eccles (EC4)					Lower Eccles (E	
Sample	Oct 2002	June 2003	Oct 2003	June 2004	Oct 2004	Oct 2002	June 2003	Oct 2003	June 2004	Oct 2004	Oct 2002	June 2003
1	0.58 g	0.13 g	0.23 g	0.26 g	0.003g	0.24 g	0.14 g	1.39 g	0.10 g	0.53 g	0.21 g	0.14 g
2	0.34 g	0.31 g	0.13 g	0.10 g	0.004g	0.40 g	0.10 g	0.59 g	4.38 g	0.15 g	0.04 g	0.07 g
3	0.07 g	0.05 g	0.06 g	0.06 g	0.005g	0.27 g	0.06 g	0.50 g	0.18 g	0.37 g	0.40 g	0.01 g
4	0.31 g	0.04 g	0.28 g	0.06 g	0.376g	0.05 g	0.12 g	0.19 g	0.33 g	0.54 g	0.43 g	0.05 g
5	0.29 g	0.11 g	0.33 g	0.05 g	0.00 g	0.07 g	0.24 g	0.43 g	1.06 g	0.19 g	0.10 g	0.10 g
total	1.59 g	0.64 g	1.03 g	0.53 g	0.39 g	1.03 g	0.66 g	3.11 g	6.05 g	1.78 g	1.18 g	0.37 g
per m^2	9.64 g/m^2	3.88 g/m^2	6.24 g/m^2	3.21 g/m^2	2.36 g/m^2	6.24 g/m^2	4.00 g/m^2	18.82 g/m^2	36.66 g/m^2	10.75 g/m^2	7.15 g/m^2	2.24 g/m^2

all stations showed an increase in biomass, but while Station EC2 was about two thirds of the fall, 2002, biomass, stations EC4 and EC5 both exceeded their previous fall estimates. Station EC4 approximately tripled its biomass, while station EC5 was only about 40% higher than the fall, 2002 estimate. The June, 2004 estimates showed station EC2 decreasing to a new low biomass level, while stations EC4 and EC5 both increased substantially, with station EC4 having over twice the biomass as station EC5 and over eleven fold more biomass than station EC2. In October, 2004, the biomass at station EC2 continued to decline, and station EC4 also declined to about a third of its spring, 2004 estimate. Station EC5, however, increased. While the station EC5 biomass was still a third less than the maximus recorded at station EC4 in spring, 2004, it was almost double the fall, 2004 biomass for station EC4. This appears to reflect the same conditions noted for the three stations in terms of both density and number of taxa. Station EC2 is losing biomass, and it is possible that the trend is paralleling the armoring of the streambed. As armoring increases in intensity in the upstream reaches (station EC2), the eroded materials move downstream and foster the peak in biomass at the intermediate reach (EC4), but with time, the accumulated materials are flushed to station EC5, fostering an increase in standing crop at that site and also resulting in declining biomass at the intermediate station. This possibility warrants further monitoring.

Biotic Condition Index

Community tolerance quotients are a part of the biotic condition index developed by Winget and Mangum (1979). The community tolerance quotients are of two types, the actual community tolerance quotient, CTQa, and the predicted community tolerance quotient, CTQp. The predicted community tolerance quotient is based on water chemistry, substrate, and gradient and was determined to be 80 using the directions in Winget and Mangum (1979). CTQa values are a simple arithmetic mean of preassigned index values for the taxa present at a given station. The CTQa indices for an idealized stream, based on a combination of taxa collected from Boardinghouse Creek in November, 2001, and all taxa collected in Eccles Creek from 2001-2004 are given in Table 5 along with the taxa collected in the fall, 2004 sampling.

Table 5. Tolerance quotients.

Eccles Creek; October, 2004 Taxa	above South Fork (EC2)	at Whisky Canyon (EC4)	Lower Eccles (EC5)	Ideal stream (species list, including Boarding-house Creek)
Ephemeroptera: Baetidae: Baetis	72	72	72	72
Ephemeroptera: early instar			72	72
Ephemeroptera: Ephemerellidae: *Drunella sp.*				48
Ephemeroptera: Ephemerellidae: *Drunella dodsei*				4
Ephemeroptera: Ephemerellidae: *Serratella*				48
Ephemeroptera: Ephemerellidae: *Ephemerella*				48
Ephemeroptera: Heptageniidae: *Cinygmula*				21
Ephemeroptera: Heptageniidae: *Epeorus*				21
Ephemeroptera: Leptophlebidae: *Paraleptophlebia*				24
Plecoptera early instar	36	36	36	36
Plecoptera: Leuctridae: *Perlomyia utahensis*				18
Plecoptera: Nemouridae: *Malenka californica*	36			36
Plecoptera: Nemouridae: *Zapada*				16
Plecoptera: Perlididae: *Hesperoperla pacifica*				18
Plecoptera: Perlodidae: *Diura knowltoni*				24
Plecoptera: Perlodidae: *Skwalla parallela*				18
Plecoptera: Perlodidae: *Isoperla*				48
Trichoptera: pupae			108	108
Trichoptera: Brachycentridae: *Brachycentrus*		24	24	24
Trichoptera: Brachycentridae: *Micrasema*				24
Trichoptera: early instar			108	108
Trichoptera: Hydropsychidae: *Arctopsyche*				18
Trichoptera: Hydropsychidae: *Hydropsyche*		108	108	108
Trichoptera: Hydroptilidae: *Hydroptila*			108	108
Trichoptera: Hydroptilidae: *Ochrotricia*				108
Trichoptera: Limnephilidae: *Dicosmecus*				24
Trichoptera: Limnephilidae: *Hesperophylax*				108
Trichoptera: Psychomyiidae: *Tinodes*				108
Trichoptera: Rhyacophilidae: *Rhyacophila*		18	18	18
Trichoptera: Uenoidae: *Neothremma alica*				8

Trichoptera: Uenoidae: *Oligoplebodes*				24
Coleoptera: Dytiscidae			72	72
Coleoptera: *Heterlimnius*			108	108
Coleoptera: Elmidae: *Optioservus*		108	108	108
Coleoptera: Haliplidae: *Peltodytes*				54
Diptera: Ceratopogonidae				108
Diptera: Chironomidae	108	108	108	108
Diptera: Empididae: *Chelifera*	108	108	108	108
Diptera: Empididae: *Hemerodromia*		108		108
Diptera: Muscidae: *Limnophora*		108	108	108
Diptera: Simuliidae: *Simulium*			108	108
Diptera: Stratiomyidae: *Allognasa*				108
Diptera: Stratiomyidae: *Caloparyphus*			108	108
Diptera: Stratiomyidae: *Euparyphus*			108	108
Diptera: Tipulidae *Dicranota*	24	24	24	24
Diptera: Tipulidae *Limnophila*		72	72	72
Diptera: Tipulidae *Tipula*		36	36	36
Diptera: Tipulidae *Pedicea*				72
Diptera: Tipulidae *Antocha*	24	24	24	24
Collembola				108
Hemiptera: Saldidae				108
Acari: Hydracarnia		108	108	108
Ostracoda			108	108
Copepoda			108	108
Cladocera				108
Mollusca: Gastropoda: *Gyraulus*			108	108
Mollusca: Spharidae: *Sphaerium*		108	108	108
Oligochaeta	108	108	108	108
Tricladida: Planariidae				108
Nematoda		108	108	108
total	516	1386	2502	4198
n	8	18	29	60
CTQa	64.5	77	86.28	69.97

Generally CTQa values less than 65 represent high quality waters, while those between 65 and 80 represent situations with moderate to high quality water. CTQa values greater than 80 represent low water quality or stressed systems. The October, 2004 stations had CTQa values of 64.5, 77, and 86.28 at stations EC2, EC4, and EC5. respectively. Based on these values, station EC2 is a high quality system, while station EC4 is an intermediate system with moderate water quality, and station EC5 is a low quality or stressed system. These results do not reflect the images being presented through biomass, number of taxa, and density data. Of most importance here is the caution made in previous reports, that the CTQa values are based on the average index from just those taxa that are present, and taxa are not weighted for differences in abundance. A site could conceivably have just a single individual, and nothing else, but if that one organism had a low tolerance quotient, the index would conclude that the community was high quality. This data set appears to reflect that problem.

Comparisons of Community Tolerance Quotient and Biotic Comparison Indices

CTQa values for Eccles Creek can be compared from the 1979, 1990, and 2000 time periods. These values detected the impact in the 1990s in three stations below the mine (EC1, EC2 and EC4; Table 6). This impact did not reach the lowest station, EC5. Beginning in 2001, the average CTQa for the stream jumped to 94 and stayed above 70 in 2002, and in June, 2003, it was 93. It was 78 in October, 2003; 87 in June, 2004; and 76 in October, 2004. The additional inflow has had a more intense impact on the stream than the 1990 detergent spill.

The biotic condition index (BCI) is CTQp/CTQa X 100. This measure (Winget and Mangum 1979) can be used in conjunction with CTQa to generate a broader interpretation of the state of stream systems, if the streams involved have separate CTQp values. Ideally, if all predictors are accurate, a pristine system will have a BCI of 100 (CTQp = CTQa). BCI values below 100 represent a condition where fewer clean water taxa than predicted are present and thus indicate a reduction in the quality of the habitat. Any BCI value above 100 represents communities whose clean water taxa are in greater abundance than predicted. In 34 of the 45 sample stations presented in this report (Table 6), the BCI was over 100. All of the stations sampled in 1979 had BCI values above 100 averaging over 120. Likewise, all but one station which was directly below the mine, in the 1990-1991 spill series had BCI values above 100. Of the 19 stations sampled since 2001, seven were above 100. Two of these were fall, 2004, samples from stations EC2 and EC4. This conflicts with the inferences generated by other data (see Tables 1, 2) by rating station EC2 (BCI = 124) with the same station in August, 1979 (BCI = 123).

Diversity

Diversity indices are a way of combing both number of taxa and relative densities into a single measurement. High diversity index values indicate more taxa and a greater number of individuals per taxon. Low diversity values generally reflect a depauperate fauna in both species and somewhat in numbers. The baseline stations (1979 samples, Table 7) had diversity values ranging between about two to three. The areas impacted by the chemical spill in 1990-1991 had diversities values around one. But in September, 1991, the values fell to around 0.5. However, in that same 1991 sample series, the Upper South Fork had a diversity of 0.7 considerably lower than the 1.7 to 1.9 recorded for the previous year. This implies that another factor may have also negatively influenced the stream system in 1990.

Table 6. CTQa and BCI values for selected studies on Eccles Creek.

	Winget 1980		Ecosystems Research Institute 1992			Shiozawa 2002a	Shiozawa 2002c	Shiozawa 2003	Shiozawa & Hansen 2004	Sh 20
Sampling date	May-June 1979	Aug 1979	June 1990	Oct 1990	Sept 1991	Nov 2001	July 2002	Oct 2002	June 2003	Oc
	CTQa/BCI	CTQa/BCI	CTQa/BCI	CTQa/BCI	CTQa/BCI	CTQa/BCI	CTQa/BCI	CTQa/BCI	CTQa/BCI	CT
South Fk. trib. abv. mine, upper site (USF2)			59/133	53/151						
South Fork trib. abv. mine (USF)	66/121		49/163	59/136	45/178					
Middle Fork trib. abv. mine (UMF)	69/117		54/148	49/163						
Eccles Creek below mine (EC1)			67/119	108/74						
Eccles Creek abv. S. Fk. (EC2)	64/125	65/123	86/93		73/110		99/81	86/93	87/92	88
South Fork Eccles Creek (SF)	59/136	64/125	55/145							
Eccles Cr. below S. Fk. (EC3)	65/123	55/145								
Eccles Creek at Whisky Can. (EC4)	62/127	61/131	69/116	70/114	63/127	94/85	52/154	69/116	94 /79	76
Lower Eccles Creek (EC5)	59/136	74/108	53/151	55/145 57/140	58/138		66/121	69/116	97/82	71
Average	62/131	64/126	59/140	64/132	60/138	94/85	72/119	75/108	93/86	78

Table 7. Diversity indices based on natural logs for selected studies on Eccles Creek.

	Winget 1980		Ecosystems Research Institute 1992			Shiozawa 2002a	Shiozawa 2002c	Shiozawa 2003	Shiozawa & Hansen 2004	Sh 20
Sampling date	May-June 1979	Aug 1979	June 1990	Oct 1990	Sept 1991	Nov 2001	July 2002	Oct 2002	June 2003	O
South Fork tributary above mine, upper site (USF2)			1.63	1.9						
South Fork tributary above mine (USF)	2.63		1.72	1.9	0.702					
Middle Fork tributary above mine (UMF)	2.11		1.66	1.9						
Eccles Creek below mine (EC1)			1.06	0.7						
Eccles Creek above south Fork (EC2)	2.44	1.964	1.58		0.400		0.398	0.836	1.314	1.
South Fork Eccles Creek (SF)	3.510	3.322	1.62							
Eccles Creek below South Fork (EC3)	2.450	2.743								
Eccles Creek at Whisky Canyon (EC4)	2.450	3.060	1.22	1.6	0.666	0.757	0.957	0.835	0.955	1.
Lower Eccles Creek (EC5)	2.280	2.590	1.24	1.8/ 1.4	0.416		0.829	0.341	0.789	0.

Diversity values for all sampled stations were below 1.0 from 2001-2002. In June, 2003, station EC2 was 1.3, while stations EC4 and EC5 were slightly below their July, 2002 levels, but above their October, 2002 readings. By October, 2003, station EC4 had increased in diversity from 0.96 in June, 2003 to 1.43. Station EC2 dropped in diversity to 1.19. Station EC5 was still below 1.0, with a diversity index value of 0.75 which was slightly lower than its June, 2003 level. The June, 2004 diversity readings showed station EC2 decreasing slightly to 1.17, and station EC4 also fell to a diversity value of 0.98. In contrast, station EC5 increased significantly in diversity to 1.47. The fall, 2004 samples indicated that station EC2 was continuing to have a decline in diversity dropping to an index value of 0.94. EC4 increased its diversity reading to 1.17, but EC5 declined to 1.05.

It appears that the three stations are fluctuating in their diversity index values between lows of around 0.9 to highs of about 1.4. Nothing suggests that the stream is moving back toward the high diversity that characterized the system in the late 1970s. No strong seasonal pattern is discernable in the more recent diversity values, and no easily followed trend which would suggest recovery is apparent at this time.

Cluster Analysis

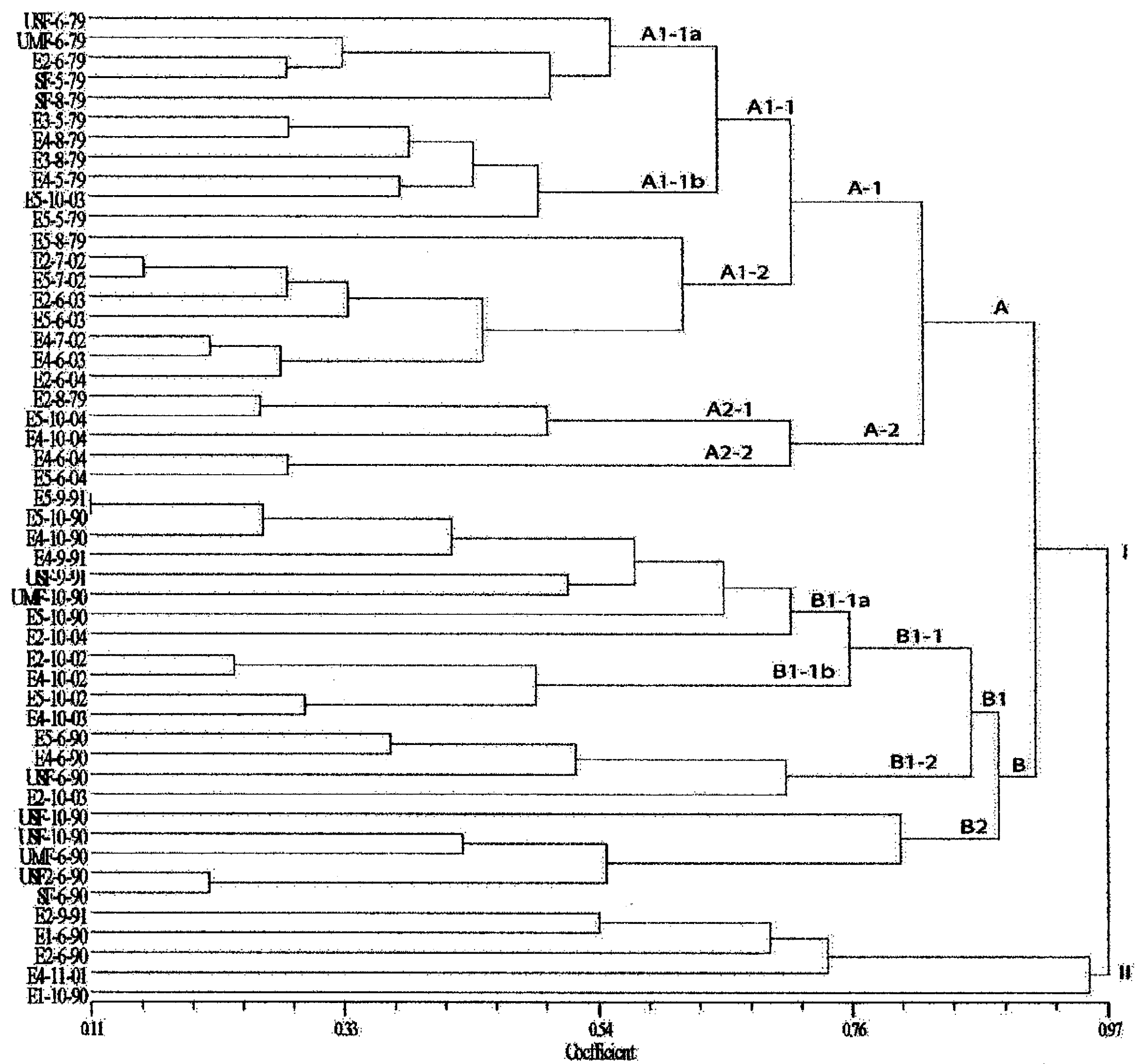
Cluster analysis is a multivariate approach that generates a visual representation of relationships among samples or stations. The Bray-Curtis dissimilarity index utilized in this study considers both quantitative counts of individuals within each taxon and the relative densities of those organisms (Poole 1974). A total of 50 station-date combinations were included in the cluster dendrogram (Figure 1). For convenience, each station-date combination will be considered a sample even though the data for each are based upon multiple samples.

The output resulting from this analysis had two main clusters that were highly dissimilar to each other labeled I and II in Figure 1. Main Cluster II contained two stations, EC1 and EC2, impacted by the chemical spill in the 1990s. These were the two stations nearest the mine and would be expected to have suffered the greatest impact from the spill. Main Cluster II also included the samples taken at station EC4 shortly after the increase in stream discharge in November, 2001. This station's inclusion with the EC1 and EC2 samples suggests that the communities responded with drastic changes in taxa composition after both perturbations. No other samples fell in Main Cluster II indicating that downstream in the 1990 event and the following years in the 2001 event, the communities showed less drastic responses.

All other samples fall into Main Cluster I. This includes the reference data collected in the late 1970s, the side streams sampled in both the 1970s and 1990s, the downstream sites sampled in the 1990s, and the remaining samples take in the 2001-2004 series. Main Cluster I had two clusters labeled A and B (Figure 1). Cluster A contains the majority of the spring-summer samples and includes all of the reference samples taken in 1979. Cluster B contains a mixture of spring, summer, and fall samples, all taken after 1990.

Cluster A separates into two sub-groups, subclusters A1 and A2. Under subcluster A1 are two additional clusters or groupings (labeled A1-1 and A1-2 on Figure 1). Group A1-1 contains the majority of the reference samples from 1979. A further subdivision of A1-1 contains sample stations

Figure 1. UPGMA cluster dendrogram of relationships among invertebrate communities from selected stations and dates in Eccles Creek



that represent the small tributaries and upper Eccles Creek station EC2 where it was still small (USF, UMF, SF, and E2; A1-1a; Figure 1). The other subset (A1-1b, Figure 1) represents the 1979 control stations in the main stem of Eccles Creek (EC3, EC4, and EC5). Only one non-control sample occurred in Group A1-1, station EC5 in fall, 2003, (E5-1 0-03, Figure 1).

Group A1-2, under subcluster A1, contains one late summer sample from the 1979 series (station EC5 from August, 1979; Figure 1). The remaining samples in this group are from the 2001-2004 sampling series. All of these samples were taken in the spring-summer period. The degree of dissimilarity between station EC5 from August, 1979, and the 2001-2004 spring-summer samples is approximately 0.61. A 61% dissimilarity value indicates that, even though the 2001-2004 spring-summer samples cluster with a summer sample from 1979, the overall differences are still quite high, and it is unlikely that this indicates a converging of the 2001-2004 Eccles community to the reference conditions.

The samples making up subcluster A-1 are spring-summer samples with just one exception. Three of the five samples in subcluster A-2 are spring-summer samples as well. The two EC5-10-03 samples are from stations EC4 and EC5 for fall, 2004, and they fall together in Group A2-1 along with an August reference station sample (E2-8-79, Group A2-1, Figure 1). The remaining two samples in Group A2-2 contain spring, 2004 samples from stations EC4 and EC5. One can conclude that the general makeup of Cluster A are from spring-summer communities. The three exceptions are samples taken from stations EC4 and EC5 in 2003 and 2004. None of the fall EC2 samples taken between 2001-2004 occur in Cluster A.

While Cluster A is a spring-summer series, Cluster B tends to be a fall series. Of the 21 samples that fall into Cluster B, 15 were taken in the fall. The six samples that were taken in the spring were collected in 1990. Under Cluster B are two subclusters, B1 and B2. Subcluster B1 can be subdivided into two additional groups, B1-1 and B1-2 (Figure 1). Within Group B1-1, two sub-groupings fall out. One, designated B1-1a (see Figure 1), contains fall samples collected during the 1990s. These include both impacted sites in the main stem of Eccles Creek as well as several tributary streams. The tributaries tend to have fewer taxa (Table 1), lower overall densities (Table 2), and lower diversity (Table 7). These are likely important factors in the tributaries clustering with the impacted main stem of Eccles Creek. One sample, EC2-10-04, also falls into subgroup B1-1a. It is the most dissimilar sample in this subgroup. The second subgroup under B1-1 is designated B1-1b (see Figure 1). This subgroup is comprised completely of the 2002-2003 samples from Eccles Creek. Their falling together into a single cluster reflects the similarity of their communities responses to the increased discharge in the stream system. However, fall samples EC5-10-03, EC4-10-04, and EC5-10-04 did not fall within this subgroup. Instead, those three fall samples were part of subcluster A2 (see A1-1b and A2-1, Figure 1). That indicates a shifting in community structure at stations EC4 and EC5 from the fall of 2002-2003 to the fall of 2003-2004. While such a shift was not apparent in the diversity indices (Table 7) or number of taxa (Table 1), it was seen in the increase in total density in those stations in fall, 2003, and 2004 (Table 2).

The second group in subcluster B1 is Group B1-2 (Figure 1). B1-2 contains three spring samples and one fall sample. The spring samples are all from the 1990 sampling series. The single fall sample is station EC2-10-03. Station EC2 is the station where scouring and armoring of the streambed has been most visible. The shift of this station from subgroup B1-1b in fall, 2002, to Group B1-2 in fall, 2003, and then to B1-2a (see Figure 1) in fall, 2004, indicates that the community structure is highly variable. The low number of taxa (Table 1) and the relatively low total invertebrate densities (Table 2) also reflect this.

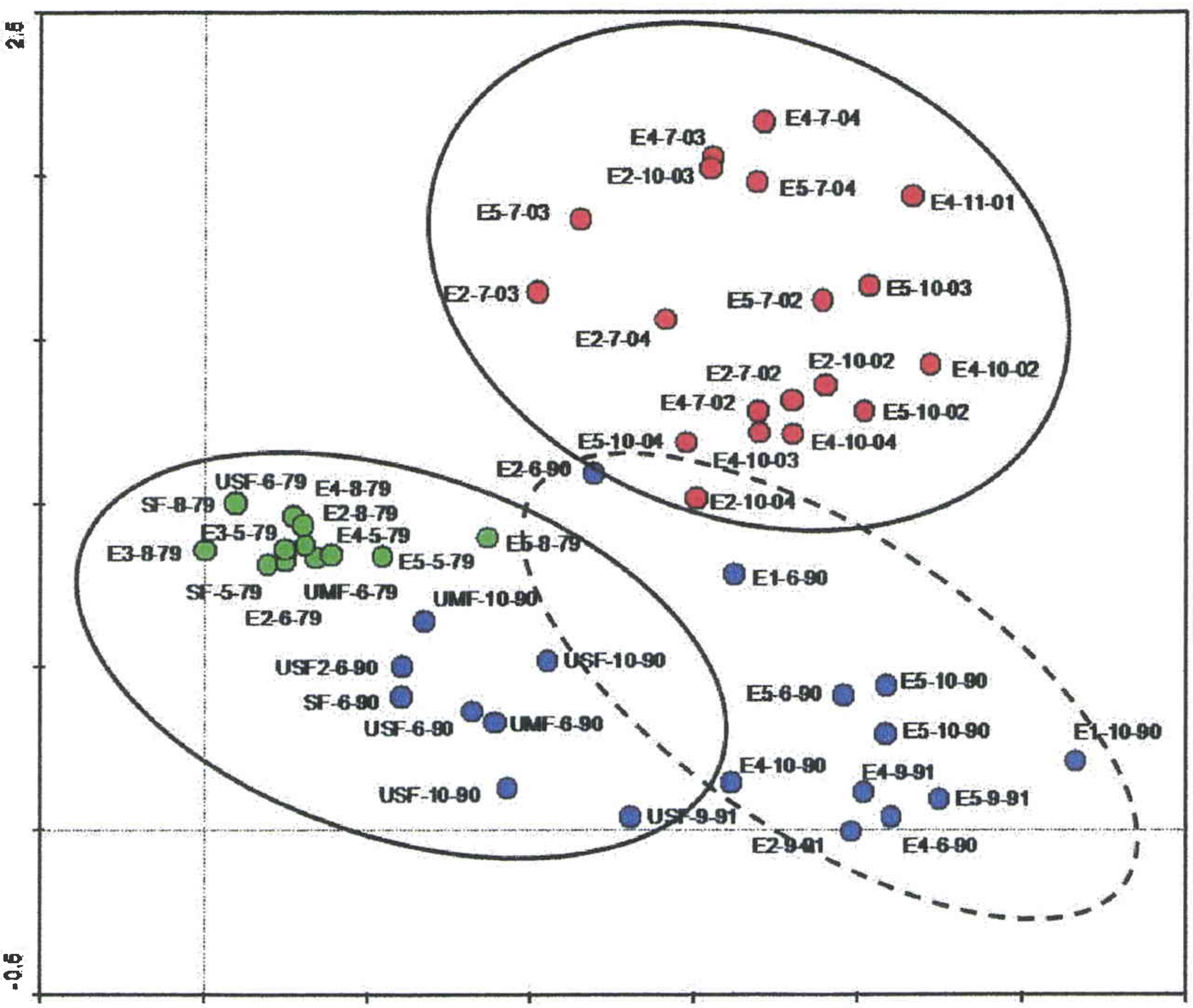
B2 is the final subcluster under Cluster B. This group contains an equal mix of fall and spring samples. All were taken in the 1990 sampling study, and all were tributary stream locations. These have already been noted above as being different from the main stem sites in the spring-summer samples taken in 1979 (Group A1-1, Figure 1). The interesting point with these samples is that they do not represent stations where the chemical spill would have directly impacted them. The spring samples, UMF-6-90, USF2-6-90, and SF-6-90, would, therefore, be expected to have been part of the baseline data cluster, subgroup A1-1a (Figure 1) rather than being part of Cluster B. Their failure to fall with the baseline set suggests that the system had changed in the interval between 1979 and 1990. Road development is one factor that is likely to have impacted the tributaries (Shiozawa 2002b). The remaining samples in subcluster B2 are fall samples from the upper South Fork area and likely should be a component of Cluster B.

It is unfortunate that the 1979 sampling series did not include fall sampling. The good separation of the tributaries from the main stem in 1979 (A1-1a from A1-1b, Figure 1) indicates that the seasonal signal would have been even stronger. The associations seen with fall samples from the 1990 series as well as the 2001-2004 series would be much easier to interpret if the base seasonality of the system was known. Nothing can be done to retrieve that lost information, but it does give insights into the design of future studies. It is clear that the 2001-2004 samples falling in the spring-summer group (Cluster A, Figure 1) are predominantly those taken in June and July. Even though they are a part of Cluster A, their clusters (A1-2, A-2, Figure 1) are still more dissimilar to the 1979 spring-summer baseline samples (Group A1-1) than the tributaries were from the main stem in 1979 (subgroups A1-1a and A1-1b, Figure 1). Three fall samples, EC5-10-03, EC5-10-04, and EC4-10-04, are also in Cluster A. This implies that they have either converged toward a more summer-like community structure as the stream community becomes more adapted to the higher discharge or that, had the 1979 series included fall samples, the fall samples would also have been a part of Cluster A. By default, the second option then suggests that Cluster B represents a perturbed system. The high degree of dissimilarity among subclusters of Clusters A and B does not allow greater clarification of the associations, since various subclusters within either cluster still represent very different communities.

Detrended Correspondence Analysis

Detrended correspondence analysis, an ordination technique (Braak and Smilauer 2002), was run on a reduced data set in order to generate a graphical view of the relationships among the stations sampled in Eccles Creek, since the baseline data was collected in 1979. This approach was included,

Figure 2. Stations by date ordination using Detrended Correspondence Analysis based on log X+1 transformed data with a reduced taxa data set. Green = baseline data from 1979, Blue = data collected in 1990-1991 following a chemical spill, Red = data collected from 2001-2004 following an increase in discharge.



because the total number of samples (stations by date) taken was becoming high enough to begin searching for emergent patterns that could visually assist the interpretation of the data.

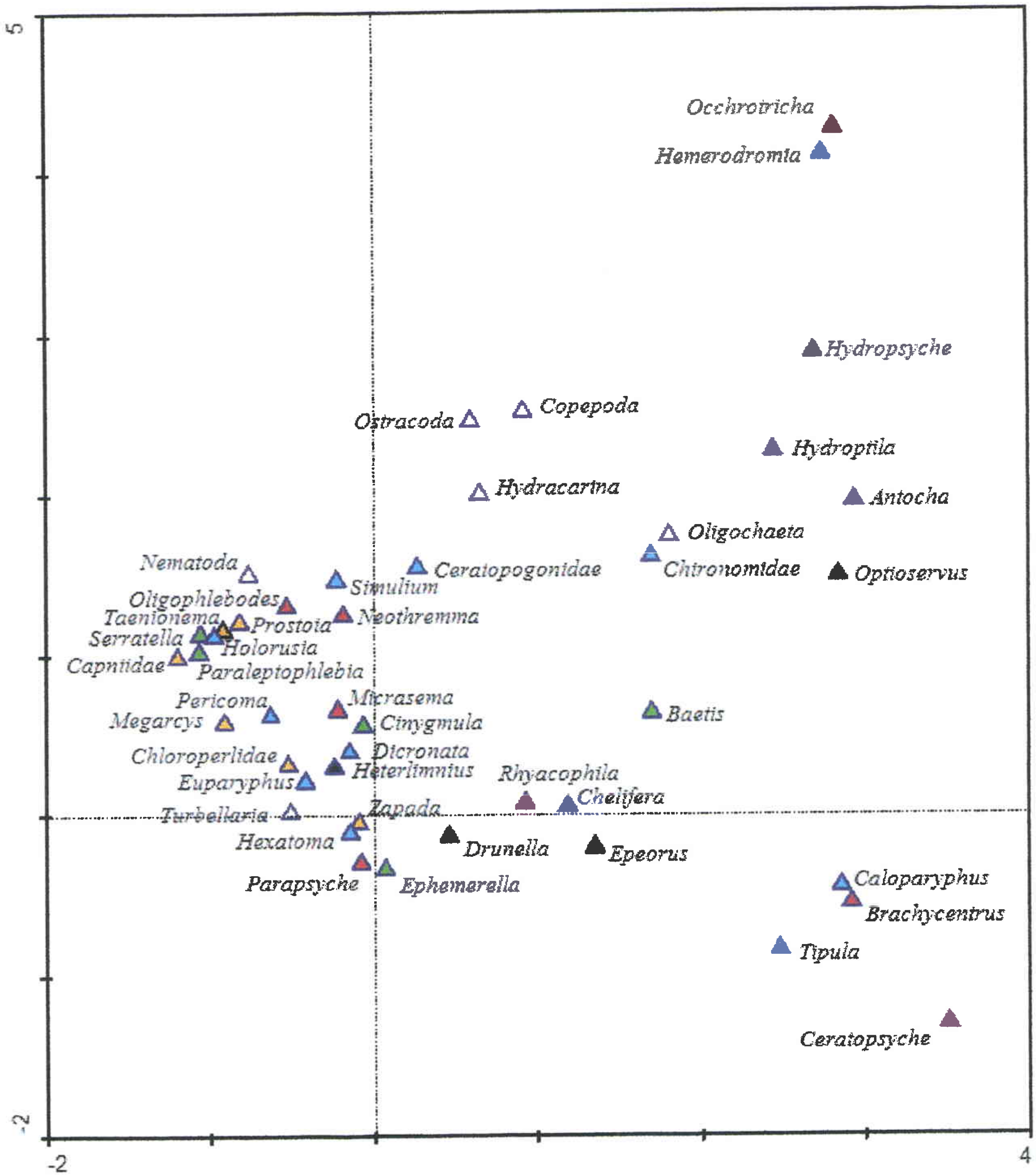
The results (Figure 2) show a clear separation of the samples taken in 1979 (denoted in green) from those taken in the 1990s (denoted in blue) and those taken in the 2001-2004 series (denoted in red). Since some of the 1990-1991 samples were taken from locations (tributaries) that were not directly affected by the spill, ellipses were drawn to help delineate those samples. The lower left ellipse thus includes both the 1979 baseline samples and the tributary streams samples in the 1990s. As noted above, the 1990 tributary series was likely impacted by road construction activities, and those sites have separated to the right on the first ordination axis and down on the second ordination axis, giving an elliptical plot that spreads diagonally across the lower left of Figure 2.

The impacted stations for the 1990 sample period fall mainly in the lower right of the figure (denoted with a dashed ellipse). Stations EC1 and EC2 (E1-6-90 and E2-6-90, Figure 2), which were the most heavily impacted by the spill, are most central on the plot, and as distance and time from the source increases, the stations shift to the right on the first ordination axis and down on the second axis. Sampling did not continue to recovery, so the long term trajectory of the stations are not known. The 2001-2004 sample series forms a discrete grouping in the upper left of the ordination plot (Figure 2). It appears to have a larger scatter in the second ordinal axis and is about equal in spread to the 1990 series on the first ordinal axis.

This analysis shows the trajectory of the stations over time with different perturbations. The data set that generated this plot consisted of a subset of the total data set (those taxa that were in abundances greater that 100 and were found in more than a few stations during the study period (1979 to 2004). A plot of the taxa utilized in the analysis (Figure 3) shows which taxa were important in the ordination of samples in Figure 2. Stoneflies (denoted in orange in Figure 3) and mayflies (denoted in green in Figure 3) are the most important higher order groups in establishing the position of the baseline stations from 1979 (Figure 2). All stoneflies and most mayflies, with the exception of *Baetis* and possibly *Epeorus*, are positioned in the left central portion of the species plot. Their placement represents their greatest abundances and corresponds with the positions of the 1979 stations in Figure 2.

Stoneflies (Plecoptera) can be divided into two functional groups (Merritt and Cummins 1996). Some are detritivores and tend to live interstitially in the substrate. The nemourid stoneflies, *Zapada* and *Prostoia*, the taeniopterygians, and the capniids are in this group. All require either accumulations of detritus or sediments in which they can burrow if they are to survive. The lack of these habitats in the 2001-2004 stations will eliminate this functional group from the stream. The other functional category for stoneflies is a predator. The other taxa on Figure 3 are predators. These require sediments (coarse gravel or rubble). They forage both within the interstitial spaces and at night will also forage on the surface of the substrate. Again, the lack of this habitat in the 2001-2004 stations has eliminated this group from the stream. Stoneflies, in general, are also very sensitive to decreases in oxygen and to chemical pollution. Their peak abundances are positioned away from the 1990-1991 region of the plot (Figure 3) reflecting those factors.

Figure 3. Plot of taxa used in Detrended Correspondence Analysis. Blue = dipterans, Red = trichopterans, Green = ephemeropterans, Orange = plecopterans, white = miscellaneous invertebrates.



The mayflies (Ephemeroptera) that have their most abundant numbers in the region of the 1979 baseline samples include three ephemerellids, *Serratella*, *Ephemerella*, and *Drunella*, the heptageniid, *Cinygmula*, and the leptophlebiid, *Paraleptophlebia*. All but *Paraleptophlebia* are clingers climbing on the surface of rocks in search of food. Most ephemerellids are collector-gatherers of detritus and algae, but *Drunella* may also be a predator. Their requirement of detrital food on the surface of rocks would limit their survival under conditions of highly erosional flow. *Paraleptophlebia* is a swimmer/crawler and falls within the collector-gatherer functional group. It too would do poorly under highly erosional flow. The heptageniid, *Cinygmula* feeds on algae which should be available under the conditions existing in 2001-2004. But this group also requires cold, well oxygenated water, and that could be a limiting factor. The mayflies also are often susceptible to pollutants explaining their greatest abundances being in the baseline samples from 1979. The heptageniid mayfly, *Epeorus*, and the baetid mayfly, *Baetis*, are intermediate in their abundances. *Epeorus* is located intermediate between the 1979 baseline samples and the 1990-1991 chemically stressed condition suggesting that this taxon is more resilient to chemical stress than is *Cinygmula*. Still, it is closer to the 1979 reference stations than to the 1990-1991 impact stations. *Baetis*, on the other hand, is a known vagrant genus. Its position intermediate to all three groups, the 1979, the 1990-1991, and the 2001-2004 sample series, is indicative of its doing well under all three circumstances. Both the dipterans and trichopterans (caddisflies) have taxa spread throughout the plot (blue = dipterans and red = trichopterans, Figure 3). *Oligophlebodes*, *Neothremma*, and *Micrasema* are case builders, and all live in erosional (riffle) habitats. They require well oxygenated water. *Neothermma*, having the most streamlined case, can often be found clinging to large boulders in swift water. The other two taxa will also cling to the surface of rocks when feeding but generally are not able to withstand the swift, laminar flow where *Neothermma* can forage.

The hydropsychid caddisflies, *Parapscyhe*, *Ceratopsyche*, and *Hydropsyche*, are net-constructing filter feeders and build retreats on sticks and rocks. They often select protected microhabitats under rocks or between boulders where they are able to filter detritus and organisms from moderately flowing water. These three strongly separate in the ordination. *Parapsyche* is dominant in the reference sites from 1979, *Ceratopsyche* appears to be tolerant of the conditions generated in the 1990-1991 spill, and *Hydropsyche* is dominant in the 2001-2004 high discharge situation. The shift from *Ceratopsyche* to *Hydropsyche* may be associated with changes in microhabitat. *Hydropsyche* nets are found on branches as well as rocks in very swift water. This group also is tolerant of higher temperatures. While the microhabitat requirements of *Ceratopsyche* are not known, it is possible that genus requires higher detrital content or prefers rocky interstitial habitat.

The trichopteran, *Brachycentrus*, appears to have done well under the chemical spill conditions. This case building caddisfly is a filter feeder and attaches its case to the surface of substrates where it is exposed to rapidly flowing currents. *Brachycentrus* will then filter feed by extending its legs into the flowing water. It collects detritus in this manner. This taxon is relatively tolerant of high temperatures and polluted water. Its reduced numbers in the 2001-2004 sites reflects the reduction of detritus in the system, a result of the high flushing flows and the armoring of the substrate.

The free living caddisfly, *Rhyacophila*, is a predator. It was most abundant in the 1979 stations and secondarily in the 1990-1991stations. It has been occasionally collected in the 2001-2003 sampling series but in reduced numbers. Two microcaddisflies, *Occhrotricha* and *Hydroptilla*, were important in separating the 2001-2004 stations from the other two sampling periods. These insects are small and build silk cases which they can attach to the surface of rocks. This allows them to forage on algae and detritus in relatively swift waters. In general, they can withstand higher temperatures.

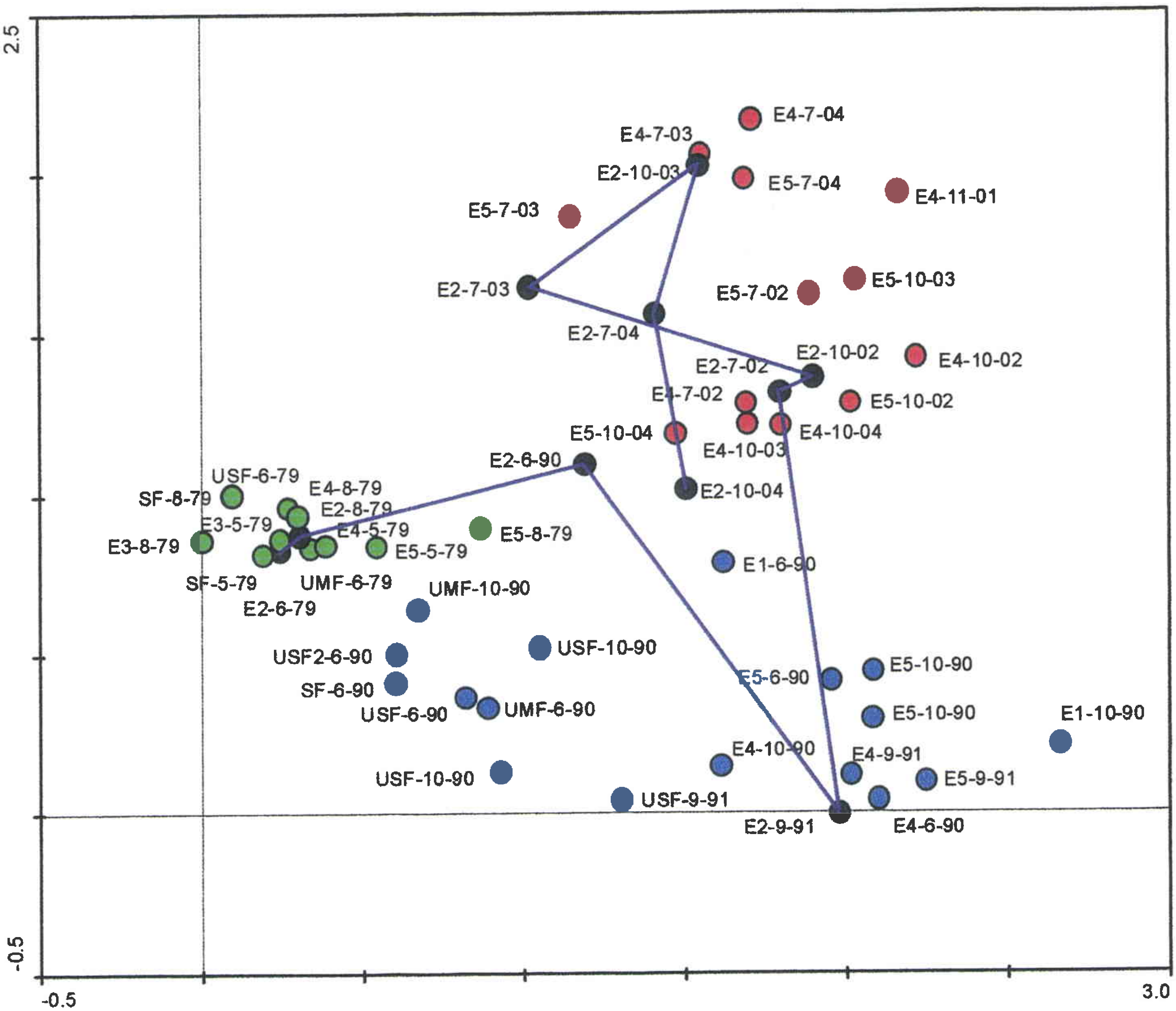
Dipterans, like the trichopterans, were important in the overall separation of the stations. Three tipulids, *Dicranota*, *Holorusia*, and *Hexatoma*, were characteristic of the baseline stations in 1979 (Figure 3). Two of these three, *Dicranota* and *Hexatoma*, are burrowing predators while *Holorusia* is a detritivore. All three require either depositional habitats or areas with a sufficiently thick boundary layer to avoid being flushed from the system. Both conditions are significantly reduced in the 2001-2003 stream. However, they would be expected to have been present in the 1990-1991 sampling series, so direct toxic effects were likely responsible for diminishing their presence at that time. *Tipula*, a burrower/detritivore, was most abundant in the 1990-1991 samples as was the stratiomyid, *Caloparyphus*. These two taxa apparently were able to withstand the conditions in Eccles Creek following the chemical spill. *Caloparyphus*, a collector-gatherer that prefers depositional habitats, was also collected in very high densities in station EC4 in June, 2004, the section of Eccles Creek that appears to have been receiving sediments eroded from upstream. The tipulid, *Antocha*, is a scraper feeding on periphyton and surface deposits of detritus occurs in erosional habitats where the current is rapid. It is most often represented in the 2001-2004 Eccles Creek samples but was also collected in high densities in a few of the 1990-1991 sample series explaining its intermediate position in the ordination (Figure 3).

The empid, *Hemerodromia*, was most abundant in the 2001-2004 samples while *Chelifera*, also an empid, was most important in the 1979 baseline data set and the 1990-1991 samples. *Chelifera* is a burrower, which prefers lotic depositional habitats, while *Hemerodromia* is a predator living in both erosional and depositional (slow water) habitats. The high flows associated with the 2001-2004 sampling period would significantly reduce the depositional habitats, so *Chelifera* would be expected to be less abundant in the armoring system that was developing with the higher discharge. *Pericoma*, a psychodid, is also a burrower in depositional habitats, and it was strongly associated with the baseline samples from 1979.

Trajectories of Individual Stations

The ordination of the full data set (Figure 2) separates the samples into the three distinct groups, "Baseline" (1979 data sets), "Solvent Spill" (1990-1991 data sets), and "Increased Discharge" (2001-2004 data sets). The separation is very clear and can be interpreted relative to the corresponding changes in various invertebrate taxa (Figure 3). However, information about directional changes within specific stations over time is also present in Figure 2. This has been alluded to in the discussion of changes in the tributary streams between 1979 and 1990-1991, but it can also be examined for the three stations sampled from 2001 to 2004.

Figure 4. Trends at station EC2 denoted in black and connected by sequential dates.



Station EC2 in May and August, 1979, was in the center of the "Baseline" samples (Figure 4). With the solvent spill in 1990, this station showed a shift initially toward the "Increased Discharge" cluster (E2-6-90, Figure 4), but by 1991, it was centered in the "Solvent Spill" cluster. The 2001-2004 samples from this station show a relatively wide variation in locations within the "Increased Discharge" cluster. The fall samples have a much greater variation than do the spring-summer samples, and the station, in October, 2004, is nearing the "Solvent Spill" cluster. This station (E2-10-04, Figure 4) was close to station EC1 from June, 1990, (E1-6-90, Figure 4) and unlike other stations collected in October, 2004, station EC2 lost taxa when compared to the previous spring. EC1-6-90 had a diversity of 1.06 while site EC2 had a diversity of 0.939 (Table 7). Only a slight seasonal signal is apparent. The spring-summer samples tend to fall in the center of the ordination (to the left of the "Increased Discharge" cluster, Figure 4), while the fall samples are to the right, top and bottom center of that cluster. Their not falling in a discrete seasonal pattern was also reflected in the positions of the EC2 samples in the cluster analysis (Figure 1).

Station EC4 began in the center of the "Baseline" ordination cluster (Figure 5), and with the 1990-1991 perturbation, this station shifted to the lower center of the "Solvent Spill" cluster. The first sample taken at this station in the 2001-2004 series was in fall, 2001. The following spring, the station (EC4-7-02, Figure 5) shifted to the lower center of the "Increased Discharge" cluster in the ordination. After that sampling date, the samples begin to fluctuate between the bottom and the top of the "Increased Discharge" cluster. The top samples represent the spring-summer community and the bottom ones the fall community structure. The position of the first sample taken in the 2001-2004 series from this station is clustering with the fall stations even though it was in spring, 2002. From the density data, it is apparent that the initial impact of the increased discharge was a reduction in invertebrates. For this station, the season shifts appear to be driven by *Hemerodromia* and *Occhrotricha* in the spring and *Hydropsyche*, *Hydroptila*, and *Antocha* in the fall.

Station EC5 began on the right edge of the "Baseline" cluster in May, 1979 (Figure 6). This station then shifted to the top of the "Solvent Spill" cluster. Three additional samples were taken in fall, 1990 and 1991. The first sample taken from this station after the increase in discharge was in spring, 2002. This sample, like the spring, 2002, samples from stations EC2 and EC4, fell close to the fall sample region of the "Increased Discharge" cluster. However, after that period, the samples showed a distinct seasonal cycling again paralleling what was detected in the cluster analysis (Figure 1). The same taxa noted for station EC4 appear to be drivers of this seasonal signal with the addition of *Oligophlebodes*, *Rhyacophila*, and *Simulium* in the fall, 2004, sample.

CONCLUSIONS

Eccles Creek was still showing significant impacts from the increase inflow of water in fall, 2004. Station EC5 appears to be moving toward the baseline conditions. It has a high number of taxa and is shifting toward the 1979 cluster of samples in the ordination (Figure 6). However, it still has relatively low diversity (Table 7). Station EC2 is showing an intensification of the effects of armoring and given the rapidity with which this has developed (since 2001), it is likely that the

Figure 5. Trends at station EC4 denoted in black and connected by sequential dates.

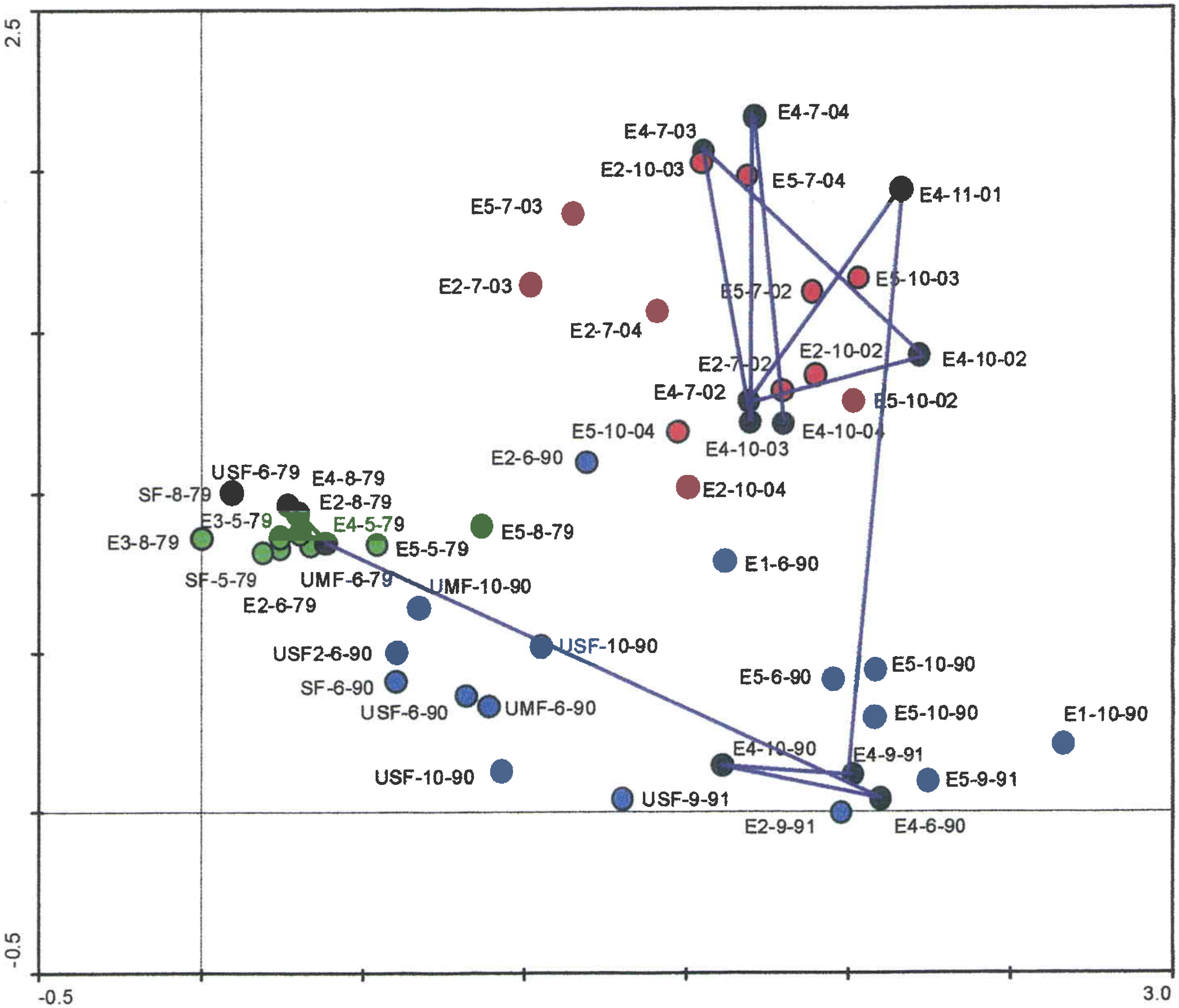
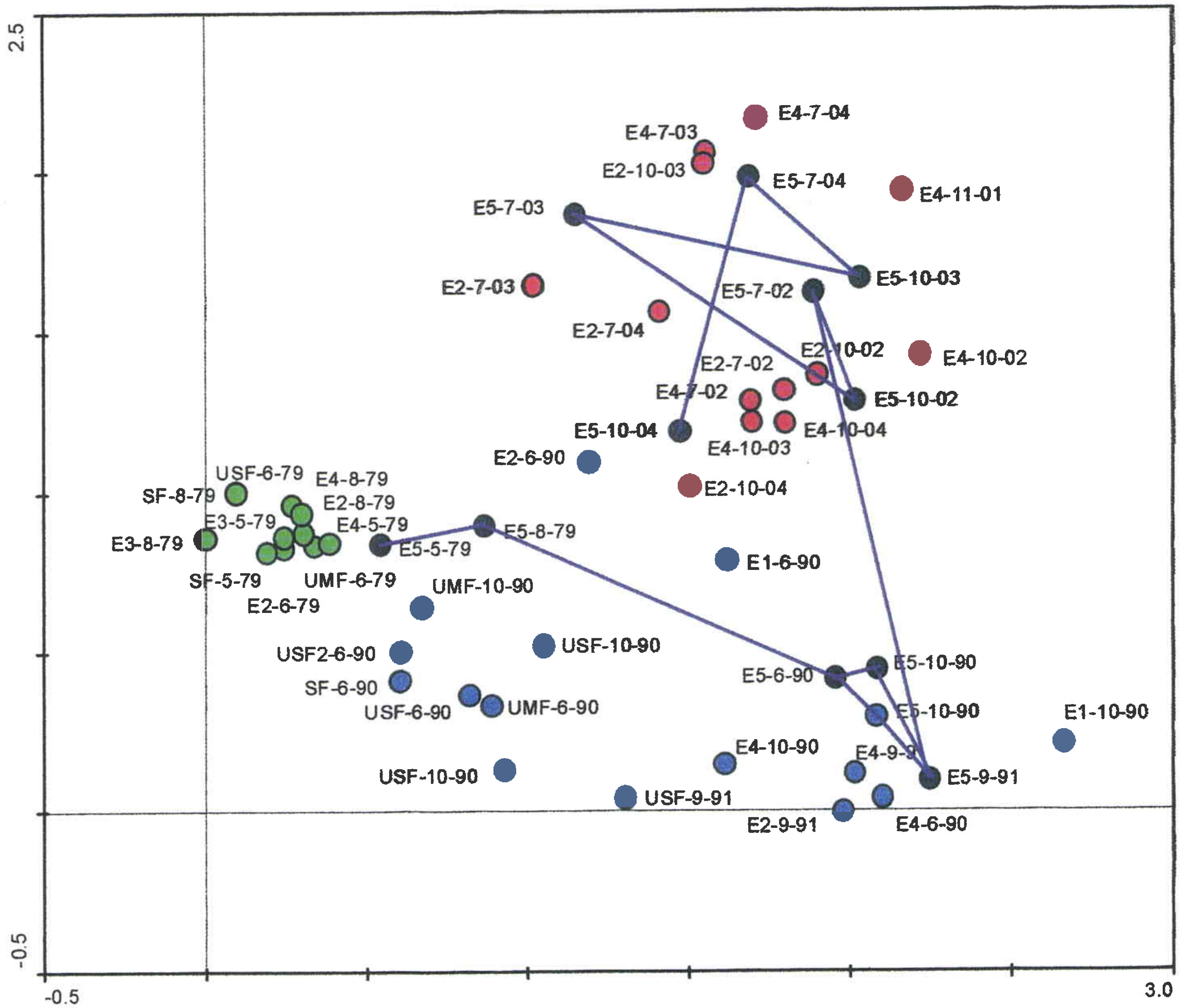


Figure 6. Trends at station EC5 denoted in black and connected by sequential dates.



armoring will continue to extend downstream eventually past station EC5. However, as of the 2004 sampling period, station EC5 had accumulated significant concentrations of sediment flushed from above.

The shifts in community structure continue to show an increase in grazers and a decrease in detritivores especially those taxa that are found in depositional habitats. Such shifts continue to reflect a decrease in the availability of detritus for detrital based food chains. The lack of detritus is one expected outcome when habitats capable of retaining detritus are greatly reduced (Shiozawa 1983). The increase to channel full discharge has occurred with sediment starved water from the mine. In open stream systems, sediments transported downstream by the stream would be replaced by sediments transported from upstream sources maintaining a quasi-equilibrium condition in the streambed. It is well known that in streams below reservoirs an armoring process takes place. When the mobile sediments are removed by the current, no replacement occurs because the upstream sediments have settled out in the reservoir. Similar processes occur in spring fed systems. The outflowing water is sediment starved, and this leads to the precipitation of calcium carbonate on the streambed and a general armoring of the bed unless water flow is slow enough to allow accumulation of fine particulate material.

Another difference between reservoir and spring fed systems is that reservoir tailwaters often have additional food input from plankton in the reservoir which can enhance the productivity of the stream below the reservoir. Spring fed systems do not have an equivalent food source and must rely on in-stream and riparian vegetation to produce energy input to the system. The water entering Eccles Creek is more analogous to a spring fed system. An additional problem is that the steepness of the channel in Eccles Canyon gives the discharged water a much greater erosional capacity (= a greater sediment transport capacity). This increases the rate of flushing of sediments from the streambed, since the stream was normally only exposed to high erosion during spring runoff or major flood events. The water is also actively precipitating calcium carbonate as excess carbonic acid is released to the atmosphere as carbon dioxide. This causes cementing of the streambed, which in effect smooths it, decreasing the ability of the system to retain detritus. The rapid transport of detritus from the system does not favor those taxa that focus their life histories on the breakdown of various sizes of detrital materials in the streambed (Cummins 1974).

Eccles Creek has been transformed by the increase in discharge. It is losing the mobile particulates from the stream channel leaving the channel armored. Because of the chemical equilibria associated with dissolved carbon dioxide and calcium bicarbonate-carbonate solubility, it is undergoing a cementing of the armored bed. These factors, along with the previous benthic community being one that was adapted to a detrital based food chain in a sediment diverse stream channel, have resulted in the dramatic community shifts observed in the system. If the discharge remains constant over time, the stream will armor and cement its bed progressively further downstream until it reaches a tributary that is transporting enough sediment to reinitiate the normal sediment dynamics of the system. If the discharge ceases, the stream will require considerable time to overcome the armoring process that has already taken place, although it is possible to take mitigation measures if a more rapid recovery is necessary.

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