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Aquatic Invertebrate Bioassessment Monitoring of Acid Mine Drainage Impacts in the Leviathan Creek Watershed (Alpine County, California)

Technical Report
submitted to the Lahontan Regional Water Quality Control Board

by

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Summary

Acid mine drainage (AMD) from the tailing soils of the abandoned Leviathan Mine creates a chronic source of water pollution and degraded habitat in the watershed of Bryant and Leviathan Creeks. These streams, north of Monitor Pass in the Sierra Nevada, have been exposed to AMD for over 40 years and show little if any indication of recovery. Acid pH, elevated heavy metals, and deposits of ferric hydroxide ("yellow-boy") continue to contaminate this watershed.

In an effort to establish biological criteria for monitoring stream health, benthic (bottom-dwelling) invertebrates were collected from a gradient of sites below Leviathan Mine. With pollution mitigation projects planned for the old open-pit mine site (now owned by the State of California), these data will provide a benchmark for evaluating the progress and success of mine clean-up efforts in accordance with water quality monitoring requirements in the Leviathan Mine Toxic Pit Cleanup Act exemption (Lahontan Regional Board Resolution No. 6-89-204). The purpose of the studies reported here is to establish baseline data for a biomonitoring plan that will (1) delineate the length and extent of stream habitat currently impacted by AMD, and (2) provide a sampling program that will serve as the basis for future comparisons of water quality. The monitoring approach taken here is based on macroinvertebrate bioassessment, which uses measures of the structure of aquatic invertebrate communities as indicators of the ecological health and integrity of stream ecosystems. Collections were taken at six sites within the watershed including unimpacted references and a gradient of stream reaches of increasing distance downstream of the mine drainage source. In conjunction with biological sampling, heavy metal sediment contamination and other physical and chemical features were also measured at each study site.

At sites on Leviathan Creek and the upper portions of Bryant Creek contamination by "yellow-boy" precipitate was extensive and sediments contained far higher contents of heavy metals including aluminum, arsenic, cadmium and copper than

on the reference sites not exposed to AMD. These locations also showed severe ecological impacts in the form of reductions in the abundance and diversity of aquatic invertebrates, leaving only a depauperate fauna of relatively pollution-tolerant organisms. On the lower portion of Bryant Creek (about 7.5 miles below the mine), some biological recovery was apparent but this location still did not achieve levels of diversity or abundance found on the reference site (the unimpacted Mountaineer Creek drainage).

These studies localize the area and extent to which stream reaches in this watershed are impacted and provide a target for ecological recovery from the effects of AMD pollution. Habitat and biological conditions are most degraded below the mine to between 3.5 to 7.5 miles downstream, where the biota begin to recover. Alternate year monitoring should continue in the late spring/early summer to assess the progress of restoration programs and be expanded to include in situ toxicity bioassays, studies of the potential for recolonization of contaminated sediments, and sampling during the fall to determine the potential for recovery under base flow conditions.

Introduction

Open pit strip mining has been used throughout the mountainous regions of the United States to uncover mineral ore and coal deposits for extraction. As the overburden soils are exposed to leaching by overland runoff from precipitation and stream flow, substantial amounts of heavy metals, sediments, and acidified waters may enter the watershed of such mining areas. Acid mine drainage (AMD) presents a severe and chronic impact to the biological integrity of stream ecosystems receiving inflow from open pit mines. Evaluation of habitat restoration programs implemented to mitigate AMD will require a monitoring program based on ecological measures of stream recovery.

From 1953 and for several years thereafter, the Anaconda Copper Company operated an open pit mine in the upper portion of the Leviathan Creek watershed (Alpine County, California) in order to extract sulfur and copper deposits. Since runoff continues to flow through the overburden mine tailings and overflows catchment ponds, the stream becomes acidified due to oxidation of sulfur producing sulfuric acid. Acidified waters in turn oxidize iron to produce the orange ferric hydroxide [$Fe(OH)_3$] precipitates that are often characteristic of AMD. The Leviathan Creek watershed, just north of Monitor Pass on Highway 89, enters Bryant Creek which in turn flows into the East Fork of the Carson River (in Nevada). At times, especially during spring snow-melt runoff, the waters of these streams run orange with the "yellow-boy" ferric hydroxide precipitate, including plumes along the side of the East Carson River receiving inflow from Bryant Creek. Along with pH values that may drop into the range of 2 to 3, AMD in Leviathan Creek also may carry toxic concentrations of heavy metals, sediments, and "yellow-boy" precipitate that covers the stream bottom and produces uninhabitable conditions for aquatic life. Restoration of water quality will require reduction of AMD chemical contamination but the ultimate goal of any pollution mitigation program is the recovery of a healthy biological community. The objective of the project described here is to provide biological measures of ecological health using the stream invertebrate community as indicators. This data will serve the purpose of delineating the area impacted by AMD, and establishing a baseline for continued monitoring of the extent and progress of ecological recovery of stream habitat.

Biological structure and function of aquatic ecosystems are not always obvious features of the environment so practical field techniques are needed to assess the ecological health of streams. Aquatic insects and other invertebrates are central to the function of stream ecosystems, consuming organic matter (wood and leaf debris) and algae, and providing food to higher trophic levels (fish and riparian birds). These native organisms also have varying degrees of pollution tolerance and so may be used as indicators of water quality and habitat conditions. For example, point source industrial pollution may cause distinctive shifts in the structure and function of the aquatic invertebrate community above and below an outfall source. Use of the stream invertebrate fauna in evaluating stream ecosystem health is known as bioassessment. This technique uses collections of the benthos (bottom-dwelling fauna) to evaluate the relative abundance of different taxa, feeding guilds, pollution indicators, and diversity to develop a quantitative basis for measuring ecological attributes of the stream. Monitoring relative to reference sites (having little or no impact but similar physical setting) and/or over time within subject sites then permits impact problems or recovery to be quantified (Rosenberg and Resh 1993, Davis and Simon 1995). Previous studies of AMD impacts on aquatic communities have also utilized biomonitoring (e.g. Peckarsky and Cook 1981, Clements 1994).

Methods

The approach taken here is to use bioassessment sampling at reference sites in comparison to a gradient of impact sites of increasing distance from the Leviathan mine AMD source. Data on the chemical properties of sediments from each sample site and physical habitat settings are used to aid interpretation of biological patterns and selection of an appropriate reference condition.

The layout of the affected watershed is presented in Figure 1. Reference sites were selected on Leviathan Creek about 1.5 miles above the mine, and on an adjacent drainage unaffected by any upstream mining activity (Mountaineer Creek, 0.1 mile above the confluence with Leviathan Creek)). Subject sites for evaluating AMD impact were located on Leviathan Creek, about 2 miles below the mine (0.1 mile above confluence with Mountaineer), and on Bryant Creek immediately below the confluence of Leviathan and Mountaineer Creek (2.1 miles downstream), and at 3.5 and 7.5 miles downstream of the mine (Bryant middle and lower, respectively). Unusually high spring flows in the East Carson River prevented reliable sampling but preliminary collections of invertebrates were made above and below the outfall plume of Bryant Creek. All biological sampling on these sites was done on June 28, 1995.

Bioassessment sampling was conducted by collecting benthic invertebrates from riffle habitats in wadable stream sections. Riffles are characterized by turbulent flows of water over rocky, shallow stream reaches. Pools and runs (or glides) are the other main types of physical stream habitats but do not contain the abundance and diversity of fauna found in riffles. Samples were taken by kicking and flushing organisms from rocks into a D-frame net held just below or downstream of the 25 x 25 cm sample area. Large wood or rock debris was then removed from the net and the sample then preserved (in alcohol) in the field. This collection contains benthic invertebrates in proportion to their relative abundance within the riffle sample areas. Three such kick-samples were taken at each site so that sampling was replicated for purposes of statistical description and comparison (in randomly located central-channel riffles). The invertebrates collected were identified to the lowest taxon possible (usually genus or species) or given an operational taxonomic unit designation until more certain identification is possible. Reference collections of all taxa have been retained for further comparisons. This will provide a resource that may be used with any future collections for comparison and verification of identifications. The procedures used were modifications of the EPA Rapid Bioassessment Protocol (Plafkin et al. 1989). The procedure used here was made more rigorous by including replication of sampling to permit statistical analysis, quantitative physical habitat descriptions, defined-area quantitative sampling, and use of more reliable metrics (based on literature reviews). The bioassessment protocol under development as a state-wide standard by the California Department of Fish and Game is based in part on recommendations and design I have provided as a member of the California Bioassessment Workgroup. The methods used here are similar to this procedure. Entire samples were sorted and counted rather than subsampled during laboratory sample processing. This gave both a more accurate description of the community and was needed to obtain as many counts as possible since some of the impact site samples held very few organisms.

In conjunction with sampling of the benthic invertebrates, physical habitat characteristics were also measured. These included stream section gradient (% slope using a clinometer), temperature, vegetation canopy cover (using a densiometer), and elevation. Along three separate transects, measures of stream width, depth, and substrate size and embeddedness (volume of rocks buried in finer sediments) were also recorded. At an earlier date (June 6, 1995) sediment samples were collected from each site for trace metal analysis by the State Water Quality Laboratory in Sacramento. Data for aluminum, arsenic, cadmium, copper and iron were selected for presentation in this report because of their known toxicity to aquatic invertebrates.

Results

Contrasts of physical habitat features among the sample sites show that Mountaineer Creek is a more appropriate reference site for comparing AMD impacts on Leviathan and Bryant Creeks. The headwater Leviathan Creek site above the mine is a poor match for habitat setting on impacted sites downstream because the elevation is much higher, channel much more narrow, substrate dominated by loose gravel and smaller particles, and temperature colder (Table 1).. The downstream sites are much more uniform with respect to these features, providing a more reliable basis for comparisons.

The relative abundance of the total of 50 species collected over all sites is summarized in Table 2, along with the tolerance values used to compute the Biotic Index. Biological impacts of AMD were assessed using selected metrics of the Biological Condition system of scoring impairment developed by the EPA (Plafkin et al. 1989). This is a provisional system and broadly ranks the extent of impact, providing one gauge for evaluating stream health. Biological criteria are under development for evaluating impacts from varied pollution sources and metrics were selected for use here that would reflect AMD toxicity (functional feeding guilds were excluded from the analysis because they probably bear little relation to the mechanism of community impact in this circumstance). Biological condition scores are presented in Table 3, showing impairment levels were severe on Leviathan Creek 2 miles below the mine and on Bryant Creek 3.5 miles below the mine. Impairment was moderate on Bryant Creek below the confluence with Mountaineer/Leviathan Creeks, and on lower Bryant Creek, 7.5 miles from the mine. Although these results indicate impairment may be alleviated somewhat with distance from the mine or below the confluence with an unimpaired drainage, other data provide more detailed resolution for evaluating site impacts. Diversity, density, and indicator metrics (Figures 3, 4 and 5) show the poorest conditions exist between the mine and the middle Bryant Creek site (at 3.5 miles downstream). Both the number of species and individuals are substantially reduced (Figure 3), and pollution indicators such as the biotic index and percent chironomidae are higher at these sites (Figures 4 and 5). The sensitive mayfly, stonefly, and caddisfly taxa (EPT) are also all but completely eliminated. Improved measures on lower Bryant Creek (7.5 miles downstream) suggest recovery begins to occur in this area, though biological health is still substantially degraded relative to the Mountaineer Creek reference station.

All sites downstream of the mine show levels of arsenic, cadmium and copper elevated one to two orders of magnitude relative to either reference site (Figure 2); aluminum and iron are elevated about 2.5 to 5 times that of the references except on lower Bryant where anomalous low values for both these elements were returned by the analysis laboratory (values well below the reference sites).

Discussion

At sites on Leviathan Creek and the upper portions of Bryant Creek contamination by "yellow-boy" precipitate was extensive and sediments contained far higher contents of heavy metals including aluminum, arsenic, cadmium and copper than on the reference sites not exposed to AMD. These locations also showed severe ecological impacts in the form of reductions in the abundance and diversity of aquatic invertebrates, leaving only a depauperate fauna of relatively pollution-tolerant organisms. On the lower portion of Bryant Creek (about 7.5 miles below the mine), some biological recovery was apparent but this location still did not achieve levels of diversity or abundance found on the reference site (the unimpacted Mountaineer Creek drainage).

Similar to the paucity of bottom fauna found in the present study, early studies after mine excavations (Wilson 1957, Davis 1969a, b) also reported from none to very few invertebrates in Leviathan and Bryant Creeks below Leviathan Mine. More recent sampling (spring and fall 1982) of benthic invertebrates (Hammermeister and Walmsley 1985) provided more quantitative data from sites including 3 of the locations sampled here (the Mountaineer Creek reference, Bryant below the confluence of Mountaineer and Leviathan, and lower Bryant). Patterns of species identity, diversity and abundance were similar to the present results, suggesting that AMD impacts from Leviathan Mine are chronic and have continued to cause impaired biological health in this watershed for over 40 years with little or no sign of recovery.

Other studies of AMD effects on aquatic invertebrates have also shown losses in abundance and diversity, dominance by chironomidae, and elimination of most mayflies, stoneflies and caddisflies (Roback and Richardson 1969, Herricks and Cairns 1972). In addition, rates of leaf litter decomposition have been shown to be reduced by elevated cadmium concentrations (Giesy 1978). Another study showed no difference in rates of litter decomposition in treated vs. untreated acid mine effluents apparently because suspended precipitate released by the treatment process also inhibited consumer activity

(Gray and Ward 1983). Feeding on contaminated sediments by collector-guild invertebrates may propagate heavy metals through aquatic food webs as well as produce direct lethal and sublethal effects on population production. Covering of substrates by "yellow-boy" is also likely to inhibit feeding by leaf shredders, algal grazers, and predators.

In addition to bioassessment, several other approaches may provide data useful in evaluating AMD impacts. A biological tolerance index specific to acid mine drainage and heavy metal toxicity is a recently developed method (Clements 1994, Clements and Kiffney 1994) that could improve upon the more general modified Biotic Index tolerance values used in this study (Hilsenhoff 1987). Field mortality bioassays may also provide another tool for evaluating relative toxicity of effluent (Peckarsky and Cook 1981).

Though the results presented here are useful for localization of the stream length impacted below the mine, the annual time frame of impacts remains unknown. Field reconnaissance of sample sites in the Fall of 1994 suggested that reduced amounts of "yellow-boy" were present and some invertebrates not present the following spring occurred in Bryant Creek immediately below the confluence of Mountaineer and Leviathan Creeks. It is possible that AMD contamination decreases in the Fall at low flow periods when holding pond flooding is no longer occurring, and the invertebrate community may rebound somewhat at this time. Seasonal sampling would allow assessment of yearly patterns of recovery.

Although there is an extensive literature on mine drainage effects in the coal mining regions of the eastern United States, and hard-rock mining in the Rocky Mountains, little data exists on mine impacts or recovery in the Sierra Nevada. Continuation of the biomonitoring program established by this study could provide a regional model for comparison to other AMD problems, and a case history for evaluating the success of reclamation efforts to restore beneficial uses.

Recommendations for further study:

- colonization studies on contaminated and uncontaminated sediments in situ to evaluate potential for recovery from "yellow-boy" precipitation
- short-term field toxicity bioassays with indicator organisms common above the mine or in adjacent uncontaminated drainages (*Cinygmula* and *Drunella* mayflies) or long-term bioaccumulation studies with filter feeders such as *Hydropsyche*
- leaf pack decomposition bioassays as a means for evaluating AMD effects on microbial processing and shredder functional feeding guild activity
- the minimum monitoring program should include alternate year sampling on the Mountaineer Creek reference, Leviathan Creek below the mine, and downstream gradient along Bryant Creek (5 sites total)
- data on pH and sediment / water chemistry should comprise a regular part of surveys
- sampling of fine sediments and quantification of the amount of "yellow-boy" precipitate per unit area for each site would also be a useful addition to this data set

These additional studies would provide not only continued field data on stream biological health as indicated by invertebrate monitoring, but controlled experiments that would permit rigorous statistical testing of actual effluent and sediment toxicity to native organisms. This integrated "triad" approach (field biomonitoring, toxicity testing, and water/sediment chemistry) would produce the most reliable methodology for evaluating water quality and sediment contamination (Canfield et al. 1995).

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Table 1. Physical Habitat Characteristics of Leviathan Mine Stream Biomonitoring Sites

Site (downstream series)	Elevation (feet)	Temperature °C	% Slope	% Cover (average)	Avg. Width (cm)	Avg. Depth (cm)	X-sectional Area (cm^2)
1-Leviathan above mine	6960	7.5	4	45.1	105	16.9	1775
2-Mountaineer (reference)	6040	12	2	49.0	283	12.5	3538
3-Leviathan below mine	6040	12	3.5	34.3	437	9.5	4166
4-Bryant below confluence	6020	12	2.5	48.5	313	17.3	5415
5-Bryant middle (between)	5800	15	4.5	86.7	350	16.8	5880
6-Bryant lower (above Doud)	5240	18.5	3.5	32.3	440	16.6	7319

Substrate Features:

Site (downstream series)	% Fines (<1 mm)	% Sand (1-2 mm)	% Gravel (3-49 mm)	% Cobble (50-249 mm)	% Boulder (>250 mm)	Average % Embeddedness	"Yellow-Boy"
1-Leviathan above mine	20	17	57	6	0	1.2	Absent
2-Mountaineer (reference)	20	0	37	43	0	19.2	Absent
3-Leviathan below mine	23	0	40	30	7	7.7	Present
4-Bryant below confluence	3	17	50	30	0	9.8	Present
5-Bryant middle (between)	7	7	17	56	13	32.8	Present
6-Bryant lower (above Doud)	20	7	23	47	3	18.3	Trace

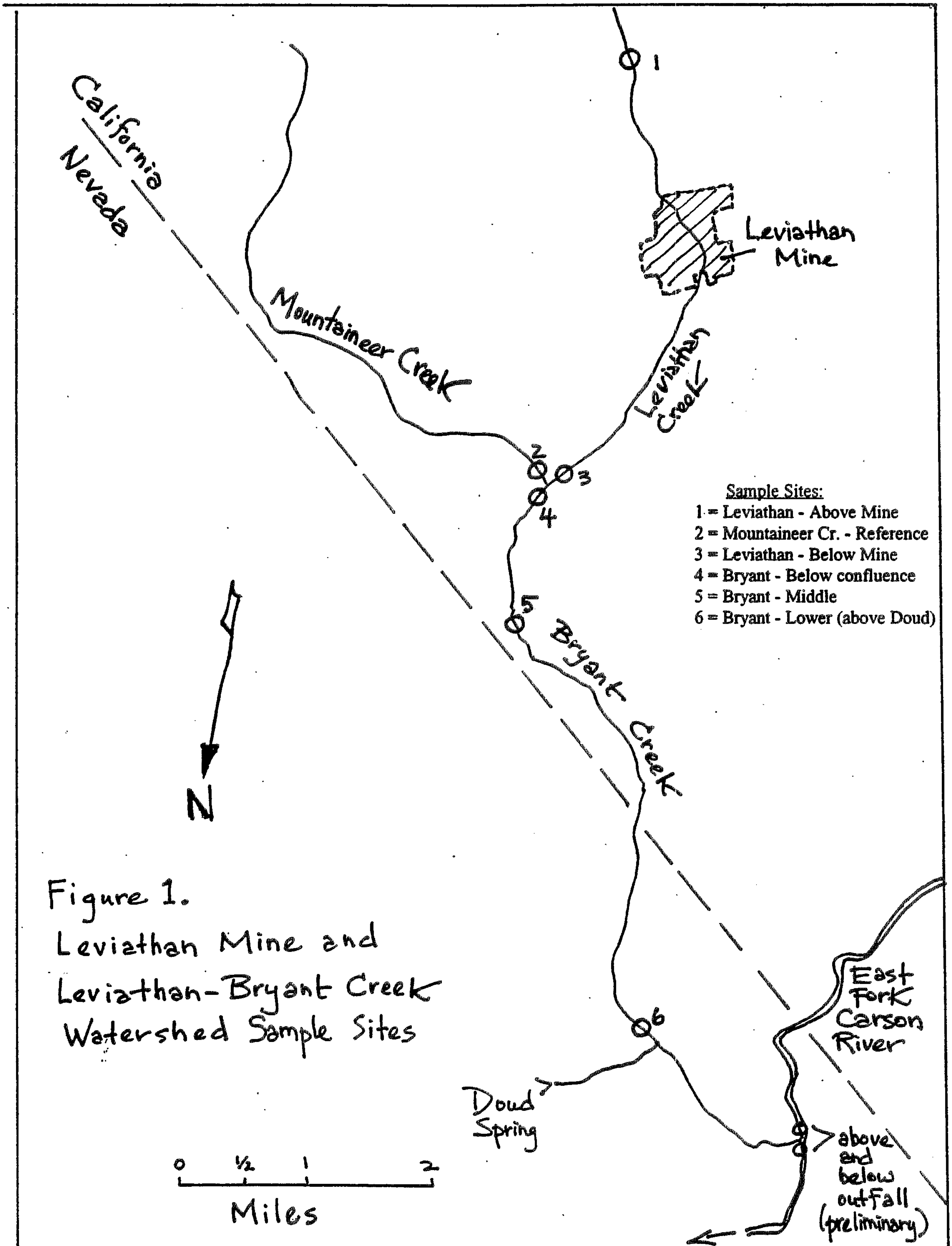
Table 2.
Leviathan Mine Data Analysis: Species List

Order	Family	Genus - species	Tolerance Value	Leviathan Above	Mtneer Reference	Leviathan Below	Bryant Below	Bryant Middle	Bryant Lower
Ephemeroptera	Heptageniidae	*Cinygmula sp.*	4	0.284	0.010		0.020		
		Ironodes sp.	4		0.002				
		Epeorus sp.	0		0.006				
	Ephemerellidae	*Serratella (teresa)*	2	0.005	0.006				
		Serratella (micheneri)	2		0.002				
		Ephemerella (inermis)	1		0.002				
		Drunella flavilinea	0		0.112				
	Siphlonuridae	*Ameletus sp.*	0		0.002				
	Leptophlebiidae	*Paraleptophlebia sp.*	1	0.005					
	Baetidae	*Baetis sp.*	4	0.055	0.210	0.069	0.224		0.217
Plecoptera	Nemouridae	*Malenka sp.*	2	0.005					0.009
	Chloroperlidae	*cf. Suwallia sp.*	1		0.006				
	Perlidae	*Doroneuria baumanni*	1		0.004				
		Calineuria californica	1						0.003
Trichoptera	Hydropsychidae	*Hydropsyche sp.*	4	0.011	0.100		0.041		0.312
	Rhyacophilidae	*Rhyacophila sp.*	0	0.044	0.018				
	Brachycentridae	*Micrasema sp.*	1		0.027				
	Limnephilidae	*Psychoglypha sp.*	1			0.017		0.025	
		Neophylax sp.	3		0.004				
		Pedomoecus sierra	0		0.002				
Coleoptera	Elmidae	*Optioservus quadrimaculatus*	4	0.142	0.192		0.020	0.125	0.036
		Zaitzevia parvula	4						0.015
	Dytiscidae	*Rhantus sp.*	5	0.005					
		Deronectes sp.	5					0.050	
	Psephenidae	*Eubrianax edwardsi*	4						0.012
Diptera	Simuliidae	*Simulium sp.*	6	0.016	0.002				
	Tipulidae	*Dicranota sp.*	3	0.005					
		Gonomyia sp.	6				0.020		
		Antocha sp.	3		0.002				
	Muscidae	*Limnophora sp.*	6	0.005			0.020		
	Empididae	*Chelifera sp.*	6	0.005	0.002				
	Chironomidae	Orthocladinae *sp.A*	6	0.295	0.165	0.500	0.306	0.475	0.294
		Orthocladinae *sp.B*	6	0.055	0.073	0.207	0.082	0.150	0.006
		Orthocladinae *sp.C*	6		0.029	0.069	0.143	0.075	0.068
		Orthocladinae *sp.D*	6				0.020		
		Orthocladinae *sp.X*	6	0.011		0.052	0.020	0.075	
		Brillia sp.	6						0.003
		Corynoneura sp.	6	0.011					
		Larsia sp.	6	0.027	0.008		0.020		0.003
		Alotanypus sp.	6						0.003
		Diamesa sp.A	6	0.005	0.004				
		Diamesa sp.B	6		0.002				
		Pagastia sp.	6						0.003
		Rheotanytarsus sp.	6		0.002				
		Tanytarsus sp.	6			0.034	0.041	0.025	
		Chironomus sp.	6			0.017	0.020		
		Polypedilum sp.	6						0.012
		Parochlus sp.	6		0.002				
	Pelecorhynchidae	*Glutops sp.*	3			0.017			
Oligochaeta	Lumbricidae	unidentified species	4	0.005	0.006	0.017			0.006
		TOTAL SPECIES / SITE :		20	29	10	14	8	16

Macroinvertebrate Species List
(relative abundance and tolerance values)

Table 3 . Biological Condition Scores of Stream Sites Exposed to Acid Mine Drainage from Leviathan Mine
[modified after the procedure for rapid bioassessment protocol level III, Plafkin et al. 1989]

Site Number / Name > **Distance From Mine >**	3. Leviathan Below Mine 2 miles	4. Bryant Below Confluence 2.1 miles	5. Bryant Middle 3.5 miles	6. Bryant Lower 7.5 miles
Metric	**Percent Relative to Mountaineer Creek Reference [and biological condition score]**			
Taxa Richness	34% [0]	48% [2]	28% [0]	55% [2]
Biotic Index (modified HBI)	69% [2]	73% [4]	70% [4]	81% [4]
EPT / Chironomidae Ratio	6% [0]	32% [2]	2% [0]	74% [4]
% Dominant Taxon	48% [0]	32% [2]	50% [0]	40% [2]
EPT Index	9% [0]	16% [0]	3% [0]	25% [0]
Community Loss Index	2.4 [2]	1.5 [4]	3.1 [2]	1.3 [4]
Sum Score & Percent of Reference Score (34 total)	4 11.7%	14 41.2%	6 17.6%	16 47.1%
Level of Impairment	SEVERE	MODERATE	SEVERE	MODERATE



Sample Sites:
1 = Leviathan - Above Mine
2 = Mountaineer Cr. - Reference
3 = Leviathan - Below Mine
4 = Bryant - Below confluence
5 = Bryant - Middle
6 = Bryant - Lower (above Doud)

Figure 1.
Leviathan Mine and
Leviathan-Bryant Creek
Watershed Sample Sites

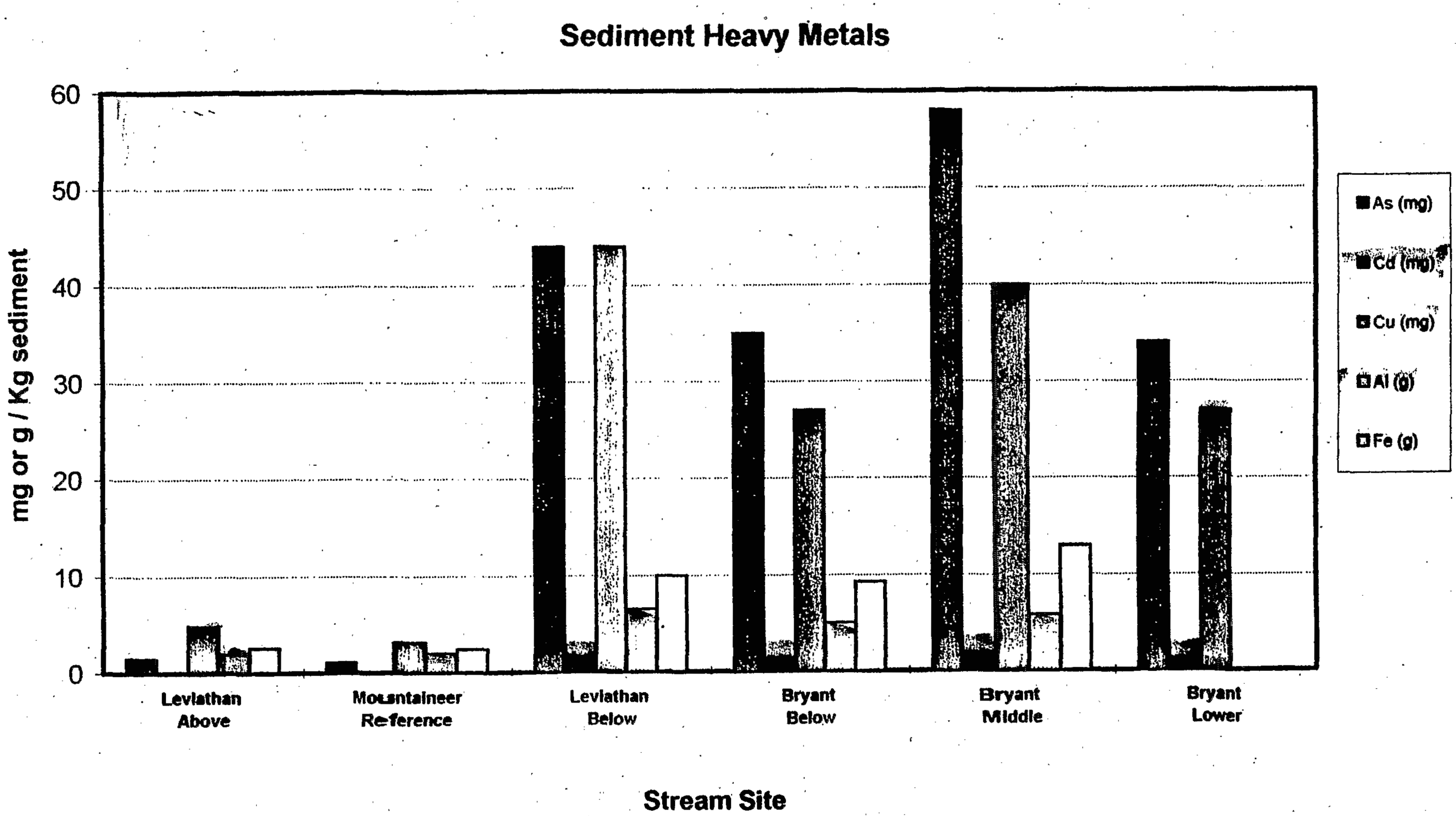
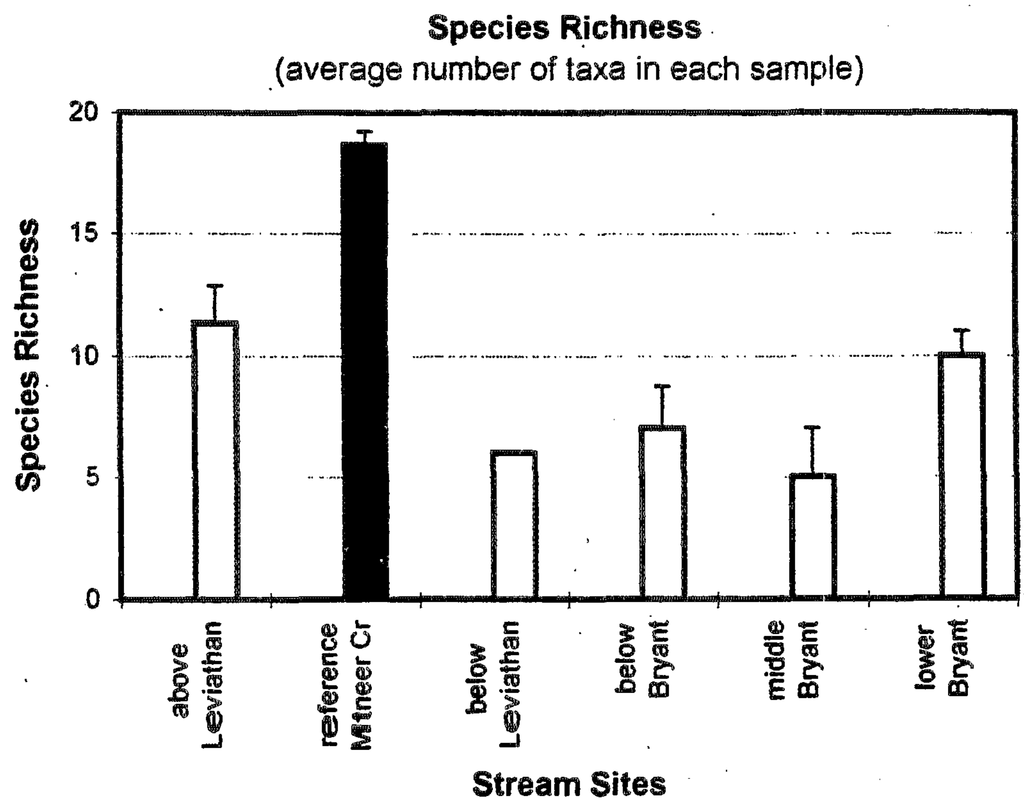


Figure 2. Heavy metal contamination of sediments from streams in the Leviathan-Bryant Creek watershed. Red = Arsenic, Black = Cadmium, Blue = Copper, Gray = Aluminum, Yellow = Iron. Sites below the mine show extensive contamination of sediments by metals. Determinations based on sediments treated with weak acid digest to mobilize metals.

Figure 3. Species diversity (top panel) and invertebrate density (bottom panel) among the stream study sites. Blue shaded bar is the reference site, shaded bar is the headwater site above the mine, open bars are AMD impact sites.



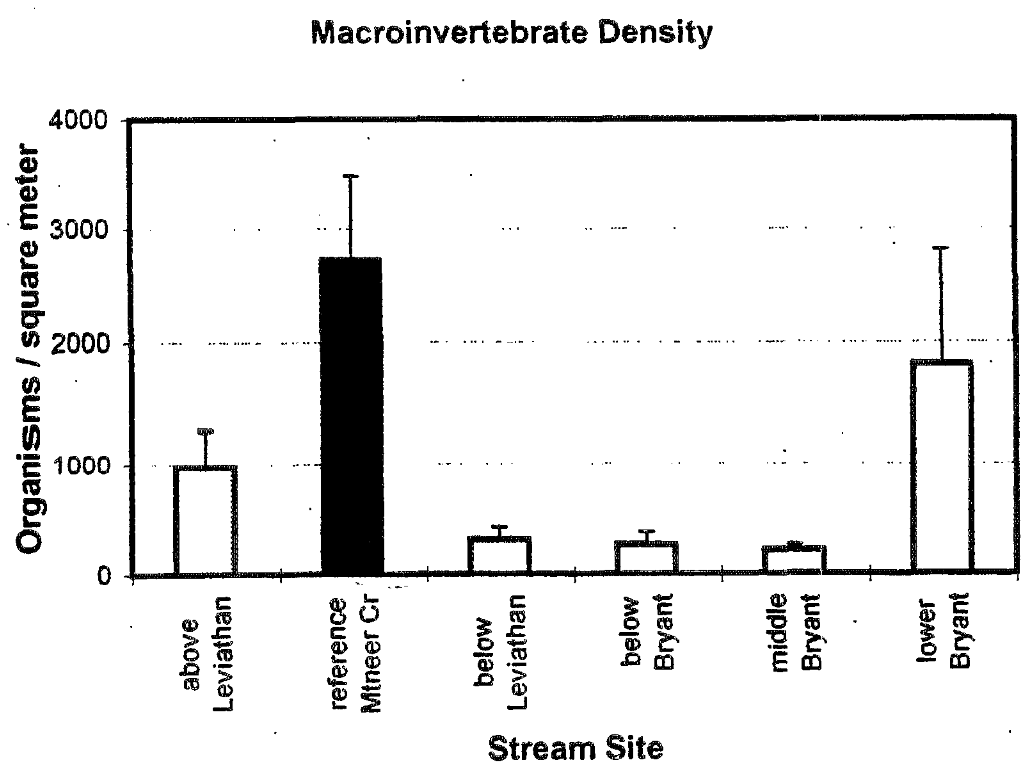


Figure 4. Indicator indices of composite pollution tolerance (Biotic Index, top panel), and number of sensitive taxa belonging to the Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, caddisflies; EPT, bottom panel).

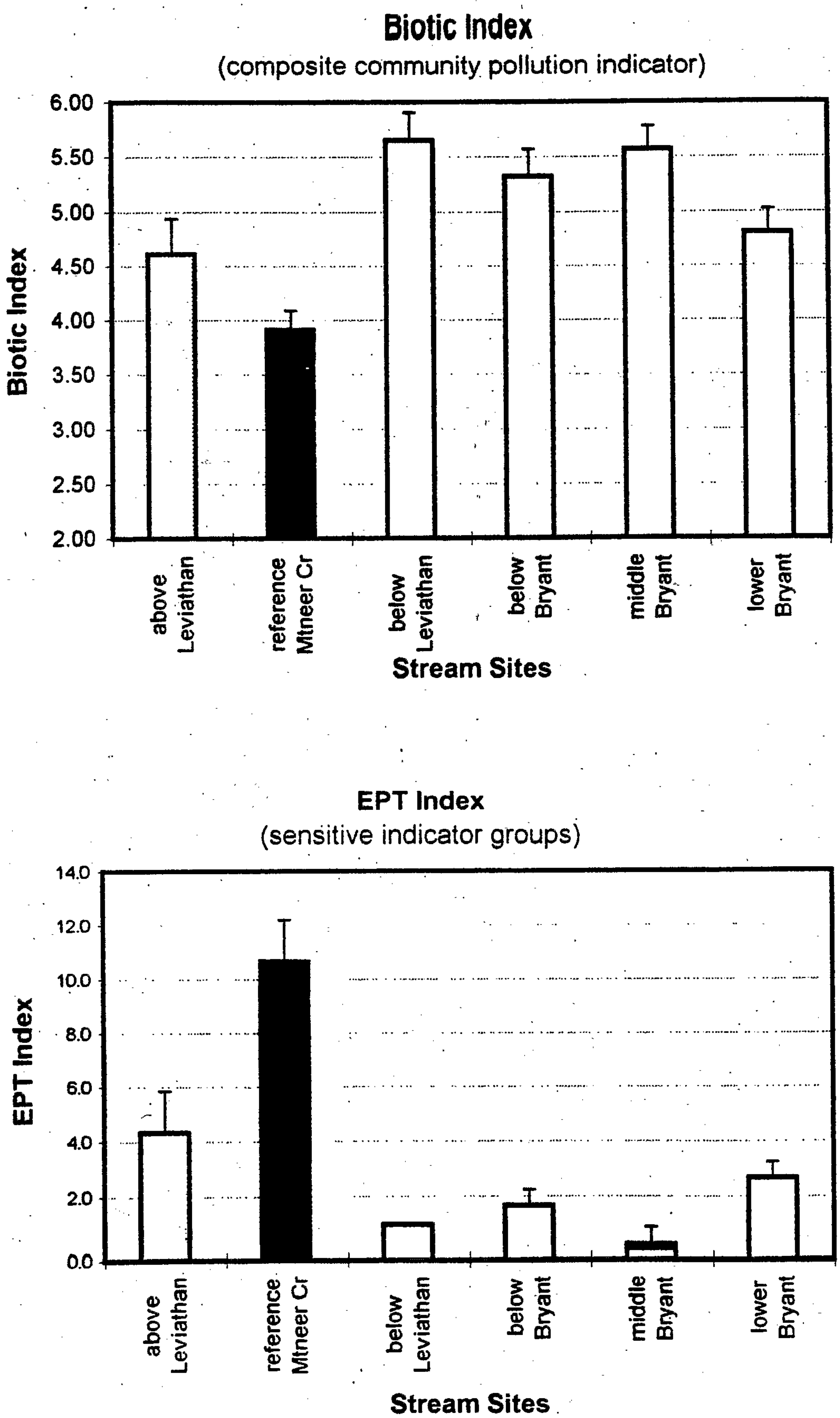
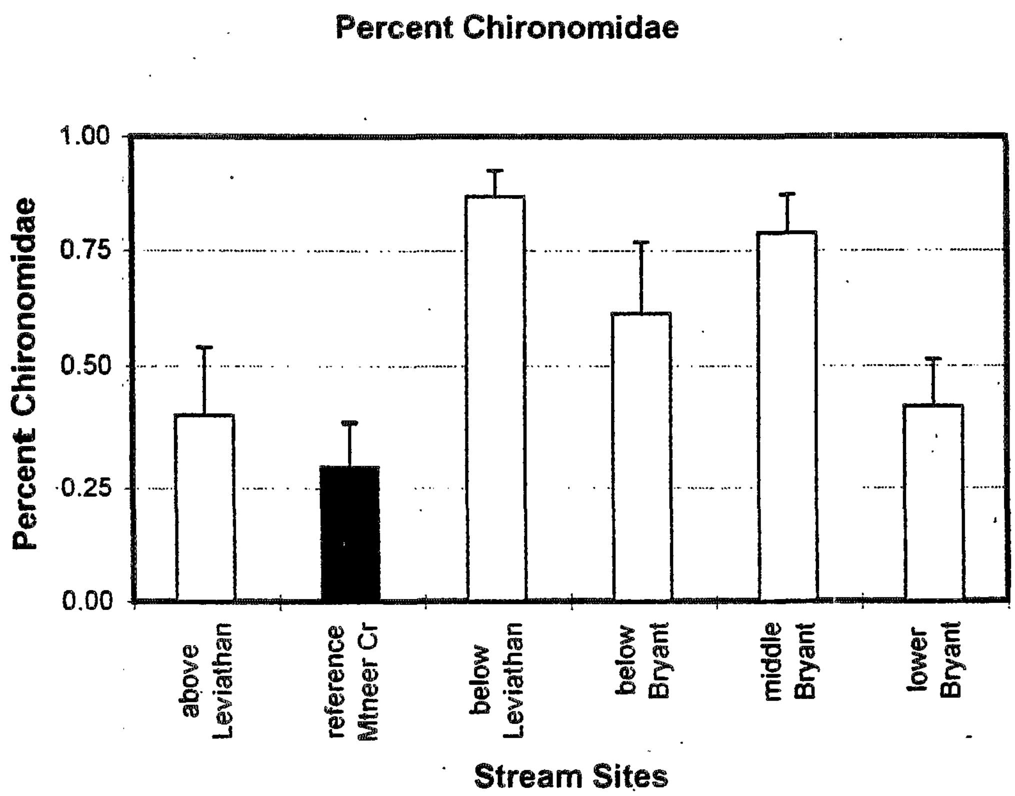
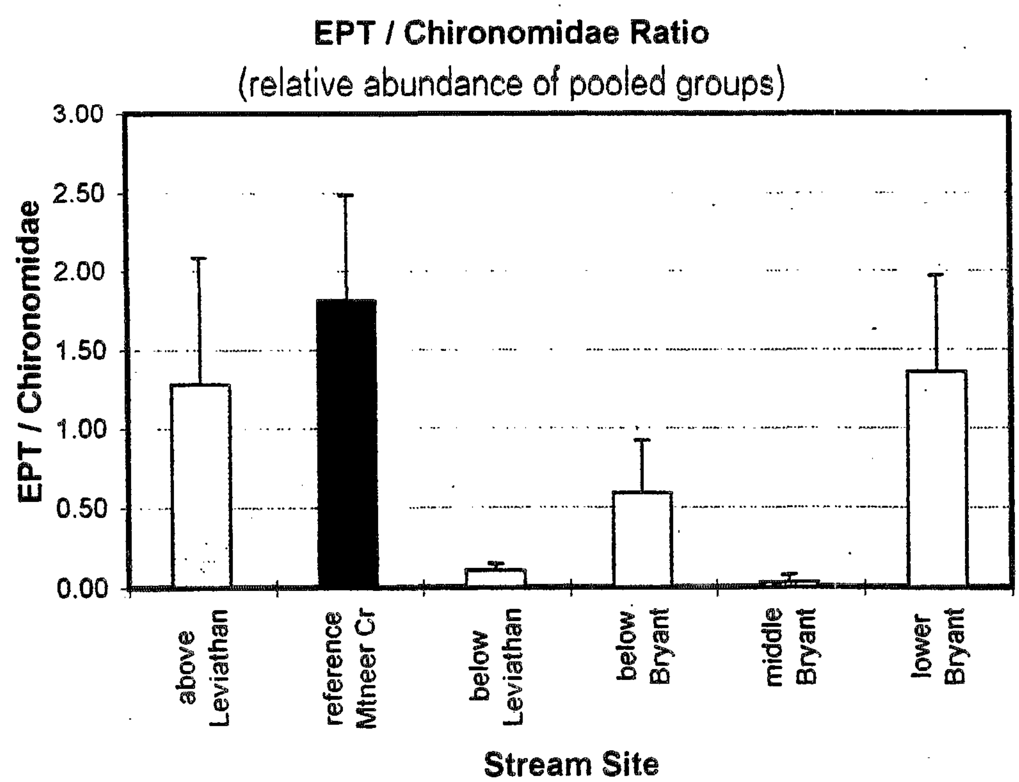


Figure 5. Pollution-tolerant chironomidae (top panel), and ratio of the relative abundance sensitive EPT taxa to the tolerant chironomidae (bottom panel).





LEFT - site 1.
Leviathan Creek:
headwaters above mine.

BELOW - site 2.
Mountaineer Creek:
reference site.
(adjacent to site 3,
Leviathan Cr. below mine)

LEFT - site 3.
Leviathan Creek:
below mine.

BELOW
Confluence between
Leviathan and Mountaineer
Creeks, forming Bryant Cr.

LEFT - site 4.
Bryant Creek: below confluence of Leviathan & Mountaineer Creeks, 2.1 miles below mine.

RIGHT - site 5.
middle Bryant Creek: 3.5 miles below mine.

LEFT - site 6.
lower Bryant Creek:
7.5 miles below mine.

BELOW - site 6.
lower Bryant Creek:
7.5 miles below mine
(another view)