Relationships Between Exceedences of Metals Criteria and Community Metrics in Mining Impacted Streams

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Abstract

To use bioassessments to diagnose specific environmental stressor gradients in streams, a better understanding is needed of the relationships between community metrics and ambient criteria. However, this relationship is not necessarily simple, because metrics generally assess measurement endpoints at the community level of biological organization, while ambient criteria are based on measurement endpoints at the individual level. For metals, the relationship is further complicated, because their bioavailability and toxicity are related to other chemical variables. Currently, freshwater water quality criteria for many metals are related to hardness. In 1993 and 1994, USEPA conducted a Regional Environmental Monitoring and Assessment Program (REMAP) survey of 105 second to fourth order streams in the Southern Rockies Ecoregion of Colorado. This ecoregion contains about 95% of the mineralized portion of the Rocky Mountains, and mining of metals over the past century has resulted in stream contamination from both active and inactive mining sites. The surveys collected fish and macroinvertebrate assemblages, physical habitat, and sediment and water chemistry and toxicity. We characterized streams as metals-contaminated based on exceedence of hardness-corrected metals criteria for cadmium, copper, lead, and zinc and on water column toxicity tests (48-hour *Pimephales promelas* and *Ceriodaphnia dubia* survival) or sediment toxicity tests (7-day Hyallela azteca growth and mortality.) Then, macroinvertebrate and fish metrics were compared among contaminated and uncontaminated sites to determine those metrics most sensitive to metal contamination. These survey data provide a framework for assessing diagnostic community metrics for specific environmental stressors.

Introduction

Three methods are used for the ecological assessment of contaminant exposure and effects in surface waters or sediments:

(1) chemical criteria (i.e., ambient water quality criteria or sediment criteria)

(2) direct toxicity assessments of environmental media (i.e., sediment or water), and

(3) bioassessments of selected biotic assemblages (i.e., fish or macroinvertebrates).

- Chemical criteria are derived using numerical methods from biossay data (Stephan et al. 1985).
- Direct toxicity assessments are bioassays with standard species to test the toxicity of water or sediment samples.
- Bioassessments enumerate samples of selected biotic assemblages, calculate metrics that describe the assemblages, and sum the metric scores to produce indices of biotic integrity (Barbour et al. 1999).

Because of differing measurement endpoints, these methods assess different levels of biological organization. Chemical criteria and direct toxicity assessments measure responses of individuals that may be extrapolated to population-level effects. Bioassessments show community-level effects. Chemical criteria and direct toxicity assessments differ, because chemical criteria use bioassay data from multiple taxa, whereas direct toxicity assessments use a few standard species.

Assumptions exist about the levels of protection associated with each tool.

- Bioassays measure individual endpoints, such as mortality, growth, or reproduction, tied to populations, because mortality and reproduction rates affect population size.
- Chemical criteria are assumed to be protective of at least 95% of the taxa in communities, because the thresholds are set at the 5th percentile of the most sensitive genera tested.
- Protection at the community level by direct toxicity assessments maybe variable, because of variable sensitivity of bioassay species relative to the indigenous community.

Such assumptions have never been tested. Use of these methods can benefit from greater understanding of the relationships between these levels of biological organization and their protection by endpoints measured by these methods.

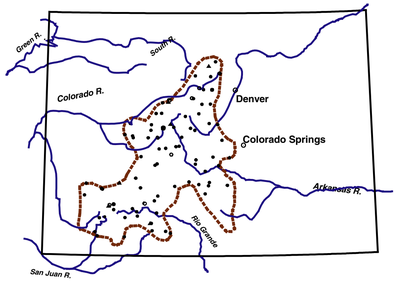
Objectives are to compare the conclusions of the different methods about the effects of contaminants at different sites to determine the relationships between the levels of biological organization protected by each method. This approach is applied to the effects of metals in streams associated with mining in the southern Rockies of Colorado.

Methods

Study Area and Survey Design

- Mineral belt of the Southern Rockies Ecoregion includes headwater drainages of the South Platte, Arkansas, Rio Grande, and Colorado Rivers (Fig. 1).
- 73 sampling sites were selected using a randomization procedure (Herlihy et al. 2000). 13 additional sites were selected upstream or downstream of mining sites. Subsets of sites were revisited within each year or between years.

Methods



● Random-selection sites ○ Downstream sites
▲ Upstream sites ····· Mineralized region

Water and Sediment Chemistry

- Stream water analyzed for dissolved and total metals and hardness.
- Sediments were digested and analyzed for total metals.

Invertebrate and Fish Bioassays

- 48-hr mortality tests were conducted with *C. dubia* and *P. promelas* on water.
- A 7-day growth and mortality test was conducted with *H. azteca* on sediments.

Macroinvertebrate and Fish Collection and Calculation of Community Metrics

- Macroinvertebrate and fish samples were collected and enumerated according to standardized EMAP methods (Lazorchak).
- Because of the preponderance of riffle habitats, only macroinvertebrate data from composite riffle samples were used in the analyses.
- The assemblage data were used to calculate various community metrics (Table 1and 2) that have been proposed in the literature (Barbour et al. 1999). The fish metrics was limited by the low natural diversity of fish assemblages in these coldwater systems (McCormick et al. 1994).

Data Handling and Analysis

- Sampling events were classified into two groups, potentially affected or unaffected by metals in surface water or sediment.
- Segregation was repeated five times, each based on a separate one of the five different individual-effects based criteria outlined in Table 3.
- Selected macroinvertebrate and fish metrics were individually compared between each pair of groups using a one-way ANOVA to answer the question, "Was the mean value of the metric different between the groups identified as affected or unaffected by metals based on the individual-effects based criteria?"

Table 1. Macroinvertebrate and fish metrics that exhibited significant differences between the two groups segregated using each of the following measurement endpoints: (D) hardness-dependent dissolved chronic criteria for Cd, Cu, Pb, or Zn (USEPA 1999, 2001); (T) hardness-dependent total chronic criteria for Cd, Cu, Pb, or Zn (USEPA 1999, 2001); (WT) results of 48-hr, water bioassays with *C. dubia* or *P. promelas*; (S) sediment threshold effects level (TEL) for Cd, Cu, Pb, or Zn based on 28-day *H. azteca* tests (USEPA 1996); and (ST) results of 7-day, sediment bioassays with *H. azteca*.

Macroinvertebrate Metrics	*D*	*T*	*WT*	*S*	*ST*	*Fish Metrics*	*D*	*T*	*WT*	*S*	*ST*
Total taxa richness	X	X	X	X	X	Total species richness	X		X	X	
Total number of individuals	X	X	X		X	Abundance, Adults		X	X		
Number, Individuals per taxon	X	X				Total Abundance		X	X		
Intolerant taxa richness	X	X	X	X	X	Proportion, Native species			X		
Ephemeroptera taxa richness	X	X	X	X	X	Salmonidae species richness	X		X		
Plecoptera taxa richness			X			Salmonidae abundance	X	X	X		X
Trichoptera taxa richness		X	X		X	Proportion, Salmonidae	X		X		
EPT taxa richness	X	X	X	X	X	Proportion, *Oncorhynchus* of Salmonidae					
Ephemeroptera + Plecoptera taxa richness	X	X	X	X	X						
Chironomidae taxa richness	X		X		X						
Orthocladinae taxa richness			X								
Tanytarsini taxa richness			X	X	X						
Proportion, Tanytarsini of Chironomidae			X	X	X						
Percentage, Coleoptera				X	X						
Percentage, Diptera					X						
Percentage, Most common taxon	X				X						
Percentage, Five most common taxa	X		X		X						
Collector-gatherer taxa richness	X	X	X	X	X						
Predator taxa richness					X						
Shredder taxa richness			X								
Grazer taxa richness			X		X						

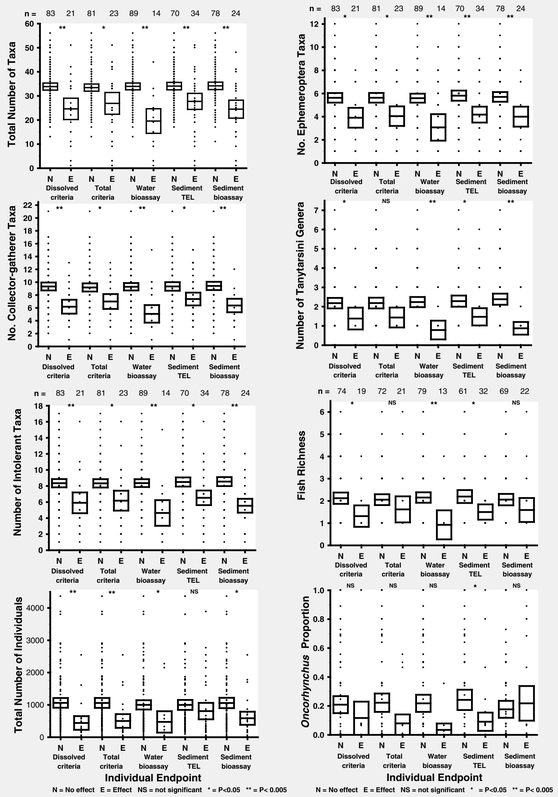


Table 2. Metrics that did not exhibit significant differences among the groups.

Macroinvertebrate Metrics	Fish Metrics
Percentage, Tolerant taxa Percentage, Ephemoptera Percentage, Plecoptera Percentage, Trichoptera Percentage, EPT Percentage, Ephemoptera + Plecoptera Ratio, EPT to EPT + Chironomidae Percentage, Chironomidae Proportion, Orthocladinae of Chironomidae Coleoptera taxa richness Percentage, Diptera and noninsects Crustacea and Mollusca taxa richness Percentage, Oligochaeta and Hirundea Hilsenhoff's biotic index Percentage, Collector-filterers Collector-filterer taxa richness Percentage, Collector-gatherers Percentage, Predators Percentage, Shredders Percentage, Grazers	Native species richness Abundance, Native species Native, Non-Salmonidae species richness Native, Non-Salmonidae Abundance Proportion, Native Non-Salmonidae

Table 3. Criteria used to divide sites into the impacted or unimpacted groups.

Variable	Individual Criterion	Source
Dissolved concentrations of Cd, Cu, Pb, or Z	Hardness-adjusted dissolved chronic criteria	USEPA (1999, 2001)
Total concentrations of Cd, Cu, Pb, or Zn	Hardness-adjusted total chronic criteria	USEPA (1999, 2001)
Survival of C. dubia or P. promelas in a 48-hr toxicity test	80% survival	control tests
Sediment concentrations of Cd, Cu, Pb, or Zn	TEL for 28-d H. azteca sediment toxicity test	USEPA (1996)
Survival or growth of H. azteca in 7-day toxicity test	85% survival or 90% growth	control tests

Table 4. Enumeration of sampling events where criteria and bioassays disagree.

Medium	Number of Sampling Events		
	Total	Conclusions based on criteria[1] and bioassays disagree	Bioassays indicated toxicity, but criteria were not exceeded
Surface Water	104	14	10
Sediments	104	29	19

[1] Criteria are hardness-adjusted chronic criteria for Cd, Cu, Pb, or Zn for surface water and the threshold effects level (TEL) for Cd, Cu, Pb, or Zn for sediments.

Table 5. Enumeration of sampling events where classification based on the surface water criteria1 for Cd, Cu, Pb, or Zn and that based on the community metric disagree.

Metric	Number of Sampling Events			
	Classified as unaffected	Metric < 95% LCL for unaffected group	Classified as affected	Metric > 95% UCL for affected group
Total number of taxa	83	30	21	8
Number of Collector-gatherer taxa	83	39	21	7
Number of intolerant taxa	83	34	21	7
Total number of individuals	83	49	21	3
Number of Ephemeroptera taxa	83	26	21	6
Number of Tanytarsini genera	83	31	21	6
Fish Richness	74	26	19	7
Proportion of Oncorhynchus	74	41	19	4

[1] For the Proportion of Oncorhynchus, the criteria used to classify the sampling events were the sediment TELs, because only sediment criteria classified the sampling events into two groups that had different means for this metric.

Results

- Several metrics exhibited differences between at least one pair of groups segregated using individual-based criteria (Table 1).
- Many metrics that did not exhibit significant differences between the pairs of groups (Table 2) - this may depend on the sensitivity of individual metrics to metals contamination.
- Many metrics (Table 1) are richness metrics (Figures 2-5).
- An exception was the total number of individuals (Figure 3), an abundance metric.

Sensitivity of richness metrics to metals is consistent with the hypothesis that affects at the individual and population-level are the basis of effects at the community-level. Toxicants, like metals, increase mortality and decrease growth and reproduction of individuals. At some threshold, recruitment fails, and a species is eliminated from the community. Because there is variation in the thresholds at which different species are affected, an increasing proportion of the community would be affected with increasing metals, and taxa richness would decrease. This also would be the basis of the observed decrease in the total number of individuals.

- There was disagreement among the individual-effects-based criteria and bioassays in assigning sites to the affected or unaffected groups (Table 4).
- There was also disagreement between the individual-effects-based criteria and the community metrics in assigning sites to the affected or unaffected groups (Table 5).

Based on the hydrogeochemistry of metals, it would be expected that some sites would have contaminated sediment but not water or vice versa. Criteria or bioassays for water and surface water would generally be expected to agree. In this case, bioassays appear more sensitive than criteria.

Sites in the unaffected group where metrics are less than expected may be affected by other stressors. Previous analyses identified increased nutrients and fine sediments and decreased canopy cover associated with livestock grazing as other stressors in these streams (Griffith et al. 2000). At sites in the affected group where metrics were greater than expected, exposure to metals may differ from that measured, because of unaccounted effects on metal bioavailability. In surface water, DOC, pH, or other anions may also affect metal bioavailability. The TEL was derived from bioassay data that did not consider possible factors affecting sediment metal bioavailability.

Metal contamination associated with mining is a complex impact on streams. In the Southern Rockies Ecoregion, the contaminants are primarily a mixture of Cd, Cu, Pb, and Zn. To simplify our analyses, we assumed an impact if at least one metal exceeded its hardness-adjusted criteria in surface water or in sediments exceeded its TEL. Also, the affected group includes a continuum of sites from those where one of the four metals minimally exceeds its criterion to those in which all four metals greatly exceed their criteria Considering such a simple classification of sites into unaffected and affected groups, one might expect that few, if any, metrics would have exhibited differences between groups. However, a number of metrics exhibited differences between the groups, although there were many sites that would have been misclassified based on the community metrics alone.

Conclusion

There is a relationship between individual-level effects and community-level effects and the individual-level effects are predictive of community-level effects. However, this relationship is affected by other stressors and site-specific factors.

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