Ecological Response Metrics for the Upper Basin of the Coeur d'Alene River, Bunker Hill Mining and Metallurgical Complex Superfund Site

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ATTACHMENTS: Coeur d'Alene Basin Ecological Response Metrics, Final Report (Stratus Consulting, 2012)

This memorandum presents the Coeur d'Alene Ecological Response Metrics (Stratus Consulting, 2012) (see attached). EPA, in collaboration with the Coeur d'Alene Basin Natural Resource Trustees[1], has developed ecological response metrics for evaluating remedial progress during the implementation period for the Selected Remedy for the Upper Basin.

The forthcoming Upper Basin Record of Decision (ROD) Amendment documents an interim remedy for surface water, soil, sediments, and groundwater in the Upper Basin. The Selected Remedy is focused on remedial actions that will reduce risks to human health and the environment present in the Upper Basin as a result of historical mining-related contamination. The Selected Remedy addresses contaminant sources (such as mine tailings, waste rock, adit drainage, and contaminated floodplain sediments), surface water quality in the SFCDR and its tributaries, and existing human health remedies that could be vulnerable to the erosion and recontamination of existing clean barriers installed within Upper Basin communities. The Selected Remedy is expected to result in significant improvements to surface water quality in the Upper Basin, although it is not expected to fully address surface water contamination at all locations. The Selected Remedy is also not intended to fully address groundwater contamination. The Selected Remedy is expected to result in the achievement of cleanup goals for soil and sediments where actions are taken.

Intended Use of Ecological Response Metrics

The ecological response metrics are intended to be used as lines of evidence to evaluate remedial progress during the implementation period for the Selected Remedy. The aquatic ecological response metrics (fishery tiers) described in the 2002 ROD for OU 3 (EPA, 2002) have been revised and updated by evaluating additional data obtained since 2002. The metrics address a suite of environmental media (surface water, soil, sediment) and biological parameters to measure environmental improvement and progress towards cleanup goals. Identification of measurable ecological response metrics will provide EPA a means to evaluate, predict, and report on environmental improvements associated with remedial actions planned and implemented in the Upper Basin. The intent of such ecological response metrics is to provide EPA and the public with:

- A means to estimate potential environmental and ecological improvements that could result from specific remedial actions;
- Target receptors to evaluate environmental recovery; and
- A means for measuring environmental recovery and progress toward cleanup goals following the implementation of remedial actions.

[1] The Coeur d'Alene Basin Natural Resource Trustees include the U.S. Department of Interior represented by the U.S. Fish and Wildlife Service and Bureau of Land Management, the U.S. Department of Agriculture represented by the U.S. Forest Service, and the Coeur d'Alene Tribe

The ecological response metrics are not meant to be used as precise projections of ecosystem recovery or as legally binding benchmarks. The ROD Amendment identifies remedial action objectives (RAOs) and cleanup levels for the Upper Basin. These cleanup levels include site-specific ambient water quality criteria (AWQC) values for surface water and a risk-management-based decision to use the site-specific cleanup level of 530 mg/kg for lead in soil or sediments. The ecological response metrics are intended to serve as one of many lines of evidence to allow EPA to assess effectiveness of remedial actions towards meeting these cleanup levels.

Ecological Response Metrics and Environmental Monitoring

EPA is currently working with stakeholders to develop an update to the environmental monitoring programs for OU 3 and OU 2, respectively in the Basin Environmental Monitoring Plan (BEMP) (EPA, 2004) and the Environmental Monitoring Plan (EMP) (CH2M HILL, 2006), to be consistent with the Selected Remedy for the Upper Basin and to consolidate all the Basin-wide environmental monitoring efforts into a single monitoring plan. The revised BEMP will guide all the environmental monitoring efforts within the Upper and Lower Basins. The fundamental approach of the BEMP is to assess changes and improvements in contaminated media, and to monitor changes in associated habitats and ecological receptors. As such, the media of interest for the long-term BEMP include surface water, sediments, groundwater (especially that which discharges dissolved metals to surface water), and biological resources. The affected ecological media include habitats and biological communities, which will also be monitored as part of this program. Data collected through the BEMP will be used to inform the ecological response metrics described in this report.

In addition to Basin-wide monitoring, the BEMP will include action-specific monitoring that will be conducted to support the overarching long-term status and trends monitoring program. The action-specific monitoring elements will be developed as part of the remedial design and in support of evaluation of the effectiveness of specific cleanup actions. The action-specific monitoring programs may be initiated in focused areas at an expedited data collection frequency in preparation for remedial design efforts, and may also be adjusted or terminated as actions and data collection objectives are satisfied. This action-specific monitoring data will also be used to inform the ecological response metrics described in this report.

Ecological Response Metrics and Adaptive Management

Given the large geographic area and scope of the required work, the implementation of the Selected Remedy is expected to take about 30 years. EPA will implement the Selected Remedy through an adaptive management approach. A key component of the success of the adaptive management process is refinement of the implementation processes and remedial approaches as new information becomes available that clarifies uncertainties regarding the understanding of a site, the effectiveness of the remedial approaches and technologies used, and the responses of environmental receptors to changes in contaminant concentrations, ecological conditions and habitat (CH2M HILL, 2010). The ecological response metrics will inform EPA on the responses of environmental receptors following implementation of remedial actions in specific areas. This will provide EPA with the lines of evidence to measure the effectiveness of remedial actions and modify (or refine) future remedial approaches to ultimately meet RAOs and cleanup levels throughout the site.

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Coeur d'Alene Basin Ecological Response Metrics

Final Report

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1. Introduction

The U.S. Environmental Protection Agency (EPA), working together with governmental partners and stakeholders, is planning a series of remedial measures for the Upper Coeur d'Alene Basin, Idaho (the Upper Basin). The goals of these measures include reducing metals concentrations in the South Fork Coeur d'Alene River (SFCDR) and a number of contaminated tributaries so that these water bodies meet Ambient Water Quality Criteria (AWQC). It is likely that it will take many years to fully achieve this goal. However, each step in the remediation process is anticipated to result in improvements in environmental conditions. Identification of measurable ecological response metrics that can serve as indicators of such environmental improvement can provide EPA with a means to evaluate, predict, and report interim benefits associated with remedial actions. This document describes the relationships between environmental media (water, sediment, and soils) and a suite of biological parameters and proposes a set of ecological response metrics to predict, measure, and report environmental cleanup progress in the Upper Basin.

1.1 Ecological Response Metrics: Intended Uses

The ecological response metrics described in this report are intended to provide EPA (and the public) with:

- Basin-specific measures of ecological conditions to aid in remedial planning and monitoring
- Tools to estimate environmental recovery trajectories following implementation of remedial actions.

The proposed ecological metrics are not intended to serve as deterministically precise projections of ecosystem recovery. Spatial and temporal variability, site-specific environmental factors, anthropogenic influences, and other ecological complexities necessarily introduce variability into the predictive precision of any response metric. For example, the presence of other anthropogenic influences may cause an adverse environmental effect that cannot be directly remedied by a specific action at a mining source. Rather, the indicator metrics developed under this task are intended to serve as estimated measures of change in aquatic conditions that can be applied at the basin level and thus be used for planning purposes. The numerical relationships associated with the proposed metrics are specific to the Upper Basin and should not be applied "as is" to other locations. In addition, metrics and analyses presented herein will be reevaluated as part of future data revisions, five-year reviews, and the adaptive management process.

1.2 Report Organization

The remainder of this report is organized as follows. Section 2 summarizes the methods used to derive descriptive metrics and predictive models, including a discussion of the geographic focus and data sources used in this analysis. Section 3 discusses the proposed ecological response metrics and presents the results of the analyses. Section 4 summarizes proposed ecological response metrics and associated numerical thresholds into a comprehensive set of ecological condition indices.

2. Data and Methods

The general analytic approach used in this evaluation entailed assembling existing environmental data from the Upper Basin. The relationships between concentrations of metals in environmental media (water, sediment, soils) and biological conditions were evaluated. Then, a suite of biological metrics were identified that can be used to predict, measure, and report on environmental changes anticipated to result from reductions in metals concentrations from remediation actions.

2.1 Geographic Focus

The geographic focus of these analyses was the SFCDR (Upper Basin), Canyon Creek, Ninemile Creek, and East Fork Ninemile Creek. Some streams were subdivided into reaches (Table 1), and reach designations served as the basis for identifying co-located water samples, sediment samples, and biological samples. The reach designations used in these analyses were based on stream reach designations employed in prior studies in the Upper Basin (e.g., LeJeune et al., 2000). However, the reach designations were used as a means of spatially aggregating data and do not need to be retained for future application of the proposed metrics. Rather, those metrics were derived from relationships between metals concentrations and biological response endpoints and therefore can be applied without reference to specific stream reaches.

All sampling stations (chemical and biological) that could be georeferenced were categorized by river mile on each respective named river or creek as provided in the National Hydrological Dataset (USGS, 2002). Water data records were omitted from further analysis if the geocoordinates were absent or if records indicated a location more than 250 m from the nearest named stream. Only Upper Basin sample locations in U.S. Geological Survey (USGS) hydrologic unit code (HUC) 17010302 were included.

Table 1. Reach designations used for spatial aggregation of data used in analyses of potential metrics

River/creek name	Reach description	River mile at lower reach boundary	River mile at upper reach boundary
SFCDR			
	North Fork Coeur d'Alene River to Pine Creek	0	2.2
	Pine Creek to Elizabeth Park	2.2	9.8
	Elizabeth Park to Canyon Creek	9.8	20.1
	Canyon Creek to Daisy Gulch	20.1	28.9
	Daisy Gulch to headwaters	28.9	Top of watershed
Canyon Creek			
	SFCDR to upriver extent of the Star Tailings Impoundment	0	2.8
	Star Tailings Impoundment to O'Neill Gulch	2.8	7.0
	O'Neill Gulch to headwaters	7.0	Top of watershed
Ninemile Creek			
	SFCDR to East Fork Ninemile Creek confluence	0	3.1
	East Fork Ninemile Creek confluence to headwaters	3.1	Top of watershed
East Fork Ninemile Creek			
	Ninemile Creek confluence to Interstate-Callahan Mine	0	3.5
	Interstate-Callahan Mine to headwaters	3.5	Top of watershed

Source: LeJeune et al., 2000.

2.2 Data Sources

Quantification of the environmental condition indices for each response metric was based on an analysis of environmental conditions in the Upper Basin and inspection of the strength of association between the proposed response metric and concentrations of key indicator metals. A set of existing datasets were identified that (1) are readily available in electronic format, (2) contain multiple metrics collected in similar space and time, and (3) were collected by well-known agencies and researchers such that the data can be used with confidence(Table 2). Although additional data exist for the Upper Basin, it is unlikely that supplementing the datasets summarized in Table 2 would alter the analysis of response metrics.

Table 2. Data sources considered in analyses

Research lead/affiliation	Program	Years	Data types
Stratus Consulting and R2 Resource Consultants	Natural Resource Damage Assessment (NRDA)	1994, 1995, 1996, 1998	Fish, macroinvertebrates, surface water quality, floodplain soil metals, floodplain vegetation
Idaho Department of Environmental Quality (IDEQ)	Beneficial Use Reconnaissance Program (BURP)	1992–2008 (not every year)	Fish, macroinvertebrates, habitat
USGS	National Water-Quality Assessment Program (NAWQA)	1998–2001	Fish, surface water quality
U.S. Fish and Wildlife Service (USFWS)	Basin Environmental Monitoring Program (BEMP)	2004–2006	Fish, macroinvertebrates
USFWS	Environmental Monitoring Program (EMP)	2003, 2006, 2008	Fish, macroinvertebrates, sediment quality
U.S. Department of Agriculture Forest Service	Pine Creek, Moon Creek	1993, 2010	Macroinvertebrates
Stratus Consulting	NRDA	2007–2009	Fish, macroinvertebrates, sediment quality, surface water quality
EPA	Water Quality Exchange (WQX)	1987–2011	Surface water quality, sediment quality

Each dataset was assessed with regard to its relevance to the process of developing ecological metrics. As discussed in subsequent sections of this report, certain portions of the available datasets were not included in the final quantitative analyses if it was determined that those data were either not relevant to or misleading because of particular geographic or temporal aspects of the data, or because of specific sampling methods used. For example, data from the most upstream, headwaters reach of the SFCDR were not included because the ecological and habitat attributes of this stream reach differ substantially from downstream locations in the SFCDR that will be influenced by remedial actions.

2.3 Water Chemistry

Water chemistry parameters used in these analyses included dissolved cadmium and zinc as indicators of dissolved metal contaminants, as well as hardness. Cadmium and zinc have previously been identified as the primary toxic metals of concern to aquatic biota (LeJeune et al., 2000). Water chemistry data were obtained from two sources: EPA's WQX (formerly called STORET) database (USEPA, 2011) and in-house data collected by Stratus Consulting on behalf of the natural resource trustees. Each of these sources is described below.

A substantial amount of chemistry data was obtained from EPA's WQX database. This database is a repository for data generated by multiple government agencies and contractors working within the Upper Basin. Stratus Consulting downloaded WQX data using the Geographic Location query web page (USEPA, 2011). Data record selection criteria included:

- USGS eight-digit HUC: 17010302 (Upper Basin of SFCDR)
- Station type: river/stream only, river/stream ephemeral, river/stream intermittent, and river/stream perennial
- Medium: water
- Other selectable characteristics unrestricted.

The database download included records from 6,667 sampling events[1] for metals of interest. Subsequent to interpretation by cross-referencing the location to geographic information system (GIS) databases, it was determined that data were available for 38 named streams. Data were included from the sampling efforts conducted by USFWS, USGS, IDEQ, and CH2M HILL on behalf of EPA.

Water chemistry data collected by Stratus Consulting and the natural resource trustees were also included in this analysis. Sampling was conducted in the autumn of 2007, 2008, and 2009. The scope of this sampling included 5 stations in Canyon Creek in 2007; 34 stations in Canyon Creek, Ninemile Creek, and the main stem SFCDR in 2008; and 43 stations in Canyon Creek, Ninemile Creek, and the SFCDR in 2009.

In all cases for which water hardness measurements were available, the ambient water quality criteria (chronic AWQC)[2] for cadmium and zinc (see Equations 1 and 2; Idaho Department of Administration, 2011) were calculated.

$$\text{Cd AWQC } (\mu g/L) = 1.101672 - (\ln(h) * 0.041838) \times e^{((0.7852 \times \ln(h)) - 3.49)} \quad \text{(Eq. 1)}$$

$$\text{Zn AWQC } (\mu g/L) = e^{((0.6624 \times \ln(h)) + 2.2235)}, \quad \text{(Eq. 2)}$$

1. A "sampling event" is defined as a sample collection at a particular time and location, regardless of concurrent sampling at other locations or relationship to a particular study, survey, or sampling program.

2. The Idaho Department of Administration (2011) uses the terms "criterion continuous concentration" (CCC) and "aquatic life criteria" to refer to "chronic" criteria and AWQC.

where h = hardness (mg/L $CaCO_3$) and

$$\text{Hardness (mg/L } CaCO_3) = (2.497 \times (Ca)) + (4.118 \times (Mg)), \quad \text{(Eq. 3)}$$

where Ca and Mg are calcium and magnesium, respectively, expressed as mg/L.

AWQCs were not estimated for samples lacking hardness records or records of calcium and magnesium.

Water chemistry records also were expressed as the ratio of dissolved metals concentration and the corresponding AWQC:

$$\text{Dissolved Cd } (\mu g/L) \text{ / Cd AWQC} \quad \text{(Eq. 4)}$$

$$\text{Dissolved Zn } (\mu g/L) \text{ / Zn AWQC} \quad \text{(Eq. 5)}$$

Average autumn low-flow water chemistry values for each stream reach were estimated by calculating the mean of all measured values collected during September and October.[3] Data describing associated biological metrics were not restricted to September and October. In cases where biological data were available for a particular reach and year but corresponding water chemistry records were unavailable, mean values of water samples collected in that reach across other years were used as surrogate values for that reach. About 10% of water chemistry records used in this analysis were surrogate values. Consequently, the influence of using such imputed values on the overall analysis is minor.

2.4 Sediment Chemistry

Sediment chemistry data included measured concentrations of lead and zinc in fine-grained sediments (< 63 µm) collected by Stratus Consulting and the natural resource trustees in the autumn of 2008 and 2009 (unpublished). The fine-grained sediment fraction has been used for many years as the preferred measure of evaluating spatial trends in metals contamination because it reduces potential variability associated with grain size (e.g., Axtman and Luoma, 1991). The scope of sampling included 34 stations in Canyon Creek, Ninemile Creek, and the main stem SFCDR in 2008; and 43 stations in Canyon Creek, Ninemile Creek, and the main stem SFCDR

3. Dissolved metals concentrations in surface water during the annual low-flow period (September and October) were considered to be reasonable indicators of metals concentrations in a particular stream reach because measurements taken in this period are less subject to large variations that occur as a result of episodic snowmelt and rainfall events which are more common in other months. Moreover, the use of fall low-flow data in these analyses is consistent with EPA's use of low-flow data in predictive models of water quality conditions.

in 2009. Sediment chemistry data extracted from WQX (USEPA, 2011) also were used. Data record selection criteria included:

- USGS eight-digit HUC: 17010302 (drainage basin of SFCDR)
- Station type: river/stream only, river/stream ephemeral, river/stream intermittent, and river/stream perennial
- Medium: sediment.

Although the sediment sampling events generally included measurements of a large suite of metals, metrics were based only on concentrations of lead and zinc in fine-grained stream sediments. Records that were not clearly identified as measurements of the fine-grained fraction were excluded from the final analyses (e.g., USFWS, 2009). Other metals present in sediments were not considered because they are highly correlated with lead and/or zinc in the Upper Basin and because they are not expected to be as important drivers of toxicity relative to lead and zinc.

2.5 Riparian Floodplain Soils Chemistry

Riparian soils chemistry data for the Upper Basin were obtained from the LeJeune et al. (2000) injury determination report. Soil sampling was conducted during August 1994 contemporaneously with vegetation community surveys. Samples were sieved to retain the < 2.0-mm fraction.

Concentrations of lead and zinc in riparian soils were included in the analysis. Soil samples were collected at the same set of sites where vegetation characteristics were recorded. Other metals present in riparian soils were not considered because they are highly correlated with lead and/or zinc or because they are not expected to be important drivers of toxicity relative to lead and zinc.

2.6 Biological Data

2.6.1 Fish

Measures of fish abundance used in these analyses were abundance of all trout/100 m^2 (cutthroat, rainbow, and brook trout)[4] and number of sculpin/100 m^2. Fish abundance data were obtained from USFWS BEMP program collected in 2003–2006 (USFWS, 2007), USFWS EMP program

4. Patterns of abundance of trout are very similar to those for cutthroat trout only, as cutthroat trout is the dominant trout species at most sampling locations.

(USFWS, 2008a), IDEQ (BURP; collected in 1996–2008), USGS (collected in 2000), Idaho Fish and Game (collected in 2006 and 2010), R2 Resource Consultants (collected in 1994–1996; R2 Resource Consultants 1995, 1996a, 1996b, 1997a, 1997b), and Stratus Consulting (collected in 1998 and 2007–2009). Benthic macroinvertebrate data were obtained from USFWS (BEMP; collected in 2004–2006), IDEQ (BURP; collected in 1996–2008), and R2 Resource Consultants (collected in 1996). Metrics were used as reported if they represented the desired units of abundance (e.g., number of fish per 100 m^2) or, if necessary, the desired units were calculated using available data and sampling information such as stream width at sample sites.

Records of trout abundance were included in these analyses only if they were collected using multiple-pass depletion electrofishing methods at locations that are representative of Upper Basin streams, particularly streams that are likely to be affected by anticipated remedial management actions (e.g., Canyon Creek, Ninemile Creek, SFCDR). Data were excluded if they were based on snorkel surveys or single-pass electrofishing because these types of collections are primarily designed to provide indices of relative abundance rather than estimates of actual population size and, consequently, are not directly comparable to multiple-pass depletion data. In addition, certain locations were excluded because they are unrepresentative of the target Upper Basin streams. For example, the uppermost headwater reaches of the SFCDR upstream of Shoshone Park are considerably different from the larger, more channelized reaches of the SFCDR downstream of Mullan, ID. Finally, recent sampling from the upper SFCDR downstream of the Lucky Friday Mine were excluded because trout abundance appears to have been influenced by recent increases in metals concentrations resulting from transient events that are not representative of long-term conditions in this reach.

For purposes of modeling, trout abundance was expressed as a percentage of background[5] abundance. Following the methods outlined in a series of NRDA reports (e.g., LeJeune et al., 2000; Lipton, 2007), the baseline trout density estimates derived from upstream reference reaches of the SFCDR, Canyon Creek, and Ninemile Creek were used to represent background trout abundance in those streams. These background abundance values were 13.9 trout/100 m^2 for the SFCDR, 8.3 trout/100 m^2 for Canyon Creek, and 35 trout/100 m^2 for Ninemile Creek.

5. The term “background” is used here to describe conditions unaffected by contamination related to the Coeur d’Alene Basin site. The concept of background is analogous to the term “baseline” used by the Natural Resource Trustees to describe conditions that would be expected to exist but for releases of hazardous substances from the site. For biological data (e.g., fish populations, macroinvertebrates, floodplain vegetation) the baseline information developed by the Natural Resource Trustees was used as a measure of background conditions. Where available, the background contaminant concentration data defined and developed by EPA were used.

2.6.2 Benthic macroinvertebrates

Data describing the species composition of the benthic macroinvertebrate community (collected in 2004–2008) were obtained from the USFWS BEMP program (USFWS, 2005, 2006) and USFWS EMP program (USFWS, 2008b) reports. Other data sources describing benthic invertebrate communities (1996–2008) included the IDEQ BURP program (Jason Pappani, Monitoring and Assessment Coordinator, IDEQ, personal communication, June 2011) and R2 Resource Consultants (1997b). Background values were adopted from baseline data developed by the Natural Resource Trustees.

2.6.3 Riparian floodplain vegetation

Measurements of the structure and density of vegetation in riparian floodplains of the Upper Basin were collected at 63 locations in the Upper Basin by LeJeune et al. (2000). Measurements of metals concentrations in floodplain soils were collected concurrently with the vegetation measurements (Section 2.5). Background values for floodplain vegetation were adopted from baseline data developed by the Natural Resource Trustees.

3. Proposed Response Metrics

The proposed response metrics address three fundamental aspects of environmental quality in the Upper Basin: chemical quality, biological quality, and habitat quality. These elements clearly are interrelated. However, given natural ecological complexities and the fact that recovery across these elements may not proceed at equivalent rates, using three distinct indicator suites will provide EPA and stakeholders greater ability and flexibility to predict, measure, and report environmental changes over time and space. These quality indicators were then combined into a set of ecological response metrics and environmental condition indices aimed at evaluating water column, benthic (sediment), and riparian habitat quality. These response metrics are described below.

3.1 Water Column Metrics

Water column metrics include:

- **Concentrations of dissolved metals in surface water**. Based on historical monitoring data for the Upper Basin and extensive toxicity testing information, dissolved zinc and cadmium were selected as the most appropriate chemical metrics to be used to evaluate aquatic environmental conditions. These two metals are highly correlated in surface waters of the Upper Basin. However, because remedial actions conceivably could have

the potential to differentially influence releases of these two metals at certain locations, both metals were included in the suite of chemical quality indicators for the water column.

- **Trout abundance**. This metric, expressed as the total number of trout per 100 m^2 in a sampled reach and trout abundance as a percent of background, was found to be well correlated with dissolved zinc and cadmium. In order to develop an ecological response metric that is sensitive to the differential toxicity of zinc and cadmium over a range of hardness values, the trout abundance was related to metals concentrations that were expressed as a multiple of the hardness-adjusted AWQC.

- **Sculpin presence/density**. Sculpin were found to be a useful indicator of both water and sediment quality. Sculpin abundance supplements trout population data and augments overall aquatic quality measures because of their close association with sediment. Inclusion of sculpin data in the overall analysis provided differentiation in ecological condition indices relative to the use of trout alone. Sculpin abundance, which typically is monitored incidentally and concurrently with in trout electrofishing studies, can be expressed in terms of the approximate number of fish per 100 m^2 in a sampled reach. However, because precise quantitative estimates of sculpin abundance are difficult to obtain in field sampling, abundance values should be viewed as approximations. Consequently, sculpin presence/absence, rather than abundance, is used here as the ecological response indicator.

3.2 Sediment and Benthic Macroinvertebrate Metrics

Benthic metrics include:

- **Concentrations of metals in fine-grained bed sediments**. Based on historical monitoring data and toxicological information from the Upper Basin, sediment-associated zinc and lead were selected the most appropriate indicators of sediment quality and associated benthic community health. The degree of correlation between these two metals is less than in in surface water. Moreover, biological responses associated with these two metals are not entirely similar, again suggesting that the inclusion of both metals as indicators is appropriate.

- **Number of mayfly (Ephemeroptera) taxa.** The taxonomic richness of mayflies has been shown to be an indicator of water and sediment quality in the SFCDR (LeJeune et al., 2000) and other metals-impacted rivers (e.g., Clements et al., 2000). However, as discussed below, mayfly taxa richness should be viewed with care as a response indicator because (1) the relatively low number of mayfly species present, even under background conditions, can reduce the overall robustness of this metric, particularly at intermediate

metals concentrations; (2) taxonomic classification of mayflies can vary among investigators; and (3) populations of benthic macroinvertebrates can be strongly influenced by drift from upstream locations (Beltman et al., 1999). Given the relatively small number of mayfly species present, even under background conditions, such variability in taxonomic classification has the potential to reduce the overall reliability of this metric.

- **Number of invertebrate taxa.** Taxonomic richness of benthic invertebrate communities has been considered a useful indicator of stream health (e.g., Beltman et al., 1999). However, the caveats noted above regarding investigator variability in classification and the influence of drift apply to this metric as well., The higher overall number of invertebrate taxa may reduce the net influence of these factors on this metric in the Upper Basin.

3.3 Riparian Habitat Metrics

Recommended indicators of riparian habitat quality include:

- **Concentrations of metals in riparian floodplain soils**. LeJeune et al. (2000) demonstrated that lead and zinc in riparian floodplain soils are key indicator metals of environmental health in riparian areas. Concentrations of these metals have been found to be correlated with a number of vegetative measures of riparian habitat quality.

- **Percent vegetative cover**. Sparse vegetative cover in riparian reaches that are not influenced by obvious anthropogenic development (e.g., concrete channelized banks, buildings) is generally indicative of the presence of contaminated tailings material in the Upper Basin (LeJeune et al., 2000). Vegetative cover is associated with a number of ecosystem functions that are related to both aquatic and terrestrial resources (e.g., water temperature regulation, source of woody debris, habitat for terrestrial biota). For analysis purposes, the percent of bare ground in a riparian sample site is used as a summary measure of vegetative cover that is not complicated by variations in the species composition at a site.

- **Number of plant species**. The total number of plant species present at a sampling site serves as a good indicator of riparian habitat quality.

- **Number of herbaceous species.** Because a large percent of the riparian vegetation in the Upper Basin is composed of herbaceous species, this indicator can also serve as a measure of riparian habitat quality.

- **Number of vegetation layers**. Structural habitat layer categories were defined by Short (1984) and included terrestrial subsurface layer, understory, shrub midstory, tree canopy, and tree bole. A larger number of structural habitat layers at a site indicate a vegetation community that is diverse and capable of providing habitat supportive of more diverse riparian wildlife communities. Background locations in the Upper Basin have been found to have up to five structural layers.

Below the analysis results relating the proposed biological quality indicators to associated chemical stressors are presented.

3.4 Assessment of Surface Water Metrics

Based on an inspection of the relationships among the relevant metrics considered, concentrations of dissolved cadmium and zinc in surface water, expressed as AWQC ratios, were identified that can serve as threshold levels that distinguish between the condition levels of the biological metrics considered collectively. The selected threshold levels are intended to integrate the relationships observed for all of the biological metrics considered, therefore specific numerical thresholds for individual metrics could differ somewhat from the integrated analysis. However, individual metric-based thresholds differ only minimally from the integrated thresholds, and therefore, this variation was not considered important in the overall analysis.

3.4.1 Relationship between trout abundance and water chemistry

Trout abundance in the Upper Basin, expressed as a percent of background abundance, was found to be inversely related to the magnitude of AWQC exceedance (Figures 1–2). Results for cadmium and zinc are generally similar because these two metals covary in the Upper Basin. For both metals, trout abundance tends to be very low at elevated AWQC exceedance ratios. Background abundance values tend to be observed when exceedance ratios are less than 2x AWQC. Because an important goal of remedial actions in the Upper Basin will be to address the ecological conditions of the SFCDR, relationships between AWQC exceedances and trout populations were developed for the SFCDR only (Figures 3–4). As with the basin-wide analysis, trout abundance is very low at elevated metals concentrations. For metals concentrations less than approximately 2x AWQC, trout populations in the SFCDR approximate background conditions. Because background conditions for the SFCDR are assumed in this analysis to be a constant (reflecting the relatively homogenous habitat within the SFCDR downstream of the Canyon Creek confluence), relationships based on total trout abundance rather than as a percent of background were also developed. Figures 5 and 6 display the relationships between trout abundance (n/100 m^2) and AWQC exceedances in the SFCDR.

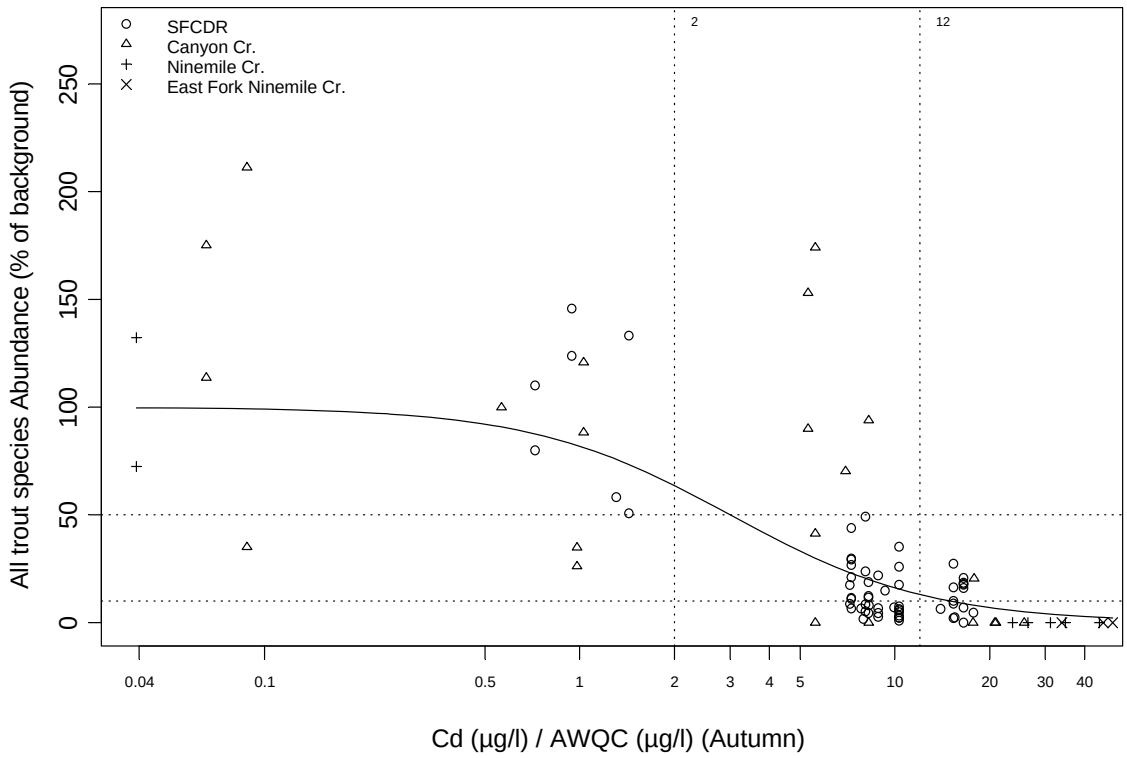


Figure 1. Relationship between the AWQC ratio for dissolved cadmium and abundance of trout as a percentage of background abundance in selected streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote trout abundance ranges for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and trout abundance (see Table 3). Patterns for Canyon Creek trout populations (triangles) are highly variable as a function of (1) uncertainties regarding background populations, and (2) recent population sampling in which intact trout populations were observed in contaminated reaches just downstream from the Burke Mill.

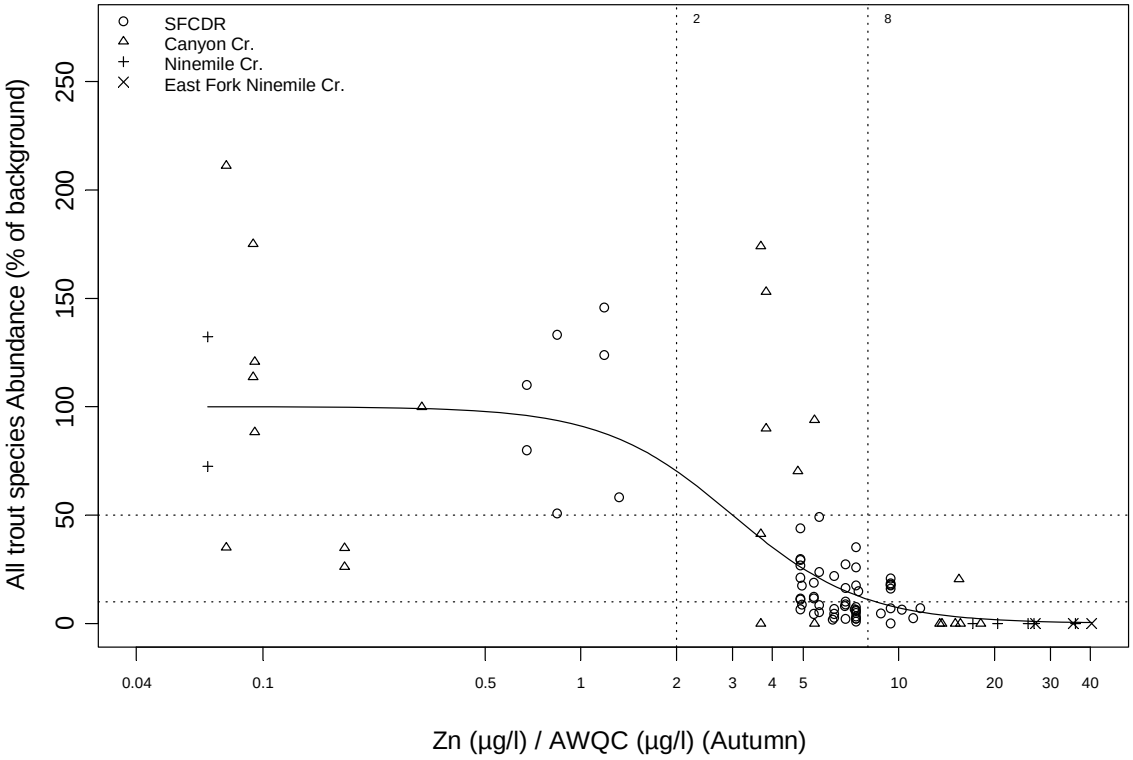


Figure 2. Relationship between the AWQC ratio for dissolved zinc and abundance of trout as a percentage of background abundance in selected streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote trout abundance ranges for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and trout abundance (see Table 3). Patterns for Canyon Creek trout populations (triangles) are highly variable as a function of (1) uncertainties regarding background populations, and (2) recent population sampling in which intact trout populations were observed in contaminated reaches just downstream from the Burke Mill.

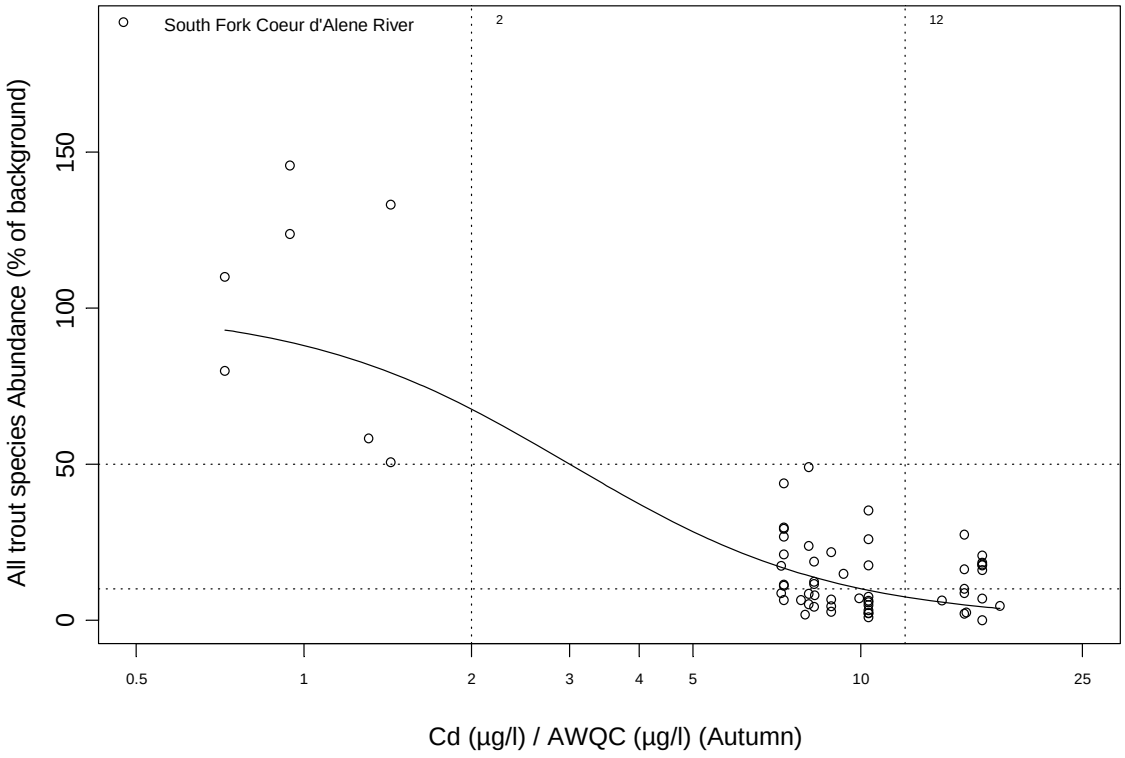


Figure 3. Relationship between the AWQC ratio for dissolved cadmium and abundance of trout as a percentage of background abundance in the SFCDR (Upper Basin) only. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote trout abundance ranges for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and trout abundance (see Table 3).

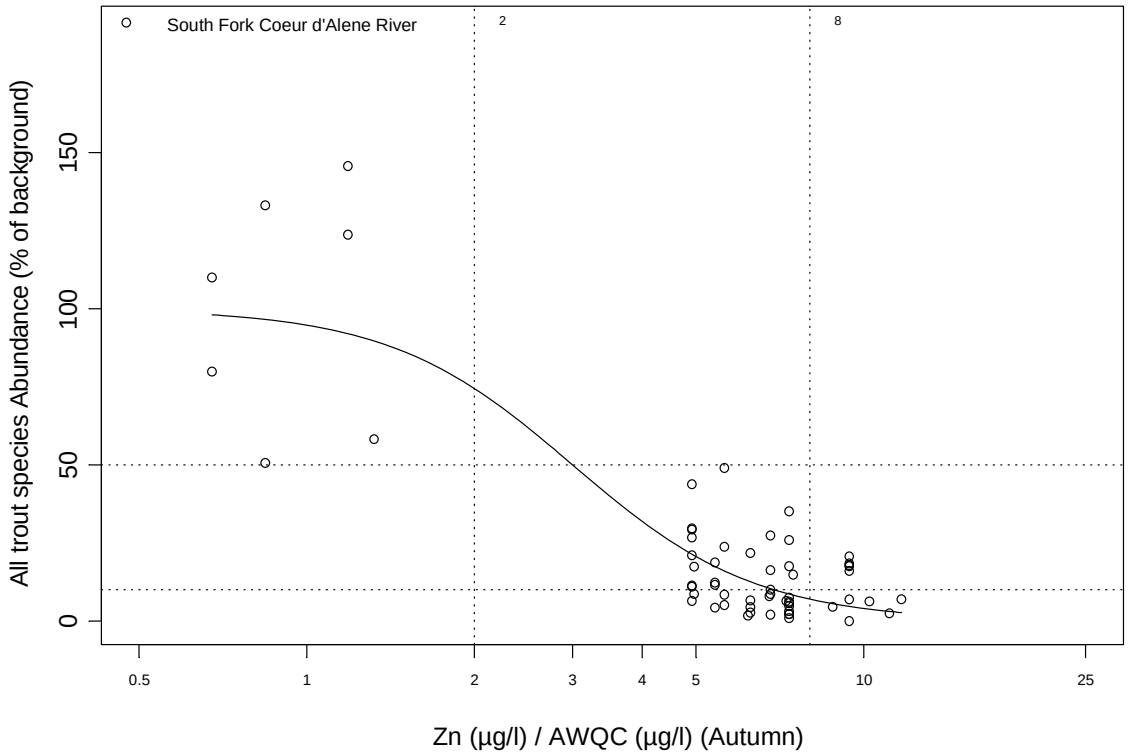


Figure 4. Relationship between the AWQC ratio for dissolved zinc and abundance of trout as a percentage of background abundance in the SFCDR (Upper Basin) only. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote trout abundance ranges for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and trout abundance (see Table 3).

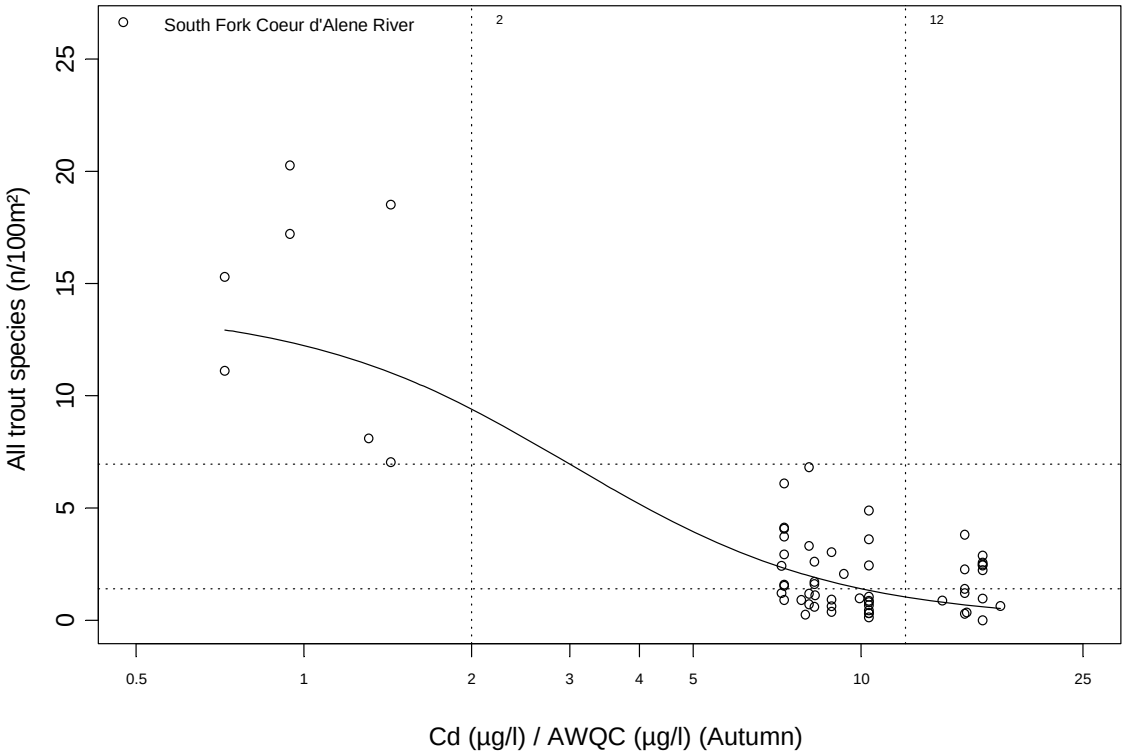


Figure 5. Relationship between the AWQC ratio for dissolved cadmium and abundance of trout in the SFCDR (Upper Basin). Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote trout abundance ranges for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and trout abundance (see Table 3).

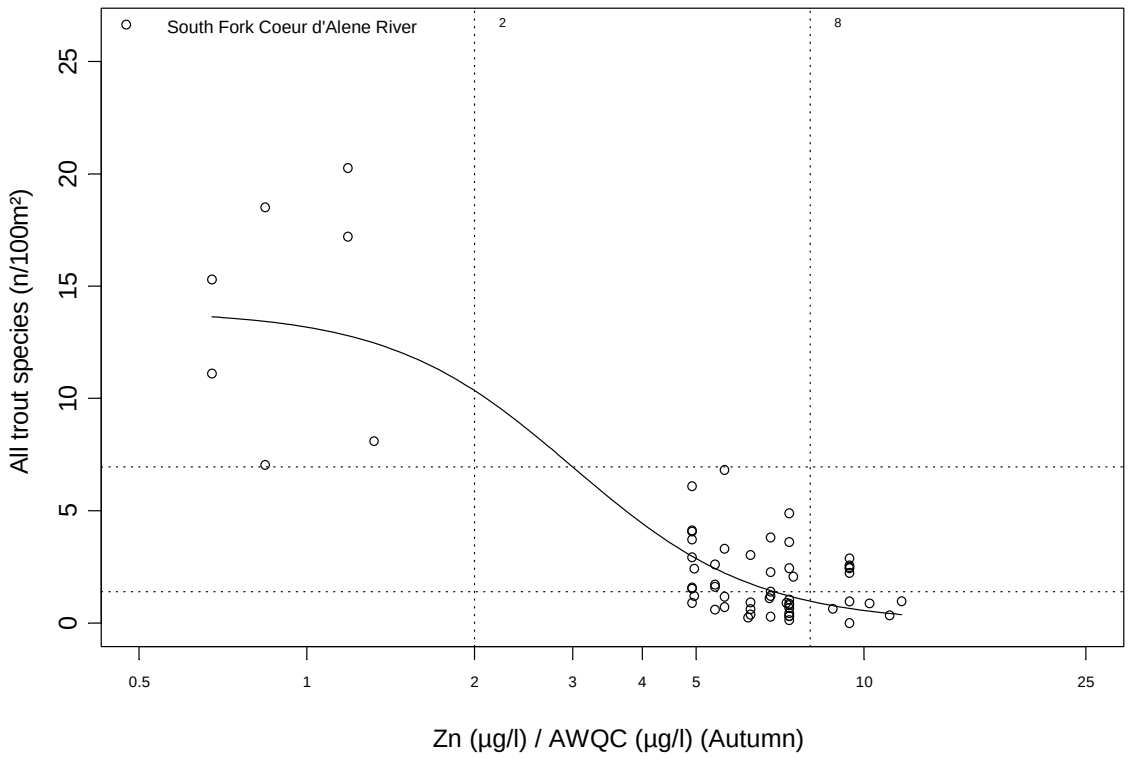


Figure 6. Relationship between the AWQC ratio for dissolved zinc and abundance of trout in the SFCDR (Upper Basin). Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote trout abundance ranges for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and trout abundance (see Table 3).

Although there is variability across sites and years, trout populations typically are quite low (< 10% of background) when metals concentrations exceed approximately 12x AWQC for cadmium or 8x AWQC for zinc (see Figures 1–4). Populations are somewhat greater (generally up to about 50% of background) at intermediate concentrations in the range of 2–12x AWQC for cadmium or 2–8x AWQC for zinc. Populations approach background densities when ambient concentrations are less than about 2x AWQC for either metal. The use of 2x AWQC as a threshold below which trout populations approach background conditions is not intended to suggest that metals concentrations greater than 1x AWQC are associated with background ecological health and should be used as cleanup targets. The regulatory level of 1x AWQC is the actual remedial action cleanup level. However, because of inherent variability in the existing data, it is numerically problematic at this time to differentiate trout abundance at metals concentrations < 2x AWQC.

Based on this analysis, three descriptive categories for trout population metrics are proposed:

1. **"Condition I"** – trout populations (generally < 10% of background trout abundance) when mean cadmium concentrations are greater than 12x AWQC or mean zinc concentrations are greater than 8x AWQC

2. **"Condition II"** – trout populations (generally 10–50% of background trout abundance) when mean cadmium concentrations are between 2 and 12x AWQC or mean zinc concentrations are between 2 and 8x AWQC

3. **"Condition III"** – trout populations (generally > 50% of background trout abundance) when mean cadmium or mean zinc concentrations are less than 2x AWQC.

Clear negative correlations between trout abundance and AWQC ratios for cadmium or zinc were evident (Figures 1–6). To develop a quantitative relationship to predict the response of trout abundance to anticipated reductions in dissolved metals concentrations, a heuristic relationship in the form of sigmoidal curves was developed that highlight the general pattern evident in each relationship. The precise form of the curves was developed through a process that considered sigmoidal dose-response relationships for metals toxicity derived from published literature (including site-specific toxicity tests evaluating the effects of cadmium and zinc on trout), estimation using nonlinear regression, and professional judgment. Table 3 provides the parameters that define each of the curves in the following sections. Each curve is defined by three parameters and the form:

$$y = k/(1 + \exp^{(S * \log_{10}(x/p))}) \qquad \text{(Eq. 6)}$$

where:

y = any of the biological condition metrics (dependent variable)
k = the maximum (or "background") value of y
S = steepness
x = any of the metals concentration variables (independent variable)
p = an inflection point of x.

Table 3. Parameter values for curves of form $y = k/(1 + \exp(S * \log_{10}(x/p)))$ used to approximate ecological condition metrics (see Eq. 6)

Independent variable	Ecological condition metric	k	S	p
Cd AWQC ratio	Percent of background trout abundance	100	3.15	3
Zn AWQC ratio	Percent of background trout abundance	100	4.88	3
Cd AWQC ratio	Trout density (n/100 m^2)	13.9	3.26	3
Zn AWQC ratio	Trout density (n/100 m^2)	13.9	5.52	3
Cd AWQC ratio[a]	Percent of background trout abundance[a]	100	4.18	3
Zn AWQC ratio[a]	Percent of background trout abundance[a]	100	6.07	3
Cd AWQC ratio[a]	Trout density (n/100 m^2) [a]	13.9	4.18	3
Zn AWQC ratio[a]	Trout density (n/100 m^2) [a]	13.9	6.07	3
Pb in sediment	Number of invertebrate taxa	50	2.21	4,500
Zn in sediment	Number of invertebrate taxa	50	2.07	3,300
Pb in sediment	Number of ephemeroptera species	3.5	5.02	3,800
Zn in sediment	Number of ephemeroptera species	3.5	4.16	4,000
Pb in riparian floodplain soils	Number of plant species	20	1.41	500
Zn in riparian floodplain soils	Number of plant species	20	3.24	1,100
Pb in riparian floodplain soils	Number of herbaceous species	14	1.46	900
Zn in riparian floodplain soils	Number of herbaceous species	14	2.11	700
Pb in riparian floodplain soils	Number of vegetation layers	5	0.90	900
Zn in riparian floodplain soils	Number of vegetation layers	5	1.33	900

a. SFCDR only.

Variables x and y for a particular type were drawn from the assembled dataset, values of k were selected by consideration of proposed background values, values of p were selected with reference to knowledge of dose-response relationships for metals toxicity, and values of S were estimated with nonlinear regression methods.

These numerical relationships provide a reasonable means of estimating changes in trout population density (both on an absolute basis and as a percent of background). However, because of inherent environmental variability in the data, the population estimates can be used for planning purposes, but should not be viewed as deterministically precise.

Inspection of Figures 1–6 demonstrates that there is variability in the underlying data associated with the proposed trout population categories. Sources of that variability include actual variation in trout abundance and imprecision due to measurement (sampling) error, as well as the water quality and trout abundance aggregation processes. Use of categorized abundance measures can reduce the possible influences of these sources of variability. To reflect this variability and to aid in remedial planning, a probabilistic analysis of categorical trout abundance metrics was conducted using a multinomial model to estimate the probability of falling into one of three classifications (Condition I, Condition II, and Condition III) for a given AWQC ratio (Figures 7 and 8). For this modeling approach, measured trout abundance observed in each sampling event was categorized into one of the three descriptive classes (the dependent variable) prior to modeling as a function of an AWQC ratio (the independent variable). For example, Figure 8 shows that a site with zinc concentrations at an AWQC ratio of 10 has about a 75% probability of having a "Condition I" trout population, a 20% probability of having a "Condition II" trout population, and a 5% probability of having a "Condition III" trout population. These relationships can be used to project, for remedial planning purposes, the likelihood that trout populations will fall within the three descriptive classes as a function of the AWQC ratio for cadmium or zinc in surface water. The results of this modeling approach also provide support for the categorical definitions derived from the threshold analysis described above.

3.4.2 Relationship between sculpin abundance and water chemistry

Abundance of sculpin demonstrates a threshold-type response rather than a steadily increasing trend along this metals concentration gradient. This may be an artifact of the difficulty of sampling sculpin with the same accuracy that can be achieved when estimating trout abundance, or it could be a function of the greater degree of association between sculpin and sediments. Future surveys of fish abundance are likely to be designed primarily to estimate the abundance of trout and will use sampling methods most suitable for that purpose, most likely based on electrofishing. As observed in previous surveys, electrofishing methods are likely to identify the presence of sculpin, but will capture sculpin with an efficiency that is too poor to allow precise quantification of their actual abundance. Despite the difficulty of obtaining precise quantification of sculpin abundance, acquiring information to demonstrate the presence of sculpin does not require any additional sampling effort beyond that used to monitor trout abundance. Further, the presence or absence of sculpin provides supplemental information about the overall health of aquatic habitat for fish, and it is therefore useful as a supplementary indicator metric. The data indicate that no sculpin are present when metals concentrations exceed about 12x AWQC for cadmium or 8x AWQC for zinc. Sculpin may be present at 2–12x AWQC for cadmium or 2–8x AWQC for zinc, and sculpin are likely to be present when ambient concentrations are less than roughly 2x AWQC for either metal.

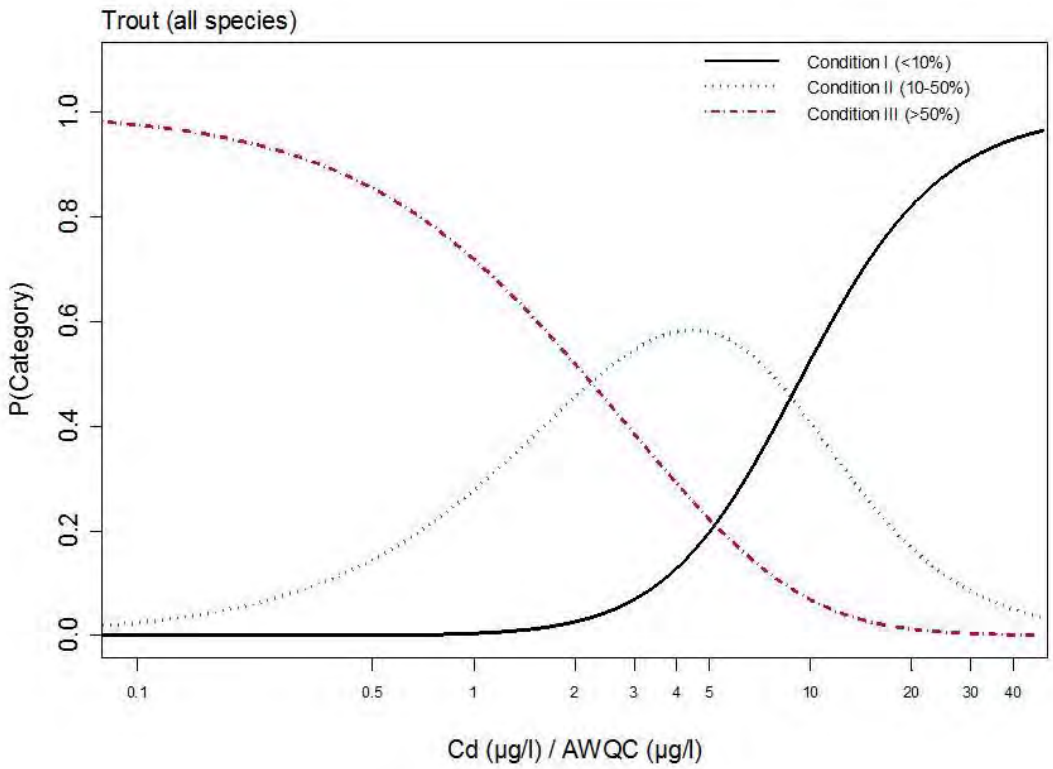


Figure 7. Modeled probability of achieving one of three categorical trout abundance levels [Condition I, Condition II, or Condition III (defined as < 10%, 10–50%, or > 50% of background abundance, respectively) as a function of the AWQC ratio for dissolved cadmium]. Models estimated using data from the SFCDR (Upper Basin), Canyon Creek, Ninemile Creek, and East Fork Ninemile Creek.

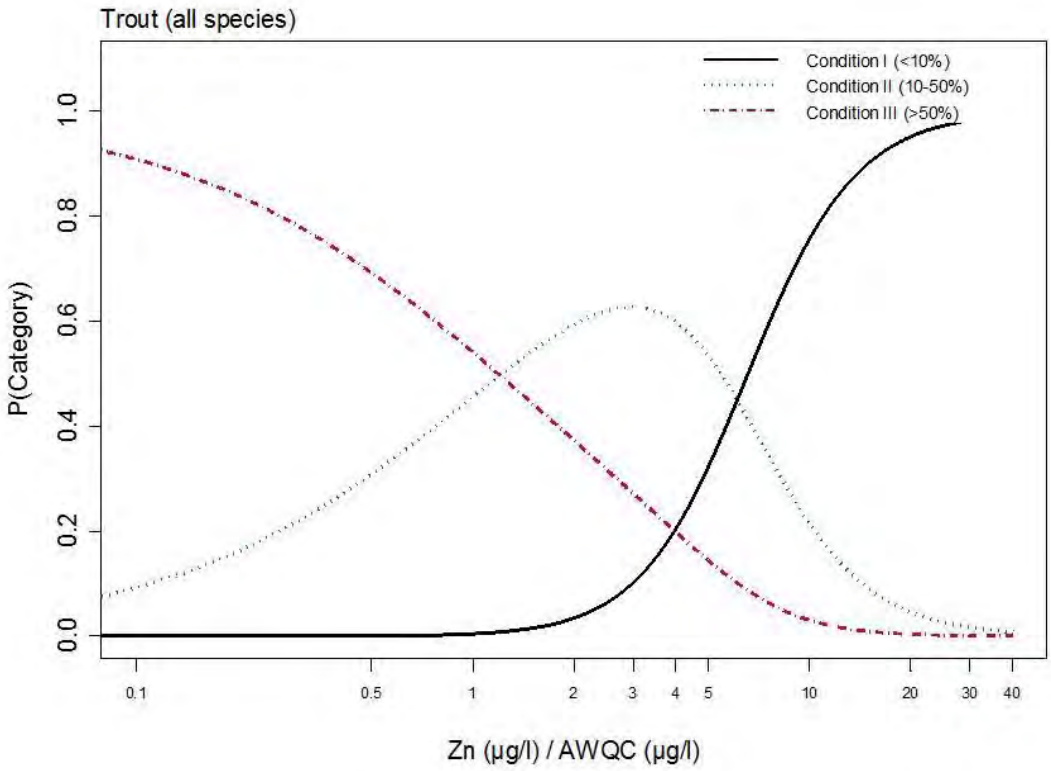


Figure 8. Modeled probability of achieving one of three categorical trout abundance levels [Condition I, Condition II, or Condition III (defined as < 10%, 10–50%, or > 50% of background abundance, respectively) as a function of the AWQC ratio for dissolved zinc]. Models estimated using data from the SFCDR (Upper Basin), Canyon Creek, Ninemile Creek, and East Fork Ninemile Creek.

Based on this analysis, three descriptive categories for sculpin metrics are proposed:

1. **"Condition I"** – sculpin populations (absent from the stream reach) when zinc is greater than 8x AWQC or cadmium is greater than 12x AWQC

2. **"Condition II"** – sculpin populations (observed infrequently in the stream reach) when zinc concentrations are between 2 and 8x AWQC or cadmium concentrations are between 2 and 12x AWQC

3. **"Condition III"** – sculpin populations (common in the stream reach) when mean zinc and cadmium concentrations are less than 2x AWQC.

3.5 Assessment of Benthic/Sediment Metrics

Based on an inspection of the relationships among the relevant metrics considered, concentrations of lead and zinc in stream sediments were identified as appropriate threshold levels that distinguish between condition levels of the biological metrics when considered collectively. Concentrations of lead and zinc in Upper Basin sediments are highly correlated ($R^2 = 0.89$ in the dataset analyzed), so remediation activities that reduce either of these metals below a particular threshold are likely to also reduce concentrations of the other metal below the corresponding threshold.

The most robust benthic/sediment metrics were associated with the relationship among sediment chemistry and the number of invertebrate taxa and presence/absence of sculpin.

3.5.1 Benthic invertebrate community richness

The number of invertebrate taxa present is negatively correlated with concentrations of lead and zinc in fine-grained sediments (Figures 9 and 10). Number of invertebrate taxa is lowest at locations where lead in sediments exceeds 4,700 mg/kg or zinc in sediments exceeds 3,200 mg/kg. Where lead in sediments is between 1,500 mg/kg and 4,700 mg/kg, or zinc is between 1,800 mg/kg and 3,200 mg/kg, the number of invertebrate taxa falls to intermediate levels. At sediment concentrations less than these values, the number of invertebrate taxa approaches background conditions. These threshold cut-offs describe "Condition I," "Condition II," and "Condition III" for benthic invertebrate communities. Table 3 provides parameter values for sigmoidal curves describing the general relationship between the number of invertebrate taxa and sediment metals.

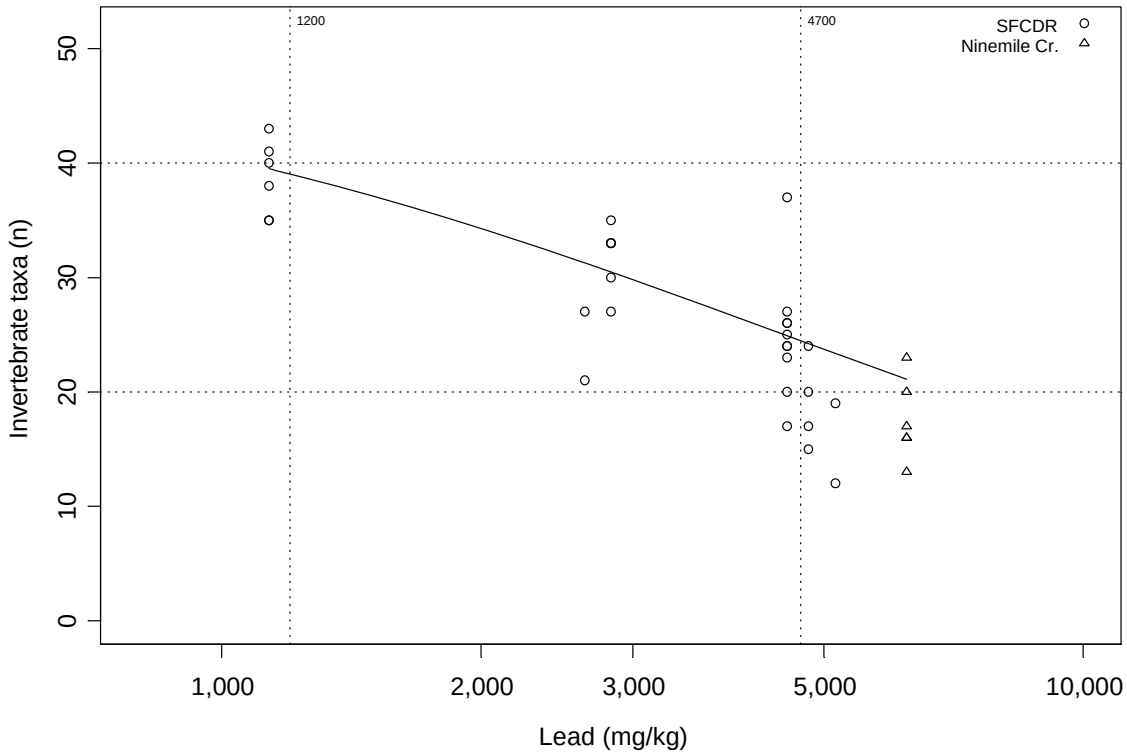


Figure 9. Relationship between lead in fine-grained sediments and number of invertebrate taxa in streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of number of invertebrate taxa for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of invertebrate taxa (see Table 3).

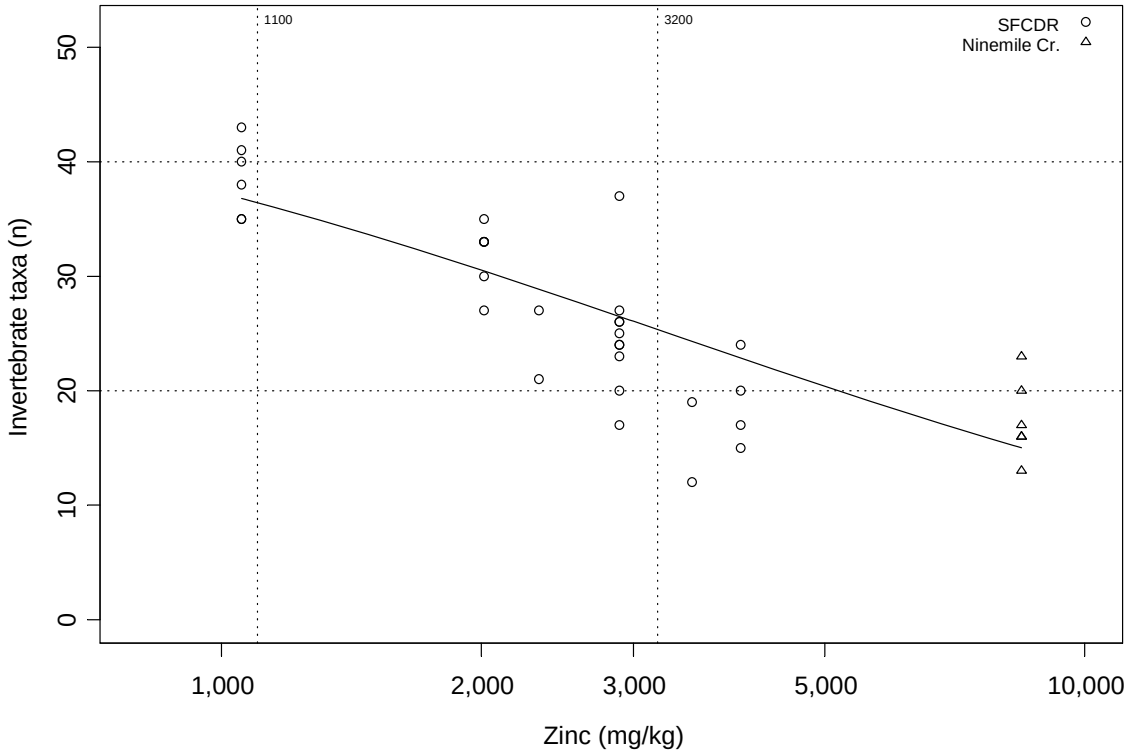


Figure 10. Relationship between zinc in fine-grained sediments and number of invertebrate taxa in streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote the range of number of invertebrate taxa for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of invertebrate taxa (see Table 3).

Based on this analysis, three descriptive categories are proposed for number of invertebrate taxa (where background is about 40 species):

1. **"Condition I"** – number of invertebrate taxa (< 50% of background) when sediment lead is > 4,700 mg/kg or zinc is > 3,200 mg/kg

2. **"Condition II"** – number of invertebrate taxa (50–100% of background) when sediment lead ranges from 1,200 to 4,700 mg/kg or zinc ranges from 1,100 to 3,200 mg/kg

3. **"Condition III"** – number of invertebrate taxa (100% of background) when sediment lead < 1,200 mg/kg or zinc < 1,100 mg/kg.

Ephemeroptera (mayfly) richness is also negatively correlated with concentrations of lead and zinc in fine-grained sediments (Figures 11 and 12). Considerable data gaps exist for mayfly taxa richness. However, responses appear to fall within the same general sediment metals ranges as for total invertebrate community richness. Two or fewer ephemeroptera species were observed at locations where lead in sediments exceeds 4,700 mg/kg or zinc in sediments exceeds 3,200 mg/kg. Where lead in sediments exceeds 1,200 mg/kg or zinc exceeds 1,100 mg/kg and is less than the above values, the number of ephemeroptera species falls to intermediate levels (usually two or three species). At sediment concentrations less than these values, the number of ephemeroptera species approaches background conditions. Table 3 provides parameter values for sigmoidal curves describing the general relationship between the number of invertebrate taxa and metals in fine-grained sediments.

Based on this analysis, three descriptive categories are proposed for number of ephemeroptera taxa (where background is about four or more species):

1. **"Condition I"** – number of ephemeroptera species (0–1 species) when sediment lead is > 4,700 mg/kg or zinc is > 3,200 mg/kg

2. **"Condition II"** – number of ephemeroptera species (1–3 species) when sediment lead ranges from 1,200 to 4,700 mg/kg or zinc ranges from 1,100 to 3,200 mg/kg

3. **"Condition III"** – number of ephemeroptera species (4 or more species) when sediment lead is < 1,200 mg/kg or zinc is < 1,100 mg/kg.

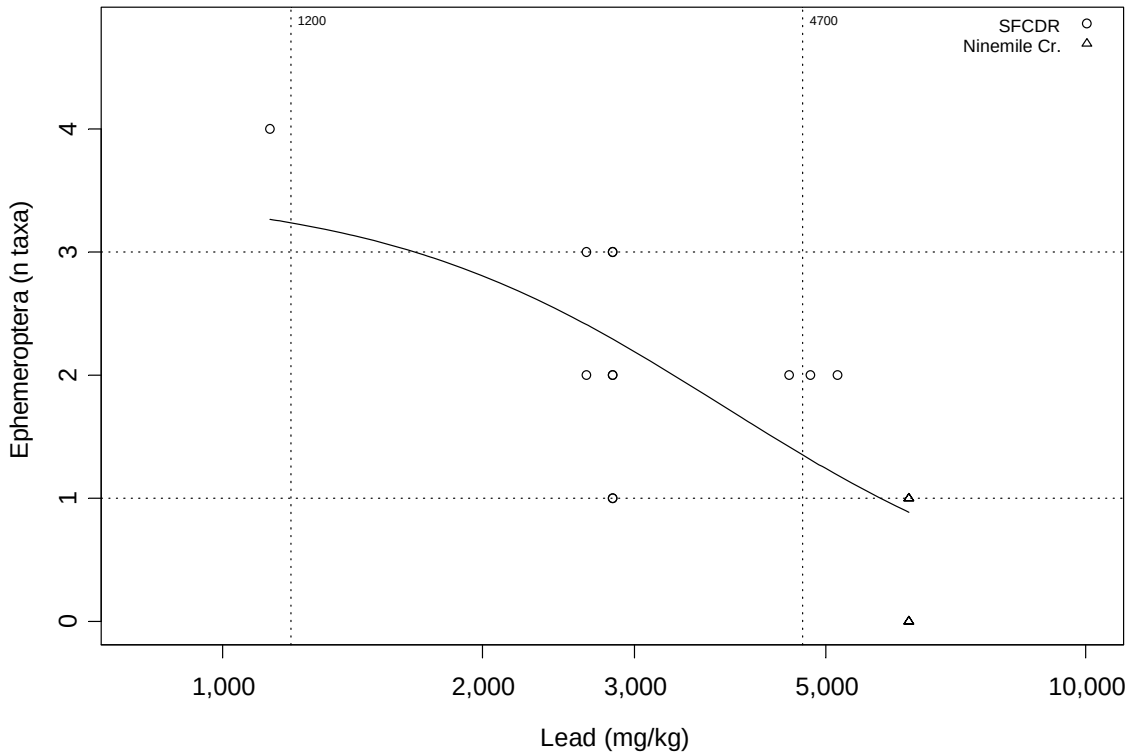


Figure 11. Relationship between lead in fine-grained sediments and number of ephemeroptera taxa in streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of the number of ephemeroptera species for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of ephemeroptera species (see Table 3).

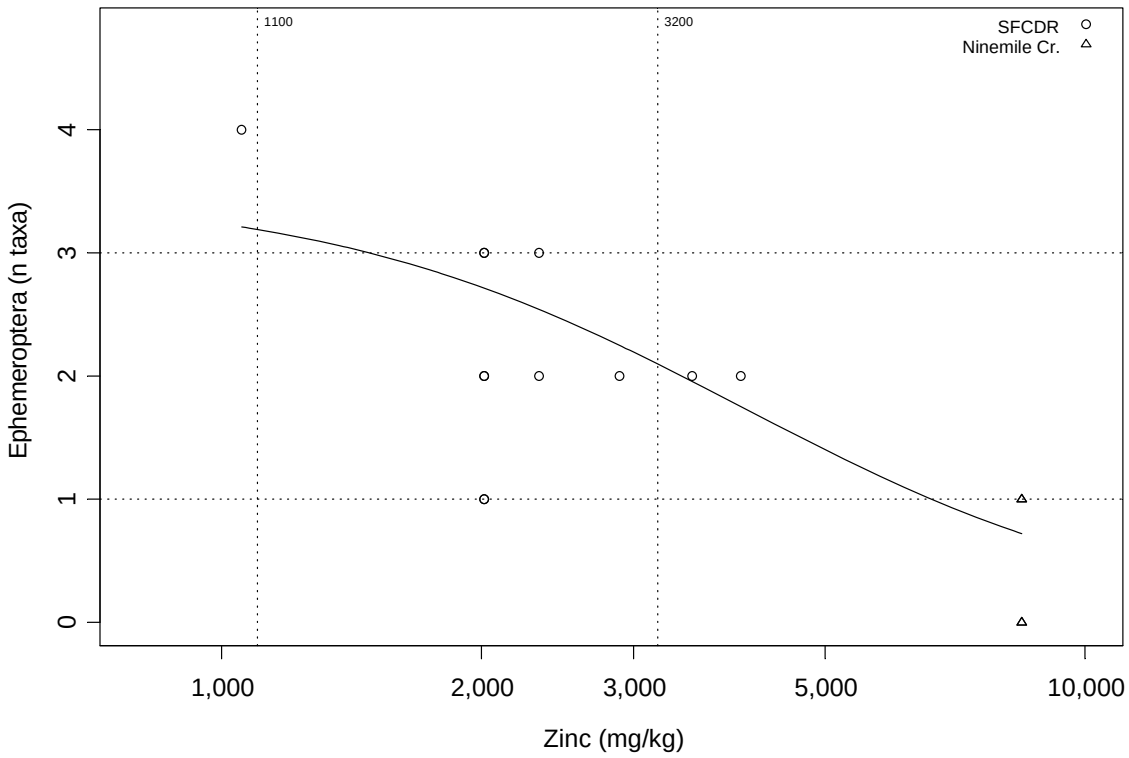


Figure 12. Relationship between zinc in fine-grained sediments and number of ephemeroptera taxa in streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of the number of ephemeroptera species for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of ephemeroptera species (see Table 3).

3.5.2 Sculpin abundance

As described in Section 3.4.2, sculpin abundance is best interpreted in terms of presence or absence rather than in terms of density Sculpin generally are not present when lead concentrations exceed 1,500 mg/kg or zinc concentrations exceed 1,800 mg/kg (Figures 13 and 14). Based on this pattern, only two classes were assigned to sculpin:

1. **"Condition I"** – sculpin populations (absent from the stream reach) when sediment lead > 1,500 mg/kg or sediment zinc > 1,800 mg/kg

2. **"Condition II"** – sculpin populations (present in the stream reach) when sediment lead < 1,500 mg/kg, or sediment zinc < 1,800 mg/kg.

Because of the threshold response for sculpin, no additional quantitative models were developed.

3.6 Assessment of Riparian Habitat Metrics

Several biological response metrics were found to be associated with concentrations of zinc and lead in riparian floodplain soils. Based on an inspection of the relationships among the relevant metrics considered, concentrations of lead and zinc in soils were identified that are appropriate threshold levels to distinguish between condition levels of the biological metrics when considered collectively. Concentrations of lead and zinc in Upper Basin soils are highly correlated ($R^2 = 0.91$ in the dataset analyzed), so remediation activities that reduce either of these metals below a particular threshold are likely to also reduce concentrations of the other metal below the corresponding threshold.

3.6.1 Vegetative cover

Vegetative cover, measured as percent of a sample site, on an areal basis, covered by vegetation instead of bare ground, was inversely associated with metals concentrations in riparian soils. Locations where lead in soils exceeded 2,000 mg/kg or zinc exceeded 1,500 mg/kg were much more likely to have > 20% bare ground than locations with lower concentrations (Figures 15 and 16). As with sculpin and sediments, this relationship demonstrated a strong threshold response. Consequently, additional quantitative modeling was not performed for this metric.

Based on this pattern, two classes were assigned to vegetative cover:

1. **"Condition I"** – vegetative cover (percentage bare ground exceeds 20%), when soil lead > 2,000 mg/kg, or zinc > 1,500 mg/kg

2. **"Condition II"** – vegetative cover (percentage bare ground does not exceed 20%), when soil lead is < 2,000 mg/kg, or zinc is < 1,500 mg/kg.

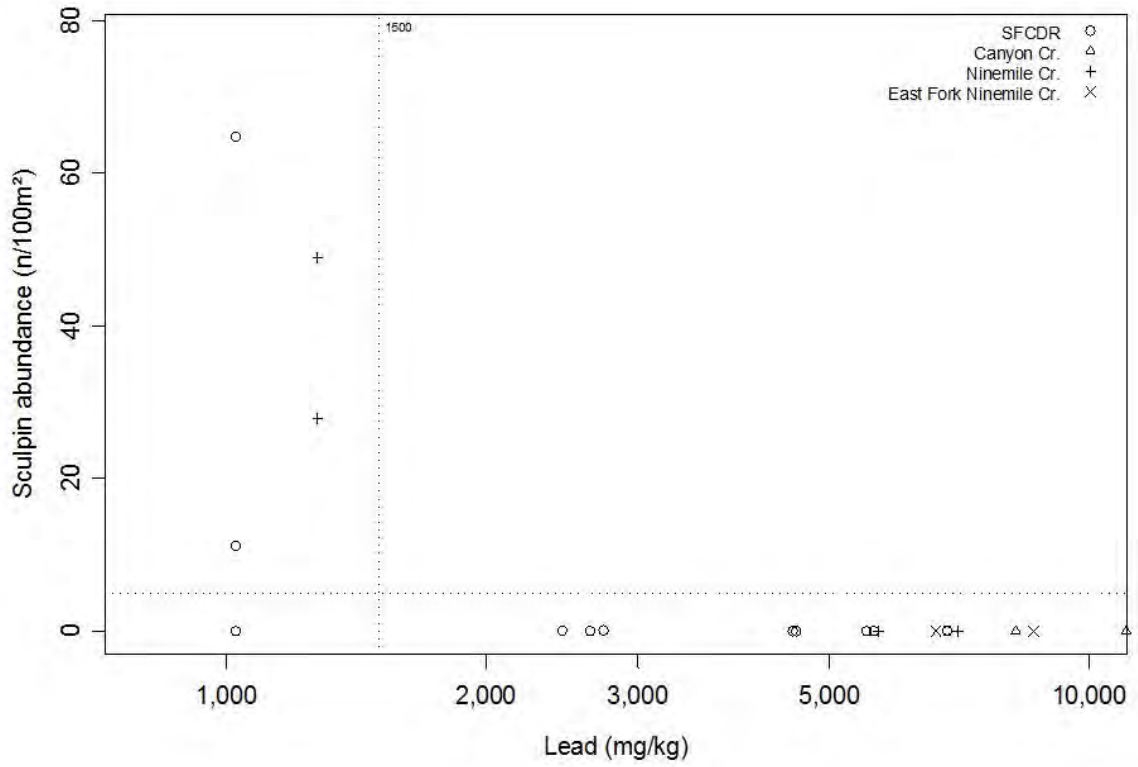


Figure 13. Relationship between lead in fine-grained sediments and abundance of sculpin in streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of sculpin abundance for the designated descriptive categories.

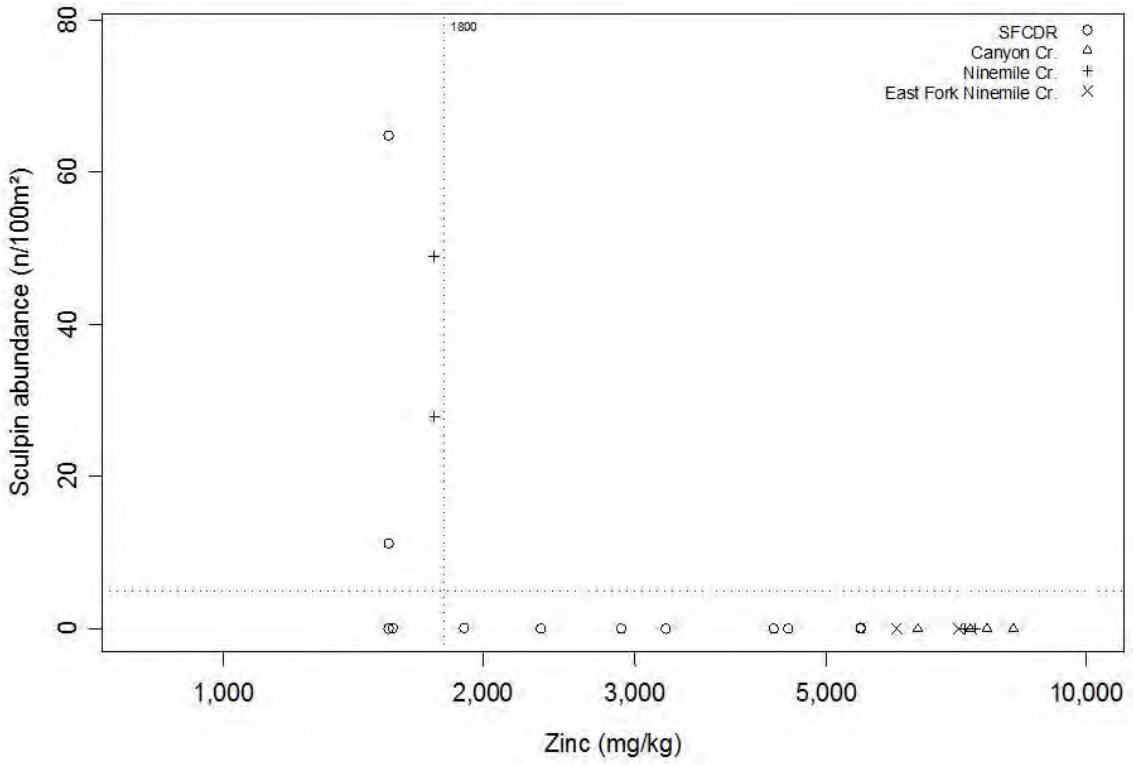


Figure 14. Relationship between zinc in fine-grained sediments and abundance of sculpin in streams in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of sculpin abundance for the designated descriptive categories

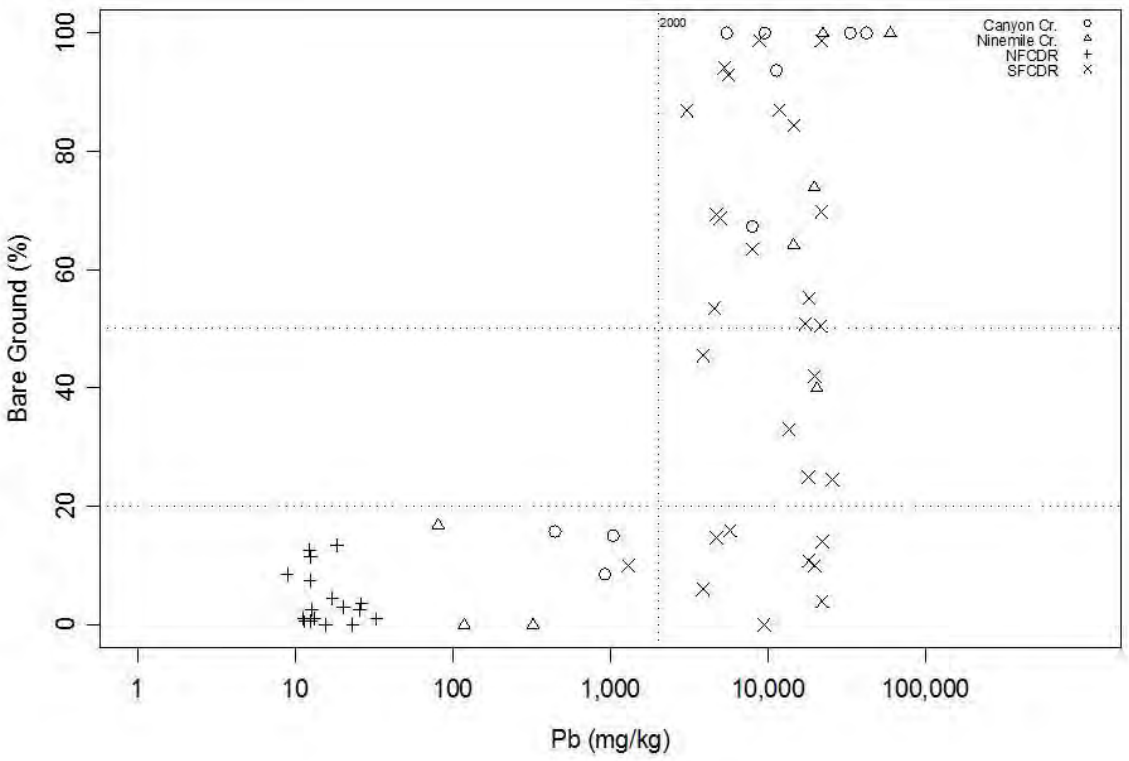


Figure 15. Relationship between soil lead concentration and percent bare ground among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of percent bare ground for the designated descriptive categories.

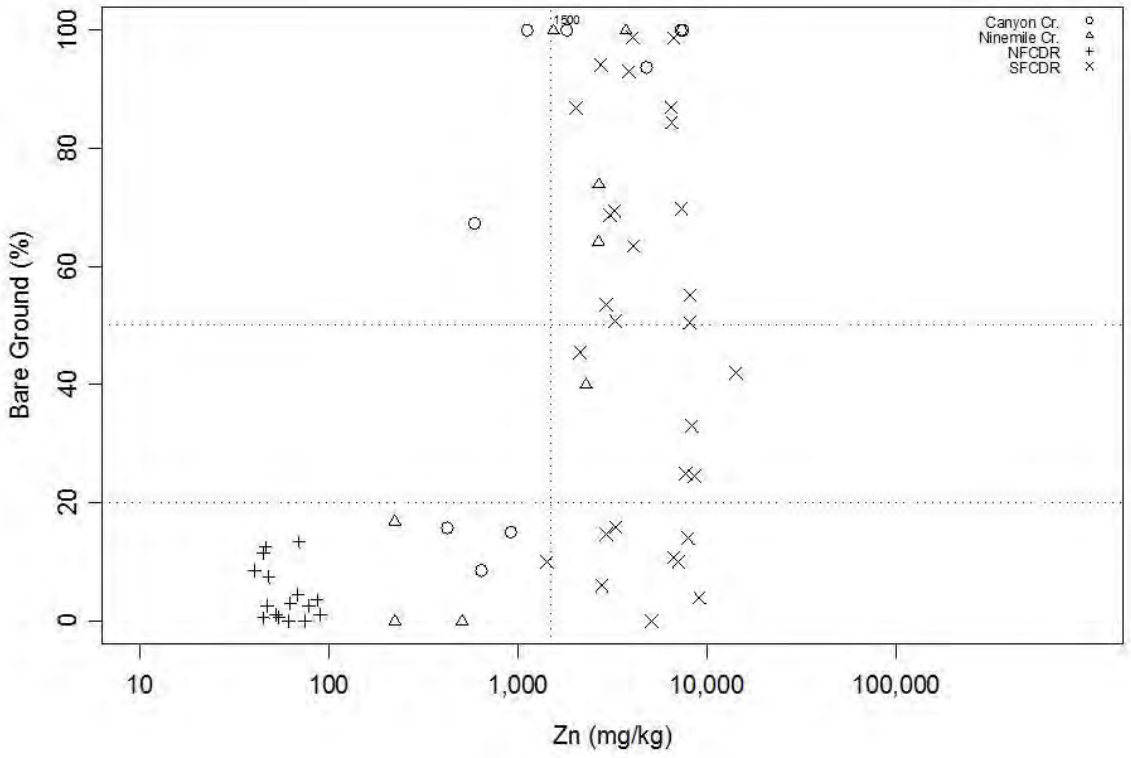


Figure 16. Relationship between soil zinc concentration and percent bare ground among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of percent bare ground for the designated descriptive categories.

3.6.2 Vegetative species richness

Locations where lead in soils exceeded 2,000 mg/kg or zinc in soils exceeded 1,500 mg/kg were also more likely to have fewer plant species than locations with lower concentrations (Figures 17 and 18). Similarly, locations where lead in soils exceeded 2,000 mg/kg or zinc in soils exceeded 1,500 mg/kg were more likely to have fewer herbaceous species than locations with lower concentrations (Figures 19 and 20). Table 3 provides parameter values of sigmoidal curves describing the general relationship between the number of plant species and soil metals.

Based on this analysis, three descriptive categories are proposed for number of plant species:

1. **"Condition I"** – plant species present (0 to 5 total plant species, 0 to 5 herbaceous species), when soil lead > 2,000 mg/kg, or zinc > 1,500 mg/kg

2. **"Condition II"** – plant species present (6 to 15 total plant species, 6 to 13 herbaceous species), when soil lead ranges from 530 to 2,000 mg/kg, or zinc ranges from 300 to 1,500 mg/kg

3. **"Condition III"** – plant species present (16 to 25 total plant species, more than 13 herbaceous species), when soil lead < 530 mg/kg, or zinc is < 300 mg/kg.

Less distinct patterns were observed between metals concentrations in soils and the number of vegetation layers present at a site (Figures 21 and 22). Among sites where soil lead exceeded 2,000 mg/kg or soil zinc exceeded 1,500 mg/kg, one vegetation layer was the most commonly observed condition, but sites with two or more vegetation layers were also observed. Three or more vegetation layer sites were present where lead was < 530 mg/kg and zinc was < 300 mg/kg. The number of vegetation layers ranged from 1 to 4 at sites with intermediate metals concentrations (lead in the range of 530 to 2,000 mg/kg or zinc in the range of 300 to 1,500 mg/kg). Although there is more variability in these responses than in other metrics, because the general pattern is consistent with other metrics it was retained as an indicator of riparian floodplain condition.

4. Summary of Proposed Ecological Response Metrics

The analyses presented above indicate a series of strong relationships between the concentrations of key indicator metals and a suite of biological response metrics that are descriptive of water column, benthic, and riparian floodplain conditions. This suite of biological response metrics can be used to project environmental recovery trajectories and can be readily monitored to evaluate ecological health.

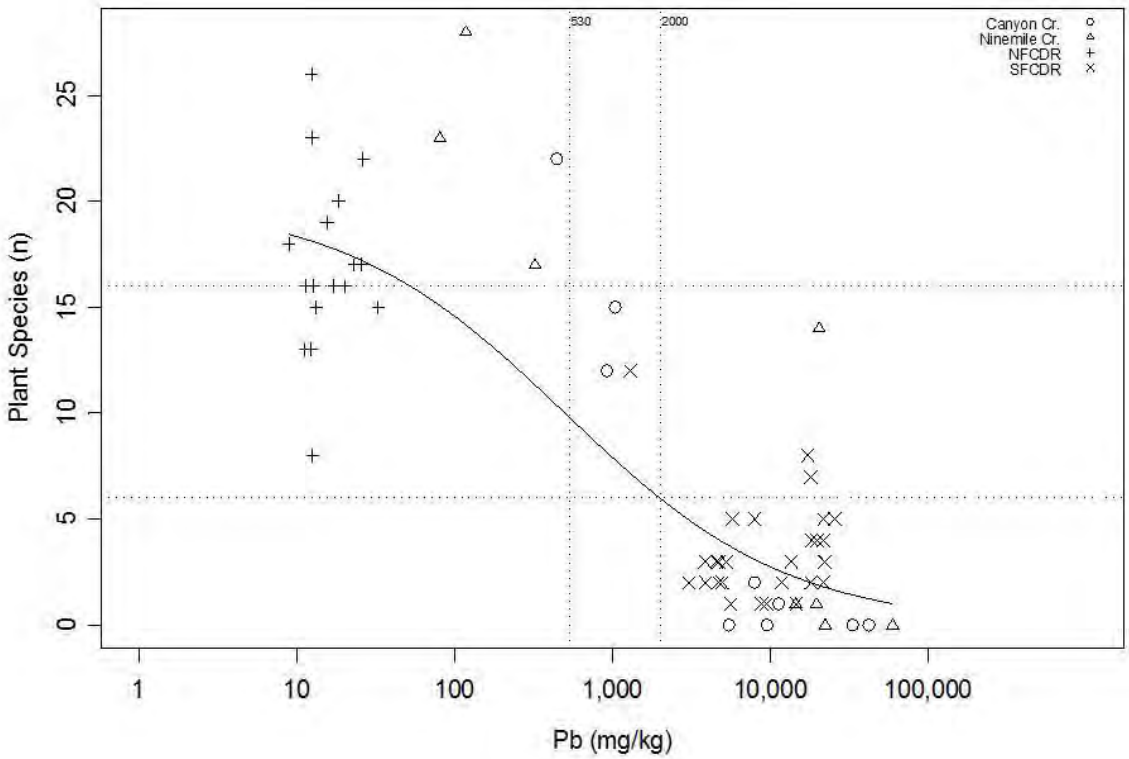


Figure 17. Relationship between soil lead concentration and number of plant species among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of number of plant species for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of plant species (see Table 3).

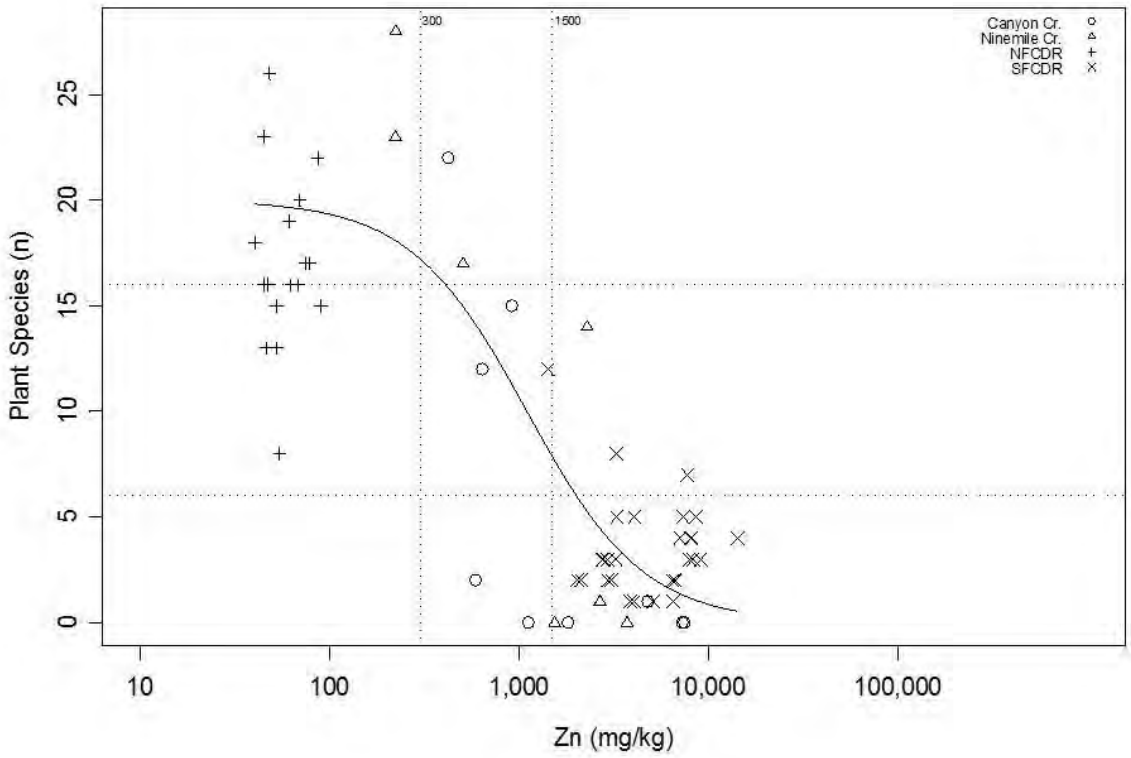


Figure 18. Relationship between soil zinc concentration and number of plant species among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of number of plant species for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of plant species (see Table 3).

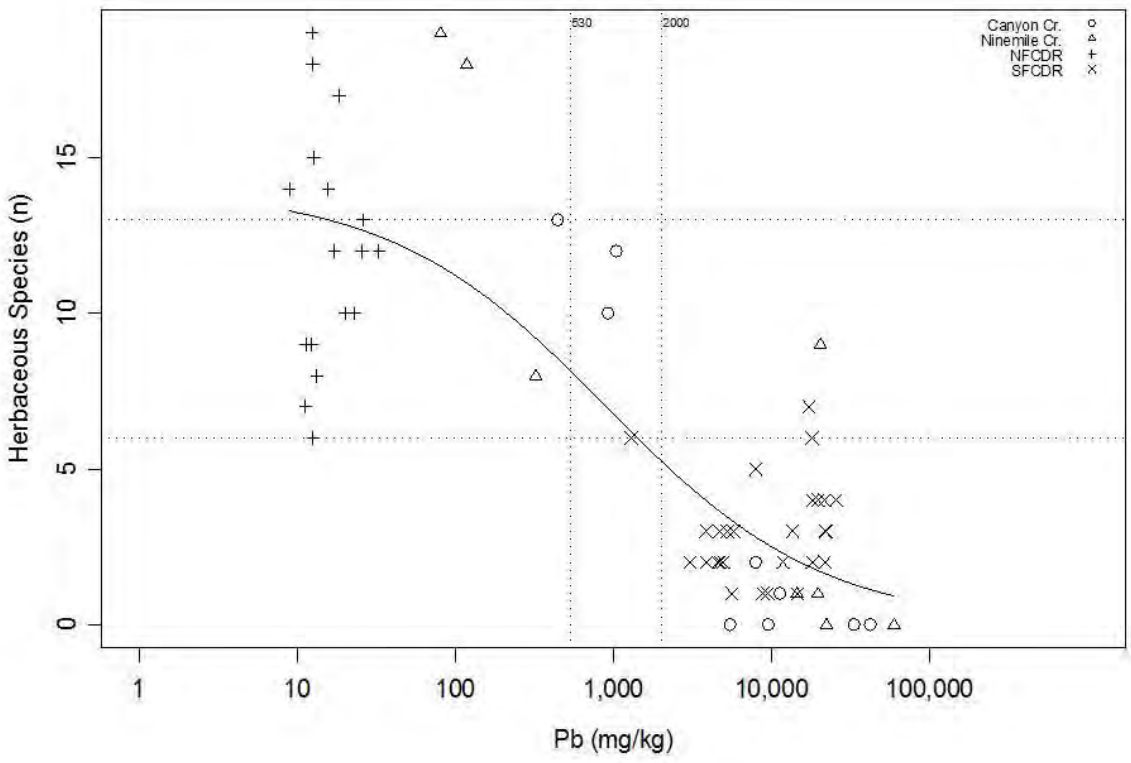


Figure 19. Relationship between soil lead concentration and number of herbaceous species among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of number of herbaceous species for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of herbaceous species (see Table 3).

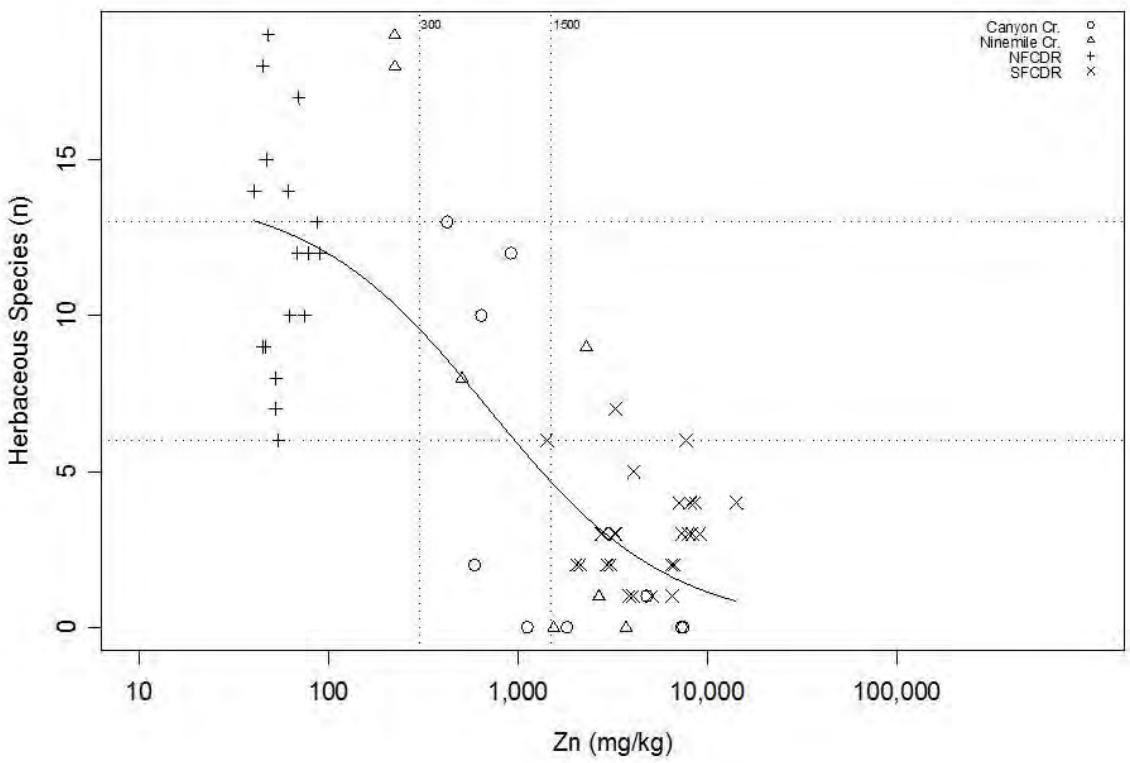


Figure 20. Relationship between soil zinc concentration and number of herbaceous species among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of number of herbaceous species for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of herbaceous species (see Table 3).

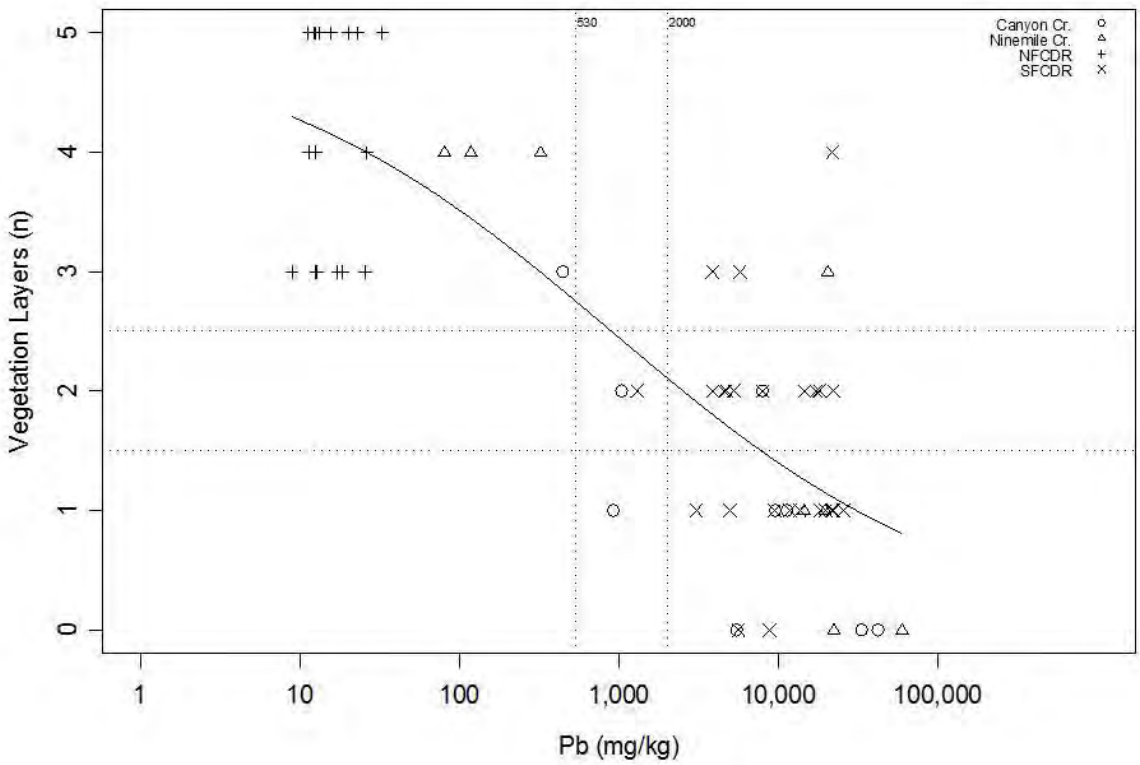


Figure 21. Relationship between soil lead concentration and number of vegetation layers among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of number of vegetation layers for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of vegetation layers (see Table 3).

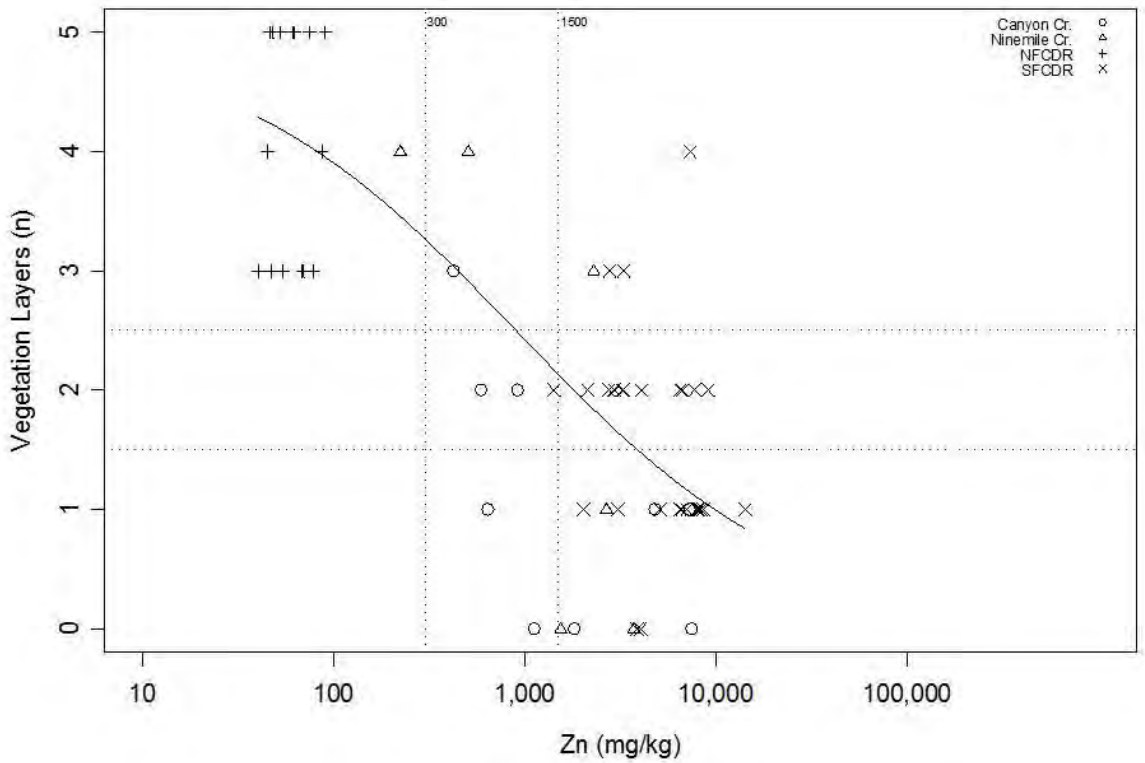


Figure 22. Relationship between soil zinc concentration and number of vegetation layers among 63 sites in the Upper Basin. Vertical lines denote proposed thresholds for descriptive categories. Horizontal lines denote range of number of vegetation layers for the designated descriptive categories. Sigmoidal curve represents the heuristic model relating metals concentrations and number of vegetation layers (see Table 3).

The use of the following environmental response metrics is proposed:

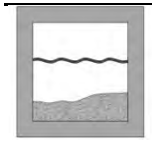
- Water column metrics:
  - Concentrations of dissolved zinc and cadmium in surface water
  - Trout abundance
  - Sculpin presence/absence.
- Benthic (sediment) metrics:
  - Concentrations of zinc and lead in fine-grained bed sediments
  - Number of mayfly (Ephemeroptera) taxa
  - Number of invertebrate taxa
  - Sculpin presence/absence.
- Riparian habitat metrics:
  - Concentrations of zinc and lead in riparian floodplain soils
  - Percent vegetative cover
  - Number of plant species (total)
  - Number of herbaceous species
  - Number of vegetation layers.

For each of these metrics, analysis of Upper Basin-specific data provided a suite of categorical threshold responses that can be used as general indices of ecological quality. A series of quantitative models were also developed that enable projections of responses of the indicator metrics across a gradient of metals concentrations.

4.1 Compilation of Metrics into Multi-Attribute Indices of Ecological Condition

Inspection of the various relationships between metals concentrations in relevant media (i.e., water, sediment, riparian soils) indicated that these metrics can be combined into a suite of qualitative environmental condition indices. In Table 4, these condition indices are combined into a simplified reporting format to describe categorical ecological status as Condition I, Condition II, or Condition III. Such simplified categorical reporting can then be supplemented with the underlying numerical analyses (including regression models and, for trout populations, probabilistic models) both as quantitative measures of ecological improvement and as quantitative tools to project ecological improvements under different remediation scenarios and recovery times.

Table 4. Compilation of individual ecological response metrics into multi-attribute environmental condition indices relevant to SFCDR (Upper Basin), Nine Mile Creek, and Canyon Creek

	Environmental indicator	Environmental condition index: Condition I	Condition II	Condition III[a]	Background values/regulatory limit
Water column	Water quality	Cd > 12x AWQC Zn > 8x AWQC	Cd: 2–12x AWQC Zn: 2–8x AWQC	Cd < 2x AWQC Zn < 2x AWQC	Cd < 1x AWQC (regulatory limit) Zn < 1x AWQC (regulatory limit)
	Trout populations	< 10% background (mean = 2.7%)	10–50% of background (mean = 23%)	> 50% background (mean = 115%)	SFCDR = 13.9 trout/100 m^2; NM = 35 trout/100 m^2; CC = 8.3 trout/100 m^2
	Sculpin populations	No sculpin present	Sculpin may be present	Sculpin present	Sculpin present
 **Sediments**	Sediment quality	Pb > 4,700 mg/kg (dw) Zn > 3,200 mg/kg (dw)	Pb: 1,200–4,700 mg/kg (dw) Zn: 1,100–3,200 mg/kg (dw)	Pb < 1,200[b] mg/kg (dw) Zn < 1,100[b] mg/kg (dw)	Pb < 171[c] mg/kg (dw) Zn < 280[c] mg/kg (dw)
	Sculpin populations	No sculpin present	No sculpin present	Sculpin present	Sculpin present
	Benthic invertebrates	Up to 20 invertebrate taxa 0–1 mayfly species	20–40 invertebrate taxa 1–3 mayfly species	≥ 40 invertebrate taxa present About 4 mayfly species present	About 40 invertebrate taxa 4 + mayfly species
Riparian habitat	Soil quality	Pb > 2,000 mg/kg (dw) Zn > 1,500 mg/kg (dw)	Pb: 530[d] –2,000 mg/kg (dw) Zn: 300–1,500 mg/kg (dw)	Pb < 530[d] mg/kg (dw) Zn < 300 mg/kg (dw)	Pb < 171[c] mg/kg (dw) Zn < 280[c] mg/kg (dw)
	Vegetation quality	> 20% bare ground (mean = 72%) < 6 total plant species (mean = 2.2) < 6 herbaceous species (mean = 2.1) 0–1 vegetation layers (mean = 0.7)	< 20% bare ground (mean = 6.7%) 6–15 total plant species (mean = 11) 6–13 herbaceous species (mean = 9.4) 2 vegetation layers (mean = 2.0)	< 20% bare ground (mean = 6.7%) 16 + total plant species (mean = 19) 14 + herbaceous species (mean = 17) > 2 vegetation layers (mean = 3.9)	< 5% bare ground 16–28 total plant species 14–19 herbaceous species > 2 vegetation layers

a. Achieving a Condition III ecological status does not imply that the remediation goals have been met, or that an ecologic metric has achieved the background goal of abundance.
b. Sediment thresholds are keyed to benthic invertebrates, while thresholds keyed to sculpin would be 1,500 mg/kg and 1,800 mg/kg for Pb and Zn, respectively.
c. USEPA, 2002.
d. CH2M HILL, 2010.

It needs to be reinforced, however, that achieving a Condition III ecological status is not necessarily the same as meeting the remediation goals (RGs) as defined by the site's Record of Decision documents, nor should it be inferred that a Condition III status indicates that an ecologic metric has achieved the background goal of abundance. The Condition statuses, as defined in Sections 3.4 through 3.6, are quantitative measurements of environmental indicators to monitor progress toward the goal of background abundance and achieving RGs.

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