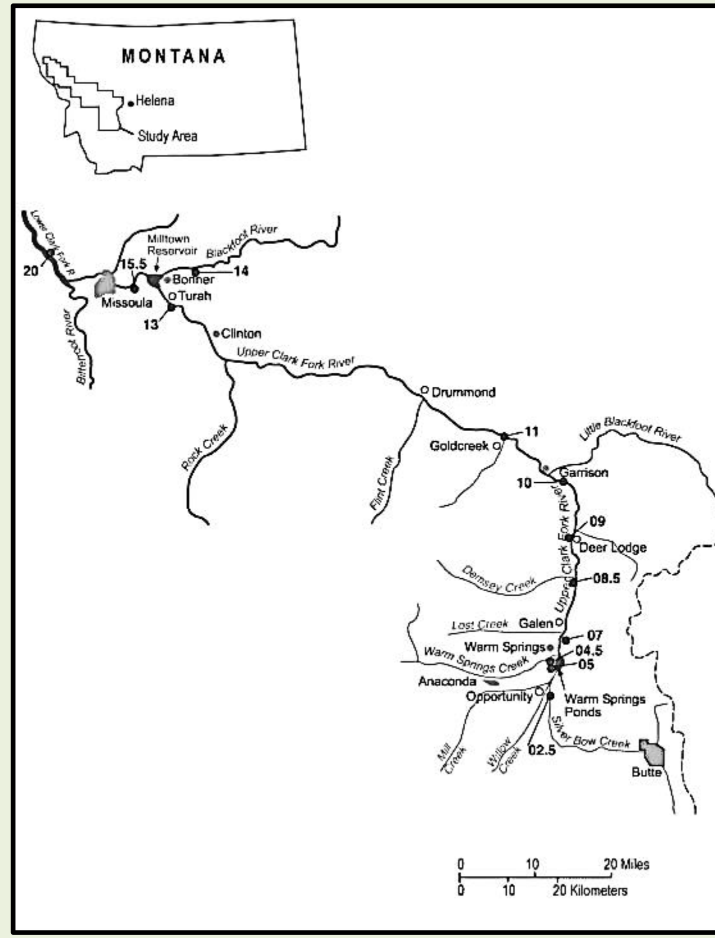
# Assessing Ecosystem Health In A Mining-Impacted River

## USGS Investigations of the Clark Fork River, MT Superfund Site

**Terry Short**
**USGS Menlo Park CA**

# Clark Fork River Basin…….

- Mining and smelting operations active in the upper drainage from 1860's to 1980's
- Downstream transport of mining spoils resulted in metal contamination to more than 250km of Clark Fork River
- Study reaches extend from Silver Bow Creek (below Butte) to the main stem Clark Fork River below Missoula




Mid 1800s: Placer gold discovery

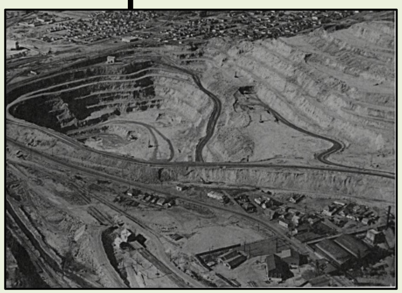
*Richest hill on earth,* Butte 1900s

1908 Flood: Missoula MT

Impacts from floodplain runoff

Silver Bow Creek, 2015

Historic Mining Activities | Legacy mine waste | Remediation / Restoration

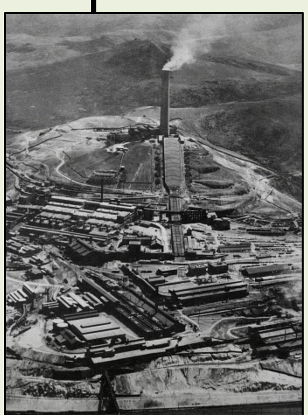


Berkeley Pit: 1959

Slickens (floodplain surface encrusted with metal precipitates)

Declared a Superfund Site: 1989

Bank removal and restoration



Anaconda Smelter: 1918-1980

Silver Bow Creek floodplains

Copper sulfate + cow bone

Removal of contaminated floodplains + soil amendments

# *Examples of ongoing USGS research activities on the Clark Fork River, MT*

USGS National Research Program – WR Menlo Park, CA
(*Michelle Hornberger, Dan Cain, Terry Short*)
USGS Montana Water Science Center, Helena, MT

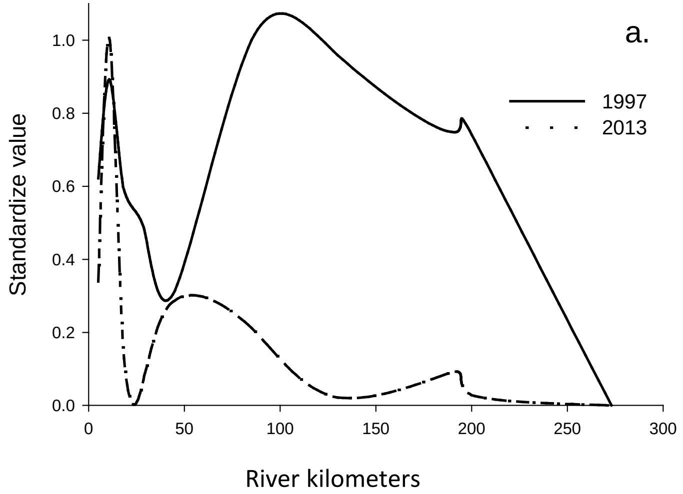
- ***Assessing historic and recent contaminant trends — responses to remediation (20+ years of physical, chemical, biological data)***
- ***Development of field and laboratory models to understand contaminant exposure and uptake kinetics in invertebrate fauna***
- ***Identifying determinants of metal exposure risk in stream invertebrates***
- ***Metal mining impacts on ecosystem processes***
- ***Identifying microbial bioindicators of metal enrichment and toxicity in mining-disturbed systems***

***Note: results shown are provisional***

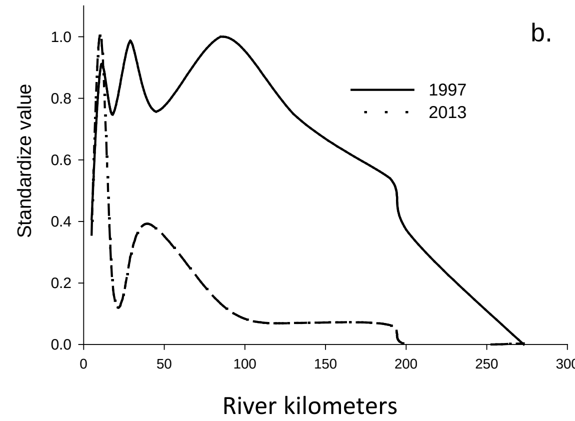
# *Assessing historic and present trends in bioavailable metals based on concentrations in Hydropsyche larvae*

***(H. occidentalis and H. cockerelli )***

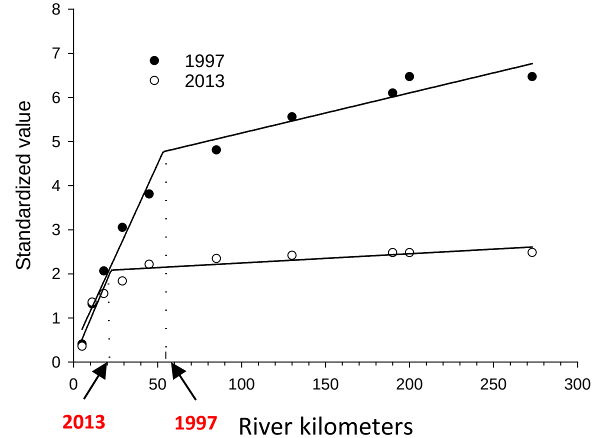
**Trends in relative (total) metal concentrations (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) — 1997 vs 2013**




**Copper trends in *Hydropsyche sp*. larvae**




**Cumulative distribution plot of standardized Cu concentrations in *Hydropsyche* larvae — concentration breakpoints identified using piecewise regression**



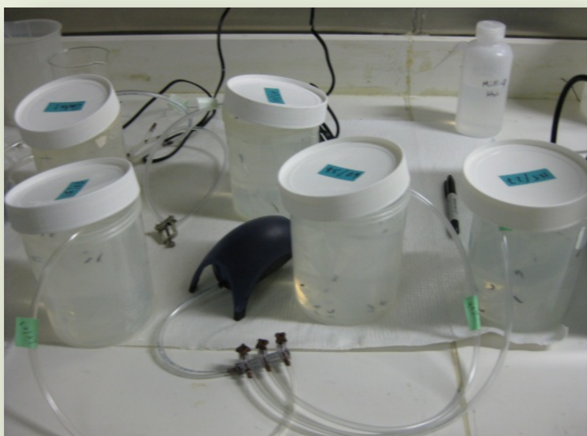
# *Contaminant kinetics — laboratory and field based models*

Laboratory experiments to quantify metal uptake-loss kinetics using enriched <u>stable isotope tracers</u>: $^{65}$Cu and $^{106}$Cd

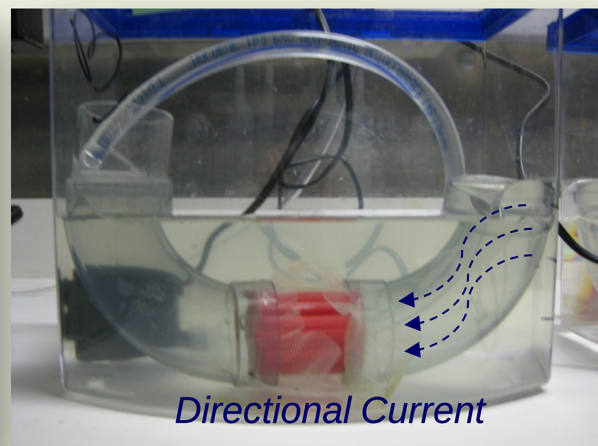
(M.Hornberger, D.Cain, M.Croteau)

*Experiments conducted using different invertebrate fauna to include Hydropsyche* and *Arctopsyche* caddisflies

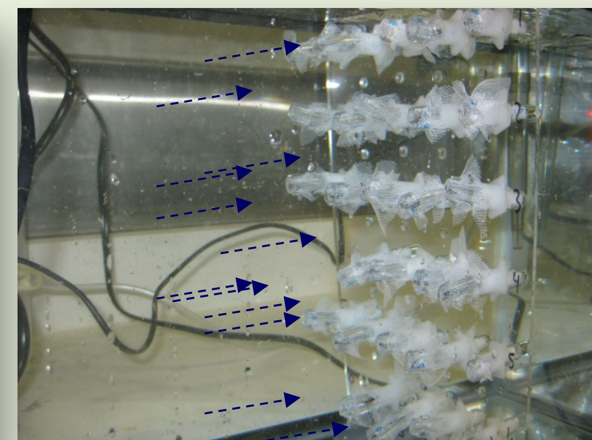
Dissolved Exposure



Dietary Exposure




Depuration



***Field transplant experiments (caddisflies transplanted from a metal contaminated site to a undisturbed tributary) to test model predictions of metal efflux***




# *Using biodynamic model to predict metal kinetics in stream invertebrates* *(M. Hornberger and others)*

Uptake (water + food)

Loss (efflux)

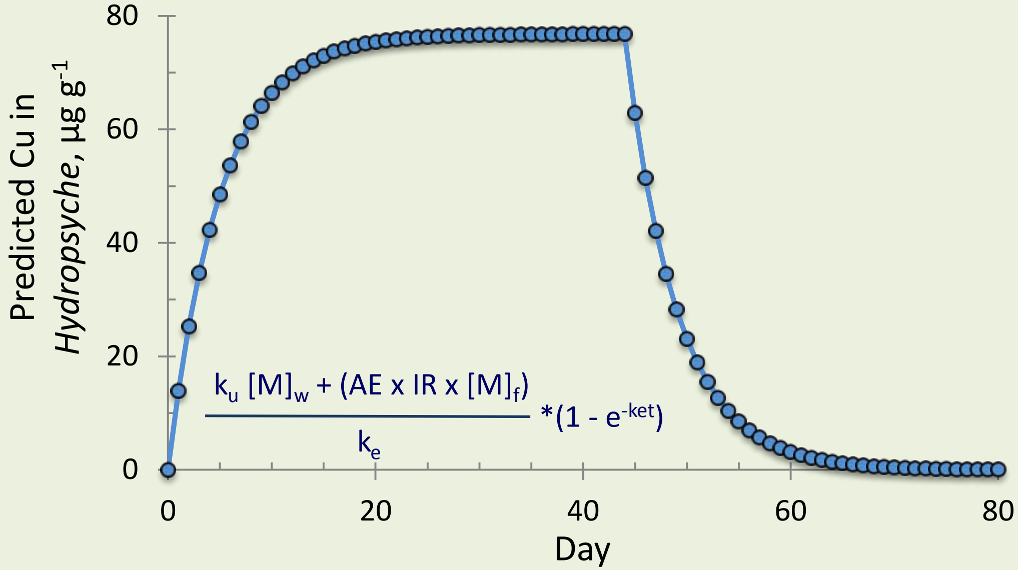
Dissolved | Diet

$$[M]_{biota} = \frac{[(k_u \cdot M_w) + (AE \cdot IR \cdot M_f)]}{k_e + k_g}$$

| | |
|---|---|
| $k_u$ | Uptake rate constant from water |
| $M_w$ | Metal concentration, water |
| AE | Metal Assimilation Efficiency |
| IR | Food Ingestion Rate |
| $M_f$ | Metal concentration, food |
| $k_e$ | Loss rate constant |
| $k_g$ | Loss by growth dilution |

- **Results for caddisfly larvae indicate that dietary influx contributes approximately 3X metal input compared to dissolved sources**

# Characterizing exposure history…




- In this example, the model predicts *Hydropsyche* can reach steady state within 2-3 weeks.
- When exposure is “removed” the initial rate of efflux is approximately 20% per day

## Implications for monitoring

- **Metal uptake by *Hydropsyche* is in part a function of discharge and will likely be at steady state if sampled during base flow.**
- **Rapid uptake and loss rates may be beneficial in identifying short term effects from episodic events (e.g., remediation).**

# *Factors influencing metal exposure risk*

## Ecological traits as determinants of metal exposure risk in stream invertebrates

- ***Development of a trait-based contaminant-exposure model which describes the strength of relationship between species-specific metal uptake and trait expression***

1) **Determine the extent to which ecological traits influence metal exposure history**

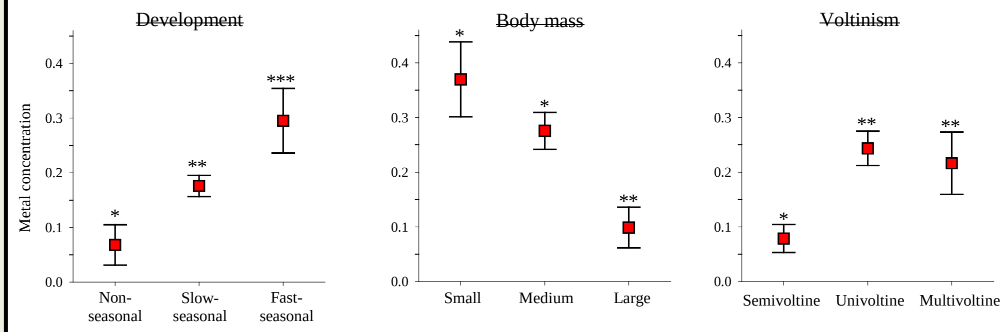
2) **Identify species at greatest exposure risk based on inherent trait properties**

3) **Explore potential for using trait-exposure models to explain long-term changes in occurrence and distribution patterns of invertebrate assemblages in a mining-impacted system**

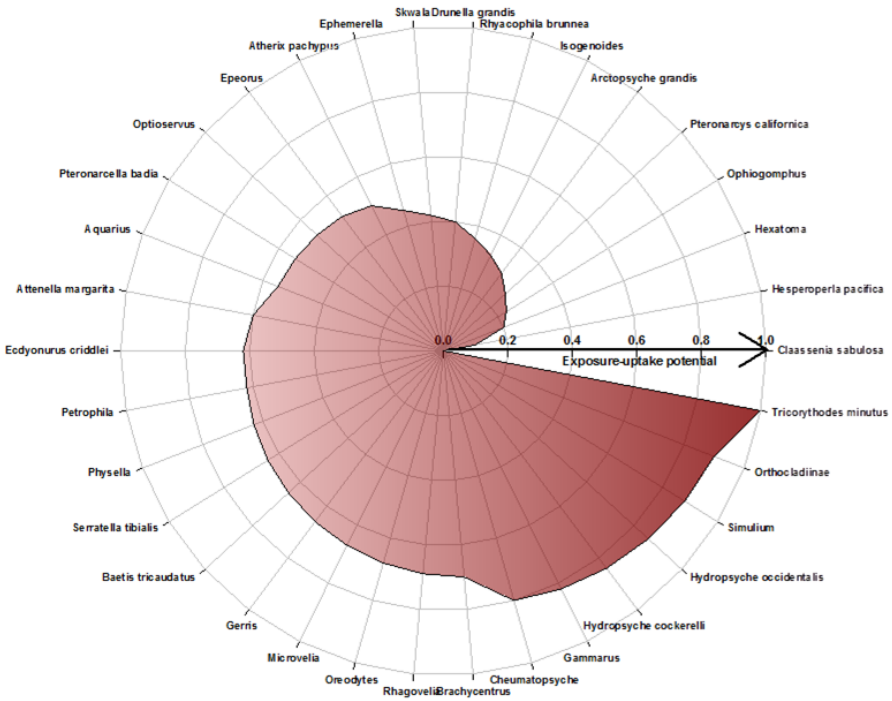
# Development of trait-based contaminant exposure model —

- Discriminant function analysis (DFA) was used to determine which traits best accounted for differences among taxa in metal bioaccumulation — individual metal concentrations were used as predictor variables for discriminating among trait characteristics
- A total of 14 traits related to feeding ecology, reproductive strategy, respiration, development, dispersal, habitat preferences, and stressor tolerance
- Results used to develop scoring metric for species traits based on metal exposure and uptake — and to assess trends in community-level responses

*Relations between trait characteristics and tissue metal concentrations for stream invertebrates*




*Radar plot shows contaminant exposure rankings for invertebrate taxa collected along a metal concentration gradient in the Clark Fork River. Results are based on behavioral and physiological attributes that predispose certain species to greater exposure risk.*



# *Mining impacts on ecosystem processes*

- ***Primary productivity in a mining-impacted river — characterizing physical-chemical stressor effects on stream trophy***

**Objectives of study……**

1) **Determine effects of dissolved metal exposure on 1$^o$ productivity**

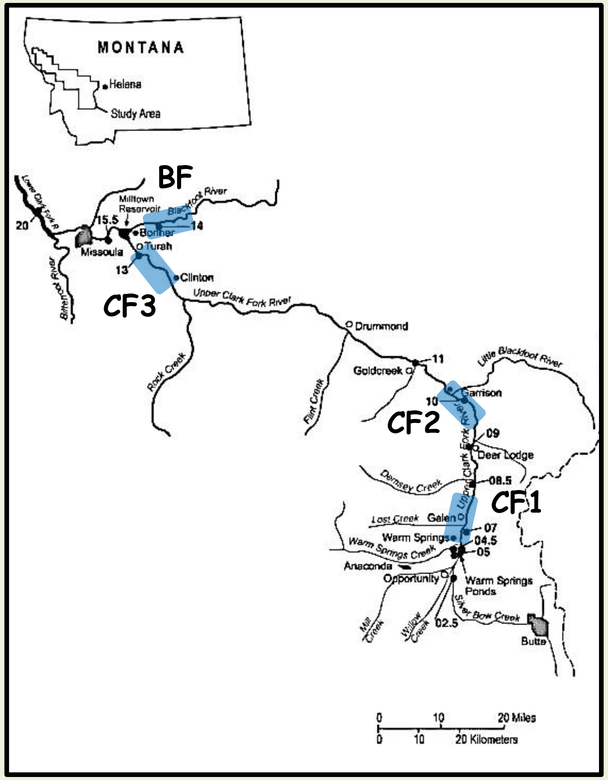
2) **Identify system-level responses to a metal-enriched environment (i.e., spatial and temporal trends in stream trophy (*autotrophy* ↔ *heterotrophy*)**

3) **Examine influence of physical-chemical factors, such as flow velocity and nutrients, on contaminant uptake in periphyton — and if uptake is rate dependent (e.g., is enrichment driving contaminant bioaccumulation dynamics by altering production rate?)**

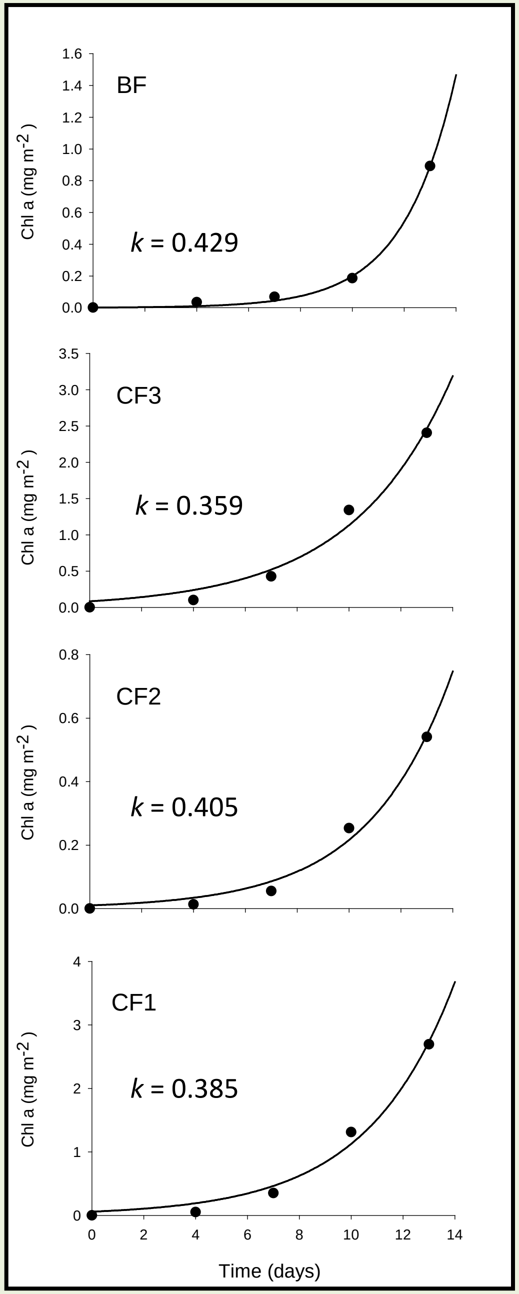
4) **Examine contaminant transfer pathways among producers, 1$^o$ and 2$^o$ consumers *"Feeding strategies of stream invertebrates: the importance of resource selectivity to contaminant uptake" (T. Short and M. Hornberger, in prep)***

***Rates of periphyton biomass accrual and metal uptake*** were assessed by interval-based sampling using artificial substrate samplers at several locations along a metal contamination gradient……

# Assessing accrual rates as a function of metal enrichment (dissolved <0.2 μm)



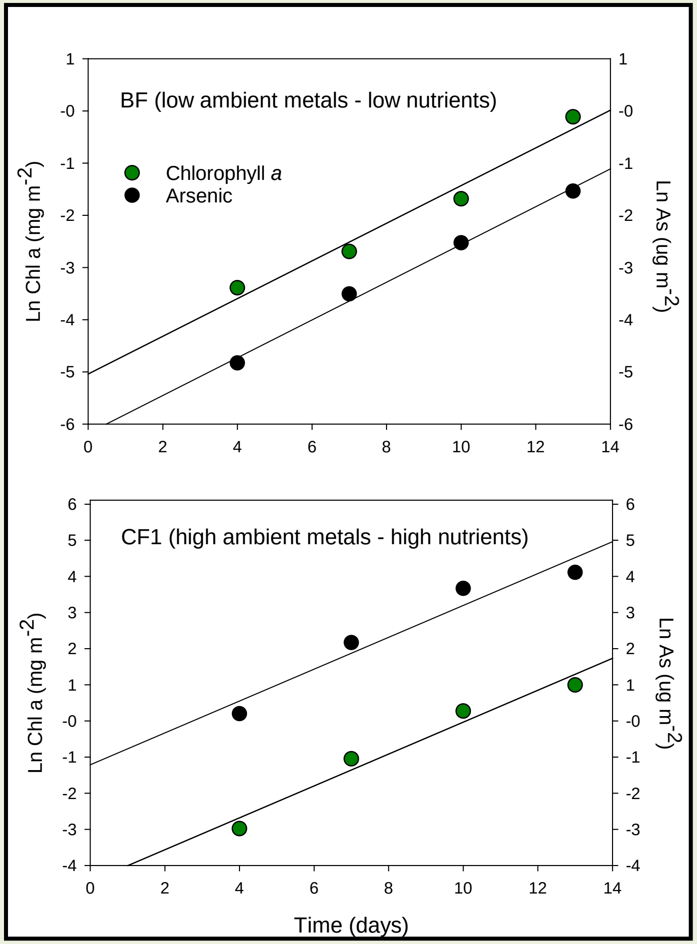

*Dissolved metal concentrations*



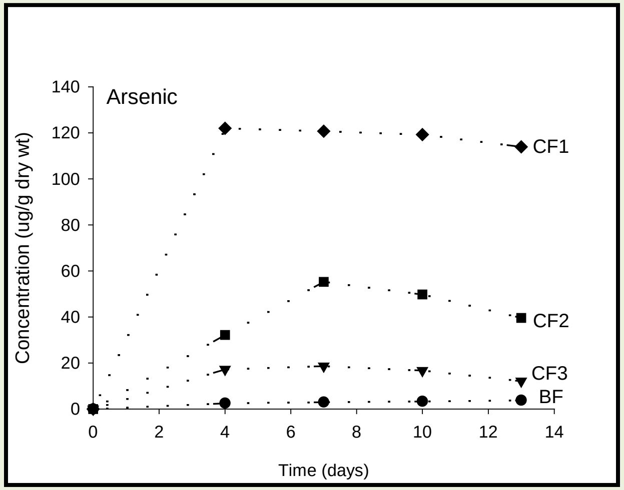

***No significant differences in rates of accrual — at concentration levels encountered (Cu = 0.5–10 μg /L)**

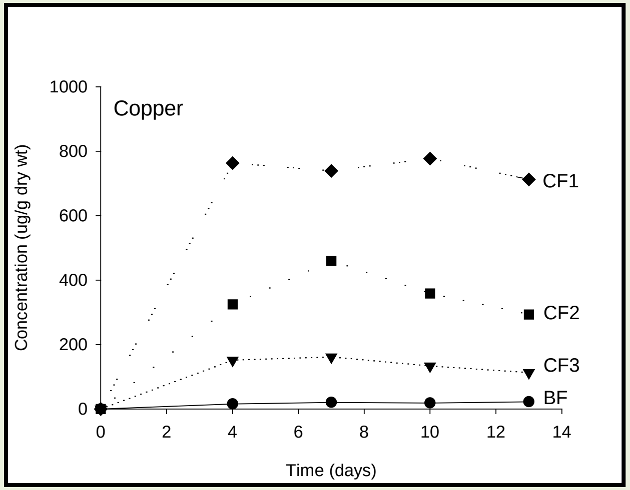
# *Relations between bioaccumulation and productivity……….*

*Plot comparing **arsenic and biomass accrual** at endpoints of contaminant gradient — showing bioaccumulation is function of productivity




*Plot showing **periphyton As and Cu concentrations over time** — concentrations reached a steady state within first few days of growth and accrual



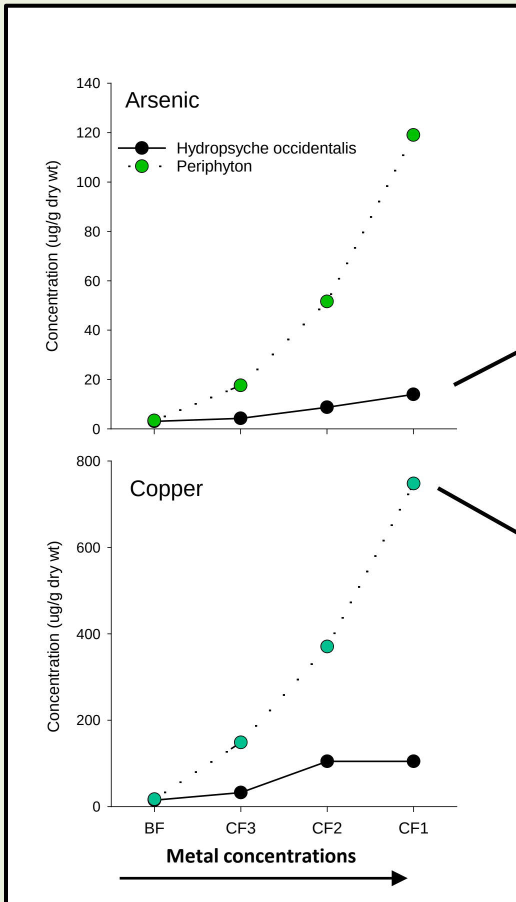



# Given the importance of dietary exposure……can differences in bioaccumulation patterns be attributed to consumer status?

- Consumer responses were based on comparisons of **feeding trait states** (50+ species)
- Coded based on **affinity scores** which show the relative contribution of each type of feeding behavior to the overall food acquisition strategy

**0** = no affinity of a species to that state
**1** = a species has that trait state exclusively

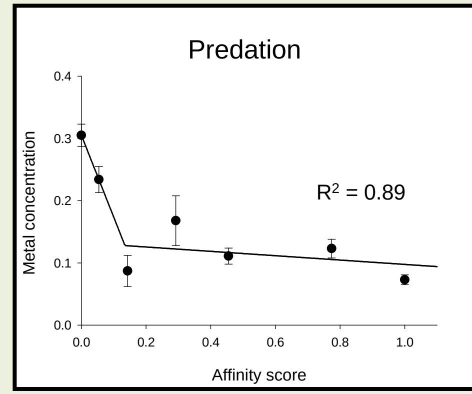
*Example of 2 dietary sources of metals (***Periphyton*** and ***Caddisfly larvae)***



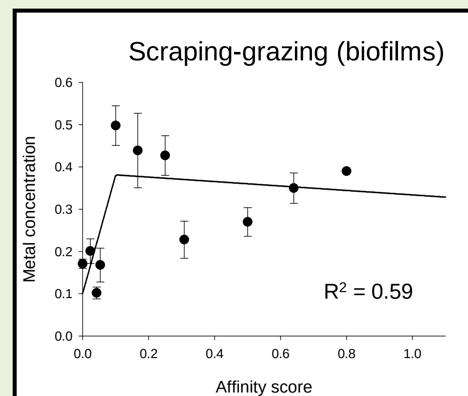

2°+ consumer

1° consumer

*"Claassenia"*



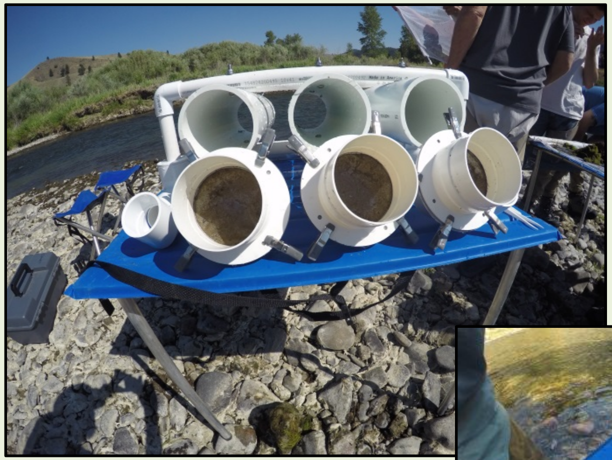

*"Petrophila"*

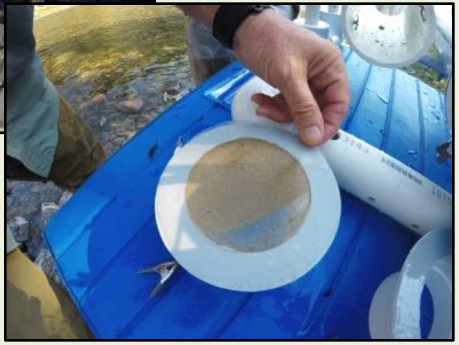


# Resource subsidies as contaminant sources — *linkages among hydrology, resource type, and invertebrate consumers*

- **SPOM as a contaminant source — contaminant transfer kinetics using suspension feeding invertebrates**

- **TAPAS "totally awesome particulate acquisition system"**
- **Wet-dry mass, organic carbon, chlorophyll, metal transport per unit time**





## *Investigation of hyporheic microbial biofilms as indicators of metal toxicity in the Clark Fork River Basin, MT* (Elliot Barnhart — Montana WSC, Helena MT)

- Gain a mechanistic understanding of microbial biofilm responses to metal contamination within the Clark Fork River Basin
- Assess temporal variability of microbial biomarkers
- Evaluate the potential use to identify remediation effects
- Develop a standardized microbial metal toxicity assay (next generation risk assessment tools using DNA sequencing)