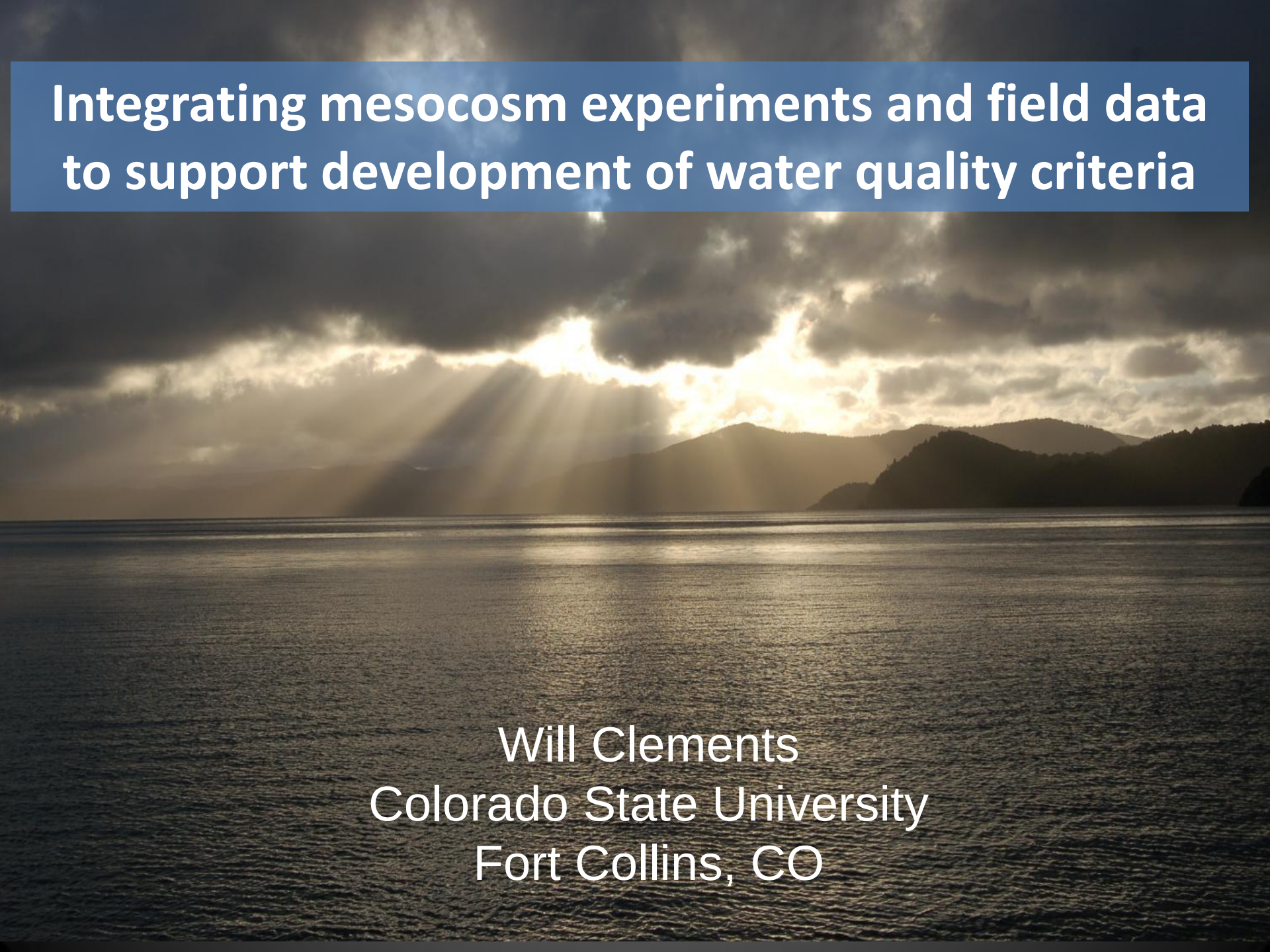


Integrating mesocosm experiments and field data to support development of water quality criteria



Will Clements
Colorado State University
Fort Collins, CO

Spatiotemporal Scale & Realism

High

Low

Field
assessments

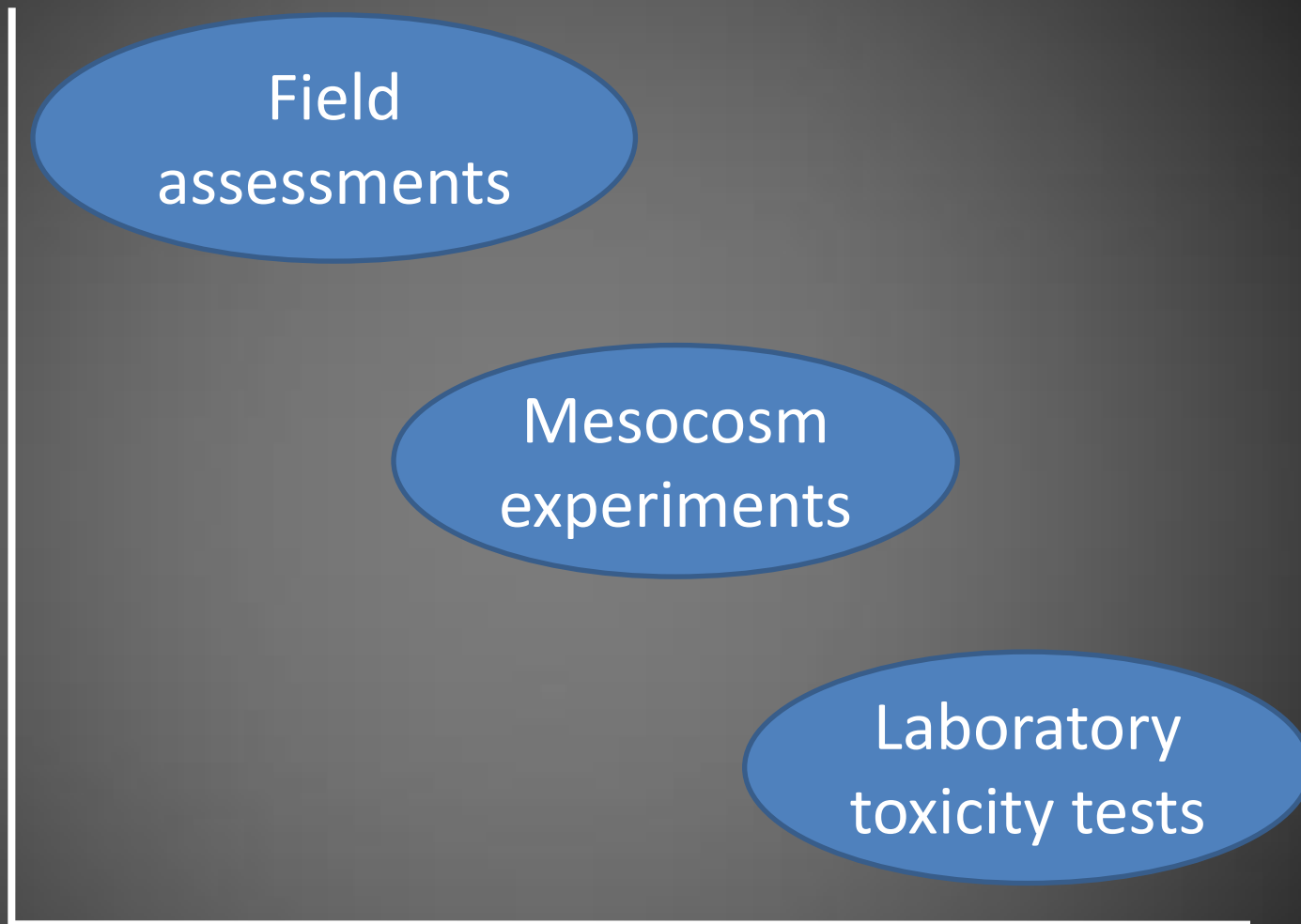
Mesocosm
experiments

Laboratory
toxicity tests

Low

High

Control & Replication



Criticism of Small-Scale Experiments in Ecological Research

“Microcosm experiments have limited relevance in community and ecosystem ecology”

“Irresponsible for academic ecologists to produce larval microcosmologists”

- Provide fast results: good for career development
- Keep faculty on campus under the watchful eye of administrators

Carpenter, 1996

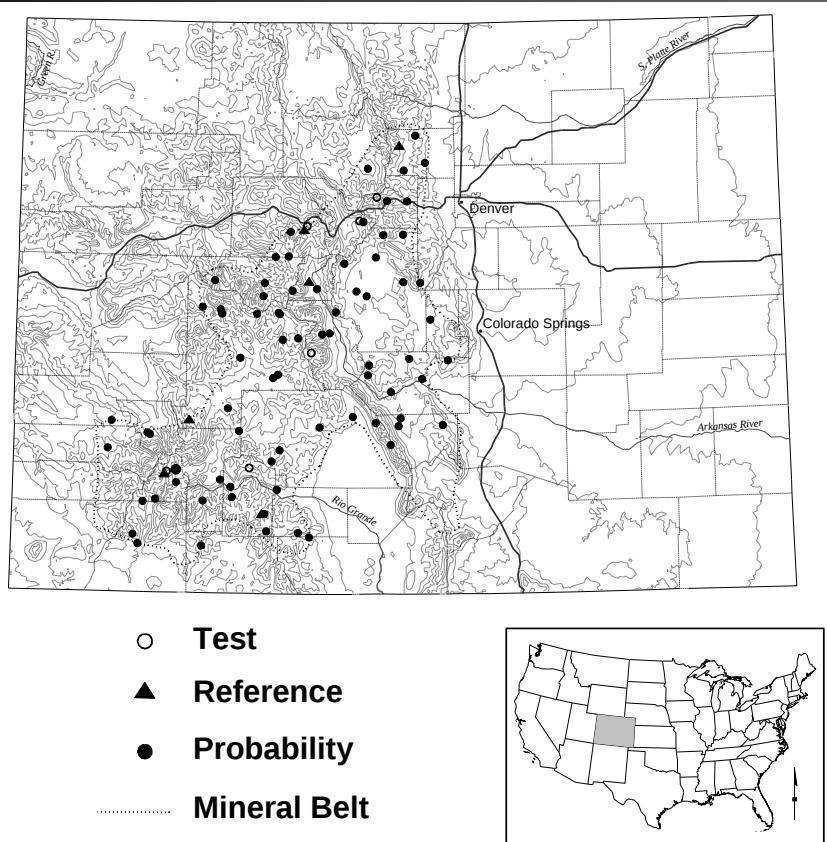
Overview

- Differences between field & lab responses to contaminants
- A few hypotheses to explain these differences
- Application of mesocosm experiments to test these hypotheses and to support the development of water quality criteria

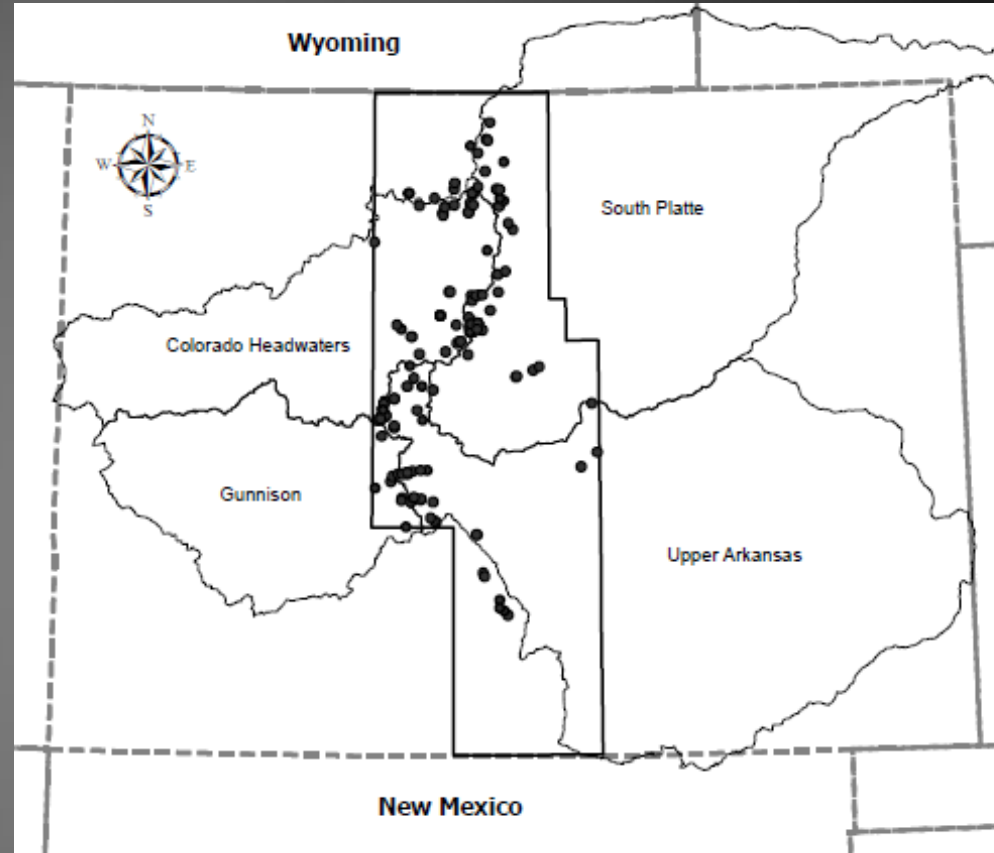
Spatially extensive and long-term surveys of metal-contaminated streams in Colorado



EPA EMAP (n = 95)



USGS & CSU (n = 154)



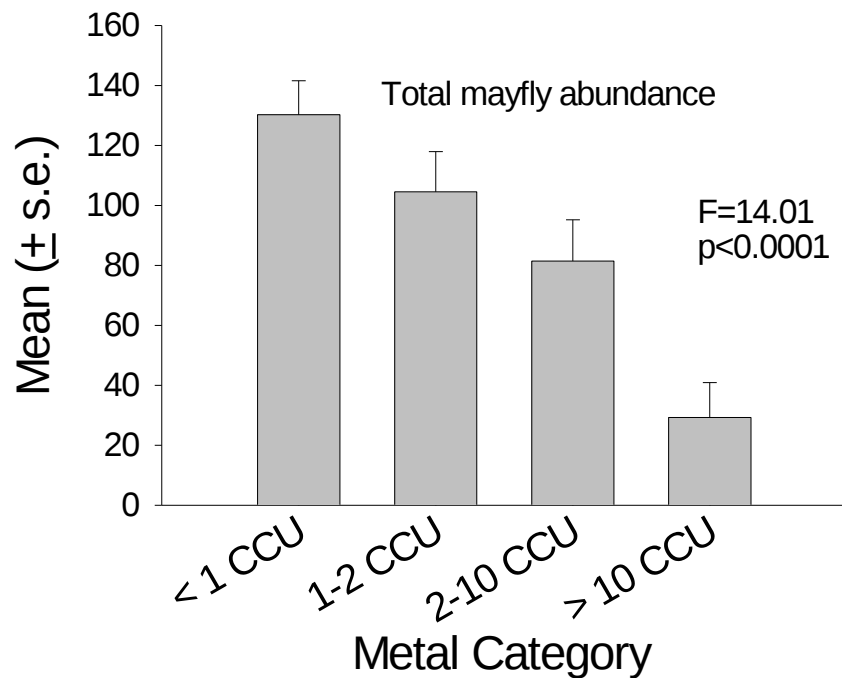
Quantify relationship among metals, aquatic insect communities and other environmental variables



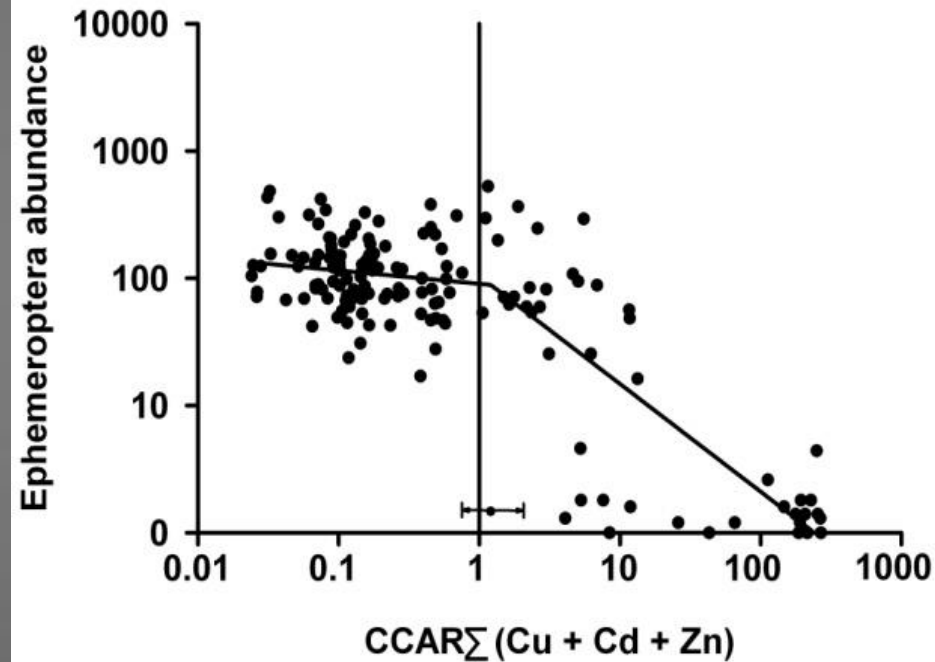
Sensitivity of aquatic insects (especially mayflies)



Highly significant effects on mayflies at relatively low metal concentrations



Clements et al. 2000



Schmidt, Clements & Cade, 2012

But, lab toxicity data do not reflect this sensitivity

Copper

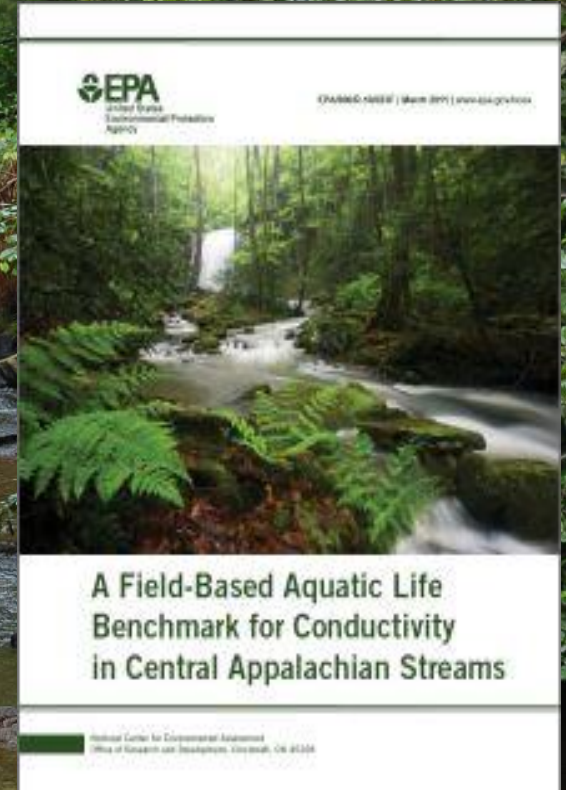
Species	LC ₅₀
<i>Ephemerella subvaria</i>	320 µg/L
<i>Drunella grandis</i>	201 µg/L
<i>Stenonema sp.</i>	453 µg/L
<i>Drunella grandis</i>	190 µg/L
<i>Rhithrogena hageni</i>	137 µg/L
<i>Isonychia bicolor</i>	223 µg/L

Zinc

Species	LC ₅₀
<i>Ephemerella sp.</i>	> 68.8 mg/L
<i>Cinygmula sp</i>	68.6 mg/L
<i>Drunella doddsi</i>	> 64.0 mg/L
<i>Rhithrogena hageni</i>	50.5 mg/L
<i>Baetis tricaudatus</i>	11.6 mg/L
<i>Baetis tricaudatus</i>	> 2.9 mg/L

Warnick and Bell 1969; Goettl et al. 1972; Dobbs et al. 1994;
Brinkman & Johnston 2008; Brinkman et al. 2012; Mebane et al. 2012

Similar patterns with major ions



Conductivity benchmark
→ 300 $\mu\text{S}/\text{cm}$

Source	Endpoint	Response (μS/cm)	Reference
Road salt (lab)	Insect survival & drift (96 h LC50)	3,526-10,000	Blasius & Merritt (2002)
Road salt (lab)	Insect survival (72 h LC50)	5,500-25,000	Kellford et al. (2003)
Salt mining (mesocosm)	Stream invertebrates (72 h survival)	5,000	Canedo-Arguelles et al. (2012)
Road salt (lab)	<i>Chironomus</i> survival & emergence (67 d)	5,000	Lob & Silver (2012)
MTM-VF (field)	Community composition of stream invertebrates	< 500	Pond et al. (2009)
MTM-VF (field)	Community composition of stream invertebrates	300	USEPA (2011) Cormier et al. (2013)

A few hypotheses to explain these differences

1. Interspecific interactions



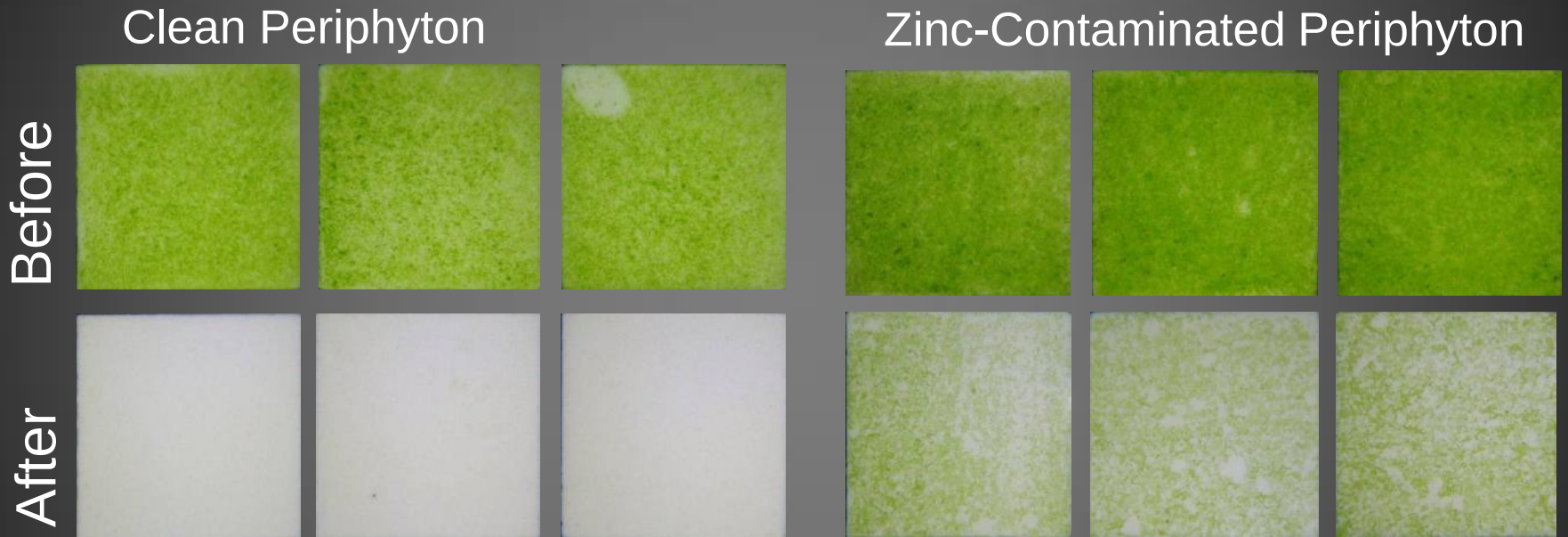
Metal exposure resulted in greater susceptibility of aquatic insects to predation

(Clements et al 1989; Kiffney 1996;
Clements 1999)

2. Dietary exposure

(Irving, Baird & Culp 2003; Xie, Funk & Buchwalter 2010; Xie & Buchwalter 2011; Cadmus 2010)

Reduced Grazing on Zn-Contaminated Periphyton



3. Short-term (96 h) experiments are inadequate for assessing effects of contaminants on aquatic insects

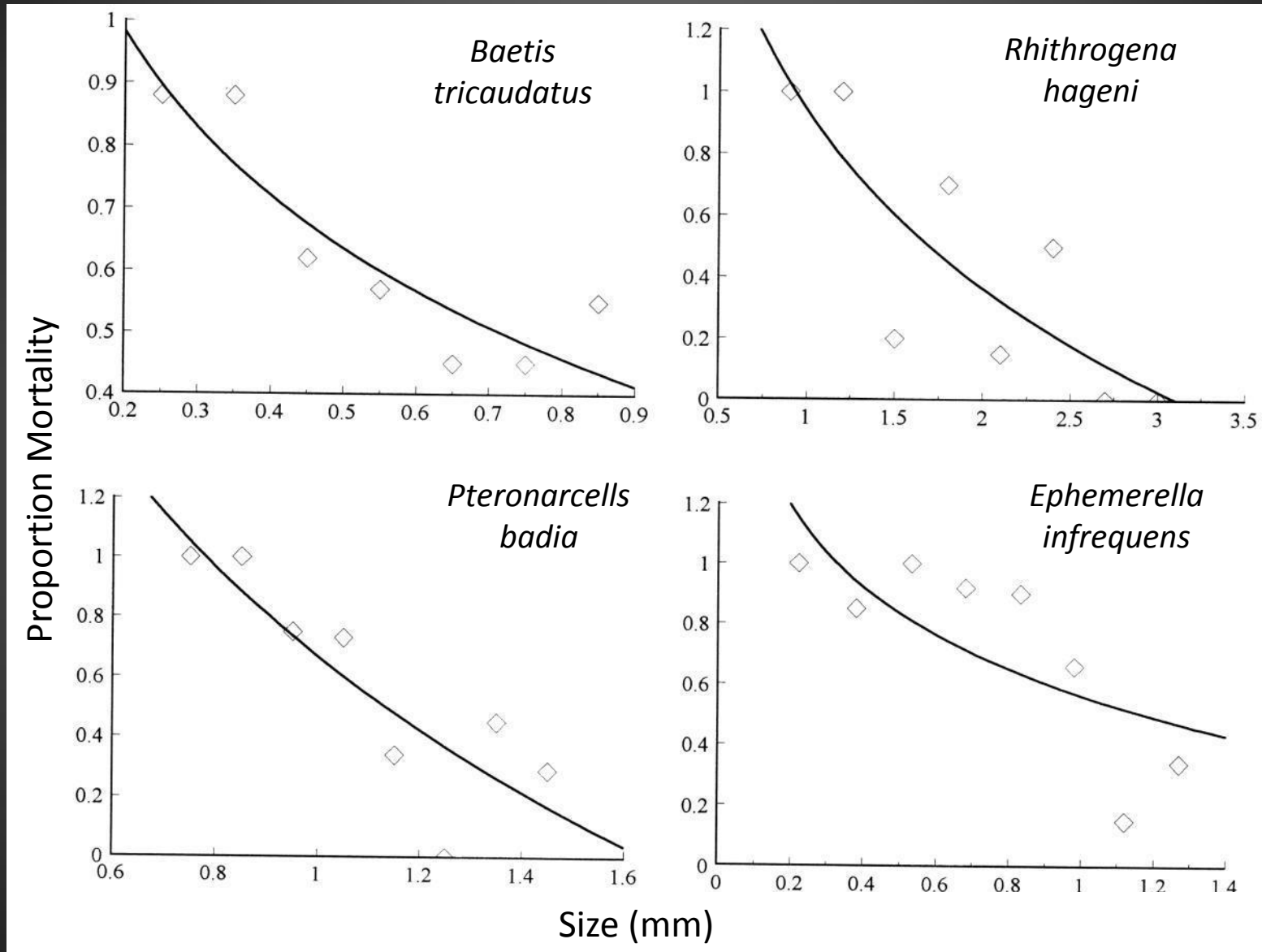
Species	Days required to reach steady state (Cd)
<i>Rhithrogena</i>	5588
<i>Ephemerella</i>	399
<i>Rhyacophila</i>	41

(Buchwalter et al. 2007)

4. Physical influences (Fe oxides)



5. Sensitivity of early instars to metals



Laboratory experiments with early instar mayflies (*Neocloeon triangulifer*) exposed to major ions

Toxicant	Endpoint	Response ($\mu\text{S}/\text{cm}$)	Reference
Brine salt	Growth (20 d)	672	Johnson et al. (2015)
Reconstituted MMVF waters	Survival (35 d)	800-1300	Kunz et al. (2013)
NaCl	Survival to pre-emergent nymph stage (23 d)	939	Soucek and Dickinson (2015)

Using mesocosm experiments to support development of water quality criteria

- Establish concentration-response relationships
 - Identify “safe” concentrations (e.g., EC20s)
- Examine multiple stressors & stressor interactions
- Measure nontraditional endpoints (e.g., drift, metabolism)
- Investigate context dependency

Stream Microcosm Experiments



Date	Stressor
Oct 1991	Zn
Jul 1992 & Sept 1992	Cd, Cu, Zn
Nov 1993 & Aug 1996	Zn
Aug 1997	Cd, Cu, Zn
Oct 1998	Cd, Zn
Nov 1999	Cd, Cu, Zn
Aug & Oct 2000	Cd, Cu, Zn
Jul 2002 & May 2003	Cd, Cu, Zn
Sep 2003	Zn
Aug 2003	Cd, Cu, Zn
September 2007	Cu
October 2007	Cu, Zn
October 2010 & May 2012	Fe
July, 2011 & 2012	Fe, Cu, Zn
July 2012	Cu + Hardness
Oct 2013 to Aug 2014	Major ions
Aug & Sept 2014	Activated carbon

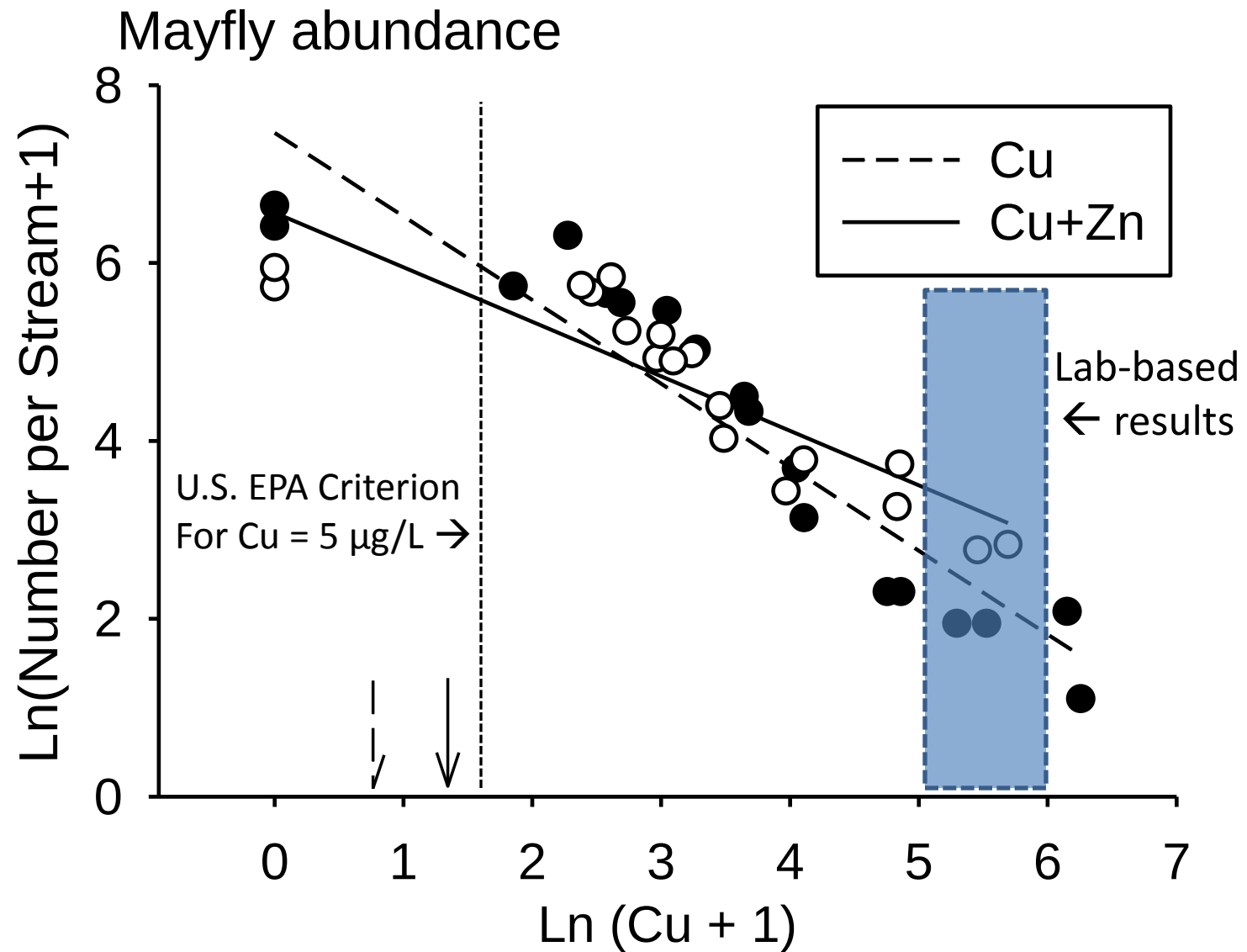
Variables

- Season
- Concentration
- Metal combinations
- Other stressors
- Source of community

Endpoints

- Survival
- Size-specific mortality
- Metal uptake
- Community comp.
- Drift & immigration
- Community metabolism
- Leaf decomp.

Interactions among metals



Effects of major ions on benthic communities

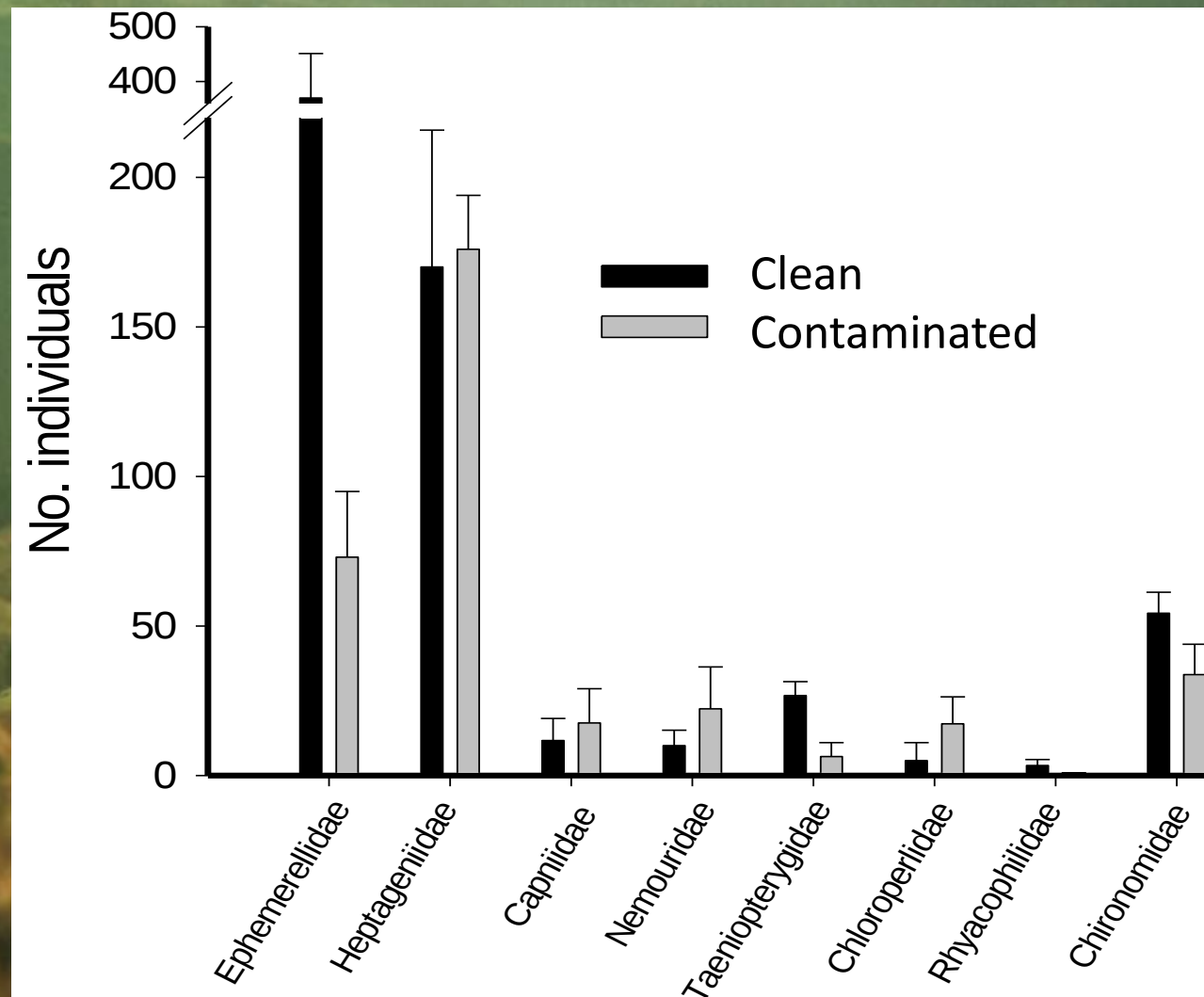
South Fork of the Michigan River

Cache la Poudre River

4 Mesocosm Experiments:

- NaHCO_3
- MgSO_4
- NaCl (2 experiments)

Colonization of Clean & Contaminated Substrate in the Animas River, CO

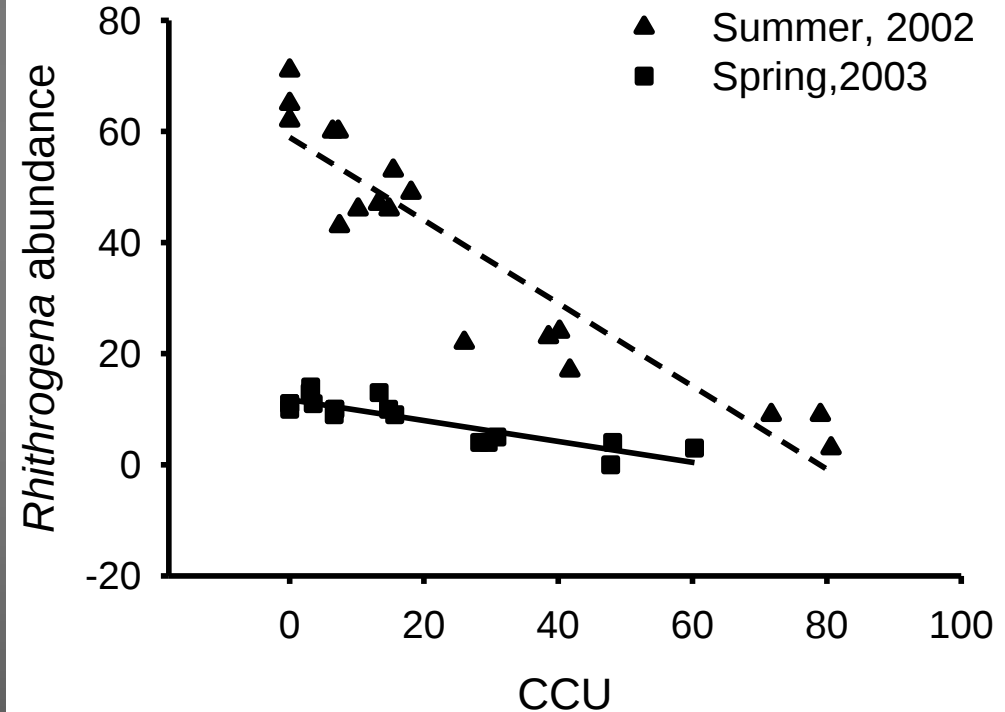
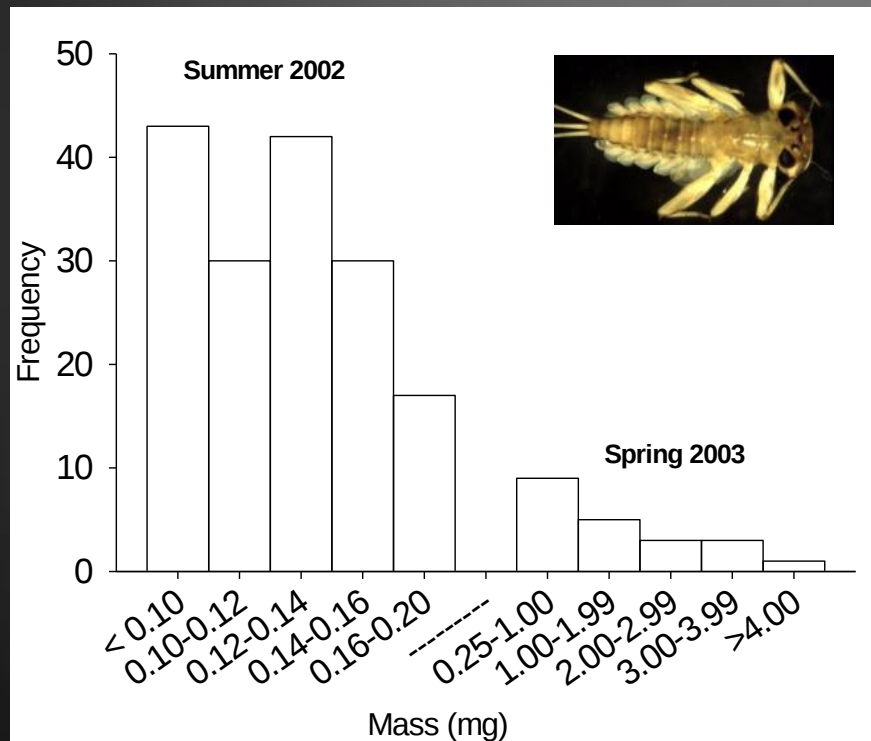


Courtney & Clements 2002

Seasonal Variation in Sensitivity to Metals

Size distribution of *Rhithrogena* in summer & spring

Responses to metals in summer & spring



Community Metabolism (light/dark O_2 measurements)



Context-dependent Responses to Contaminants

Reference
stream



Arkansas
River



Sub-alpine
stream



Foothills
stream



Use of Mesocosm Experiments to Support the Development of Water Quality Criteria

- Ecologically realistic conditions & endpoints
- Test hypotheses to explain discrepancies between lab & field
- Essential for stressors that show little direct toxicity in the lab (e.g., nutrients, Fe)



Thanks!

>100 CSU graduate & undergraduate students

Funding:

U.S. EPA, USGS, U.S. FW&S, CDOW, NIEHS
IZA, ICA, Rio Tinto