Explanations for the disconnection between the laboratory and field in understanding the effects of metals on aquatic insects

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Overview – major themes

1. Representation of taxa

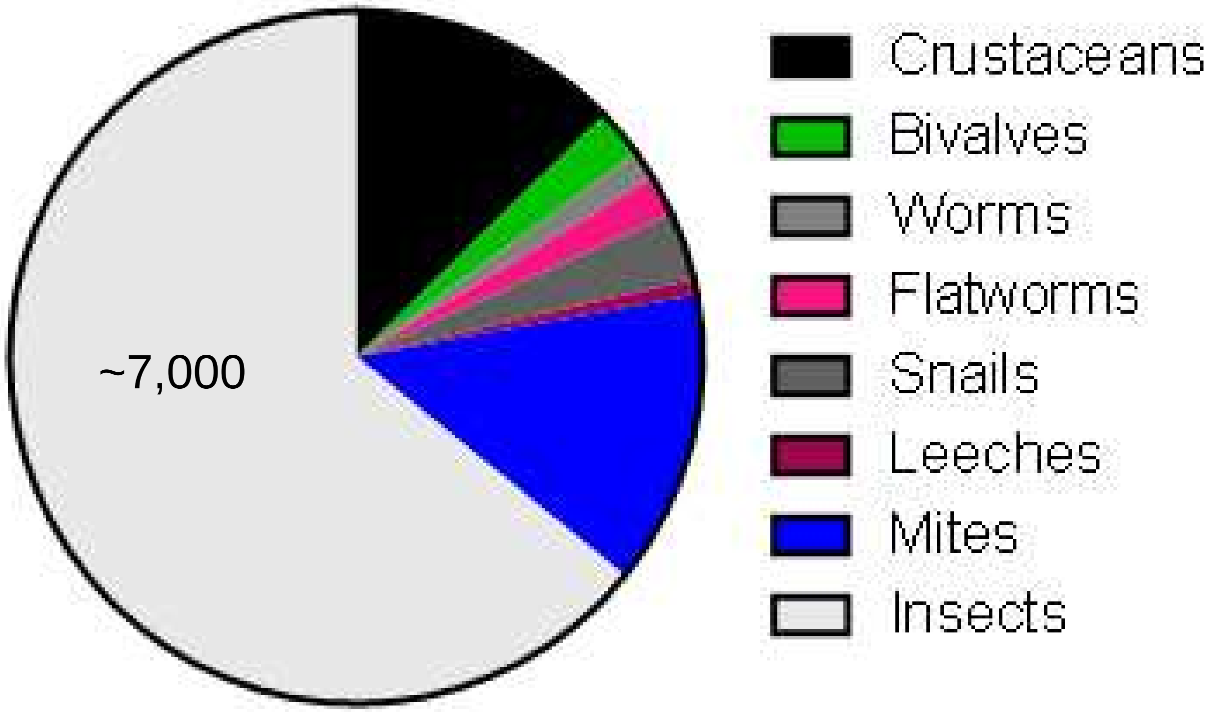
2. Adequacy of testing approaches

3. Potential paths forward

Minimum requirements – freshwater – 8 families

- Salmonidae (Class Osteichthyes)
- A second family (Class Osteichthyes) (preferably commercially or recreationally important warm water species)
- A third family in the phylum Chordata
- A planktonic crustacean
- A benthic crustacean
- An insect
- A family in a phylum other than Arthropoda or Chordata
- A family in any order of insect or any phylum not already represented

Invertebrate Freshwater Diversity in North America



Total=11,000 - 15,000

In practice……

- Species (3) from the genus *Chironomus* have been the “go-to” test organism to represent ~7,000 insects
  - Based on ease of lab culture
  - Generally extremely tolerant
  - Inadequately protective of sensitive groups (e.g. mayflies)
  - *Daphnia* more often represent “sensitive” inverts in species sensitivity distributions

Two Sides of the Clean Water Act Coin

Develop WQC to
protect communities

Monitor communities
in nature

NABS (www.benthos.org)
NABS (www.benthos.org)
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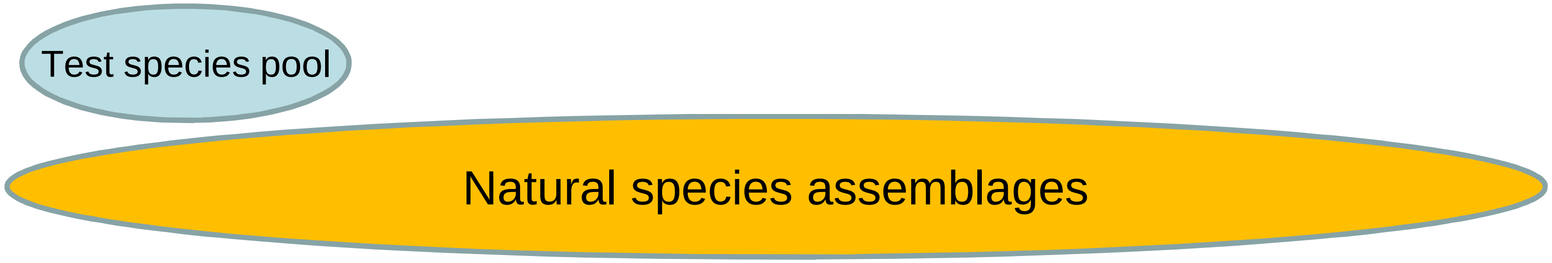
For metals……



………there is a fair amount of toxicity data for insects

Species	Common name	Hardness ($CaCO_3$) (mg/L)	**LC_{50} (ug/L)**	References
Arctopsyche sp.	Caddisfly	30	**467**	Windward, 2002
Aedes aegypti	Mosquito	38	**16,500**	Rayms-Keller et al., 1998.
Baetis tricaudatus	Mayfly	156	**1,160**	Irving et al. 2003
Baetis rhodani	Mayfly	50	**2,500 (pH = 7.0)**	Gerhart, 1992
Baetis rhodani	Mayfly	50	**1,000 (pH = 5.0)**	Gerhart, 1992
Chironomus riparius **(2nd instar)**	Midge	105	**13,000**	Williams et al., 1986
Chironomus riparius **(4th instar)**	Midge	152	**300,000**	Williams et al. 1986
Chironomus riparius **(4th instar)**	Midge	124	**140,000**	Pascoe et al., 1990
Chironomus tentans	Midge	17	**8,000**	Suedal et al., 1997
Ephemerella grandis	Mayfly	44	**2,000**	Warnick & Bell, 1969
Ephemerella grandis	Mayfly	NA	**28,000**	Clubb et al., 1975
Leptophlebia marginata	Mayfly	50	**4,400 (pH = 7.0)**	Gerhart, 1992
Leptophlebia marginata	Mayfly	50	**3,600 (pH = 5.0)**	Gerhart, 1992
Pteronarcella badia	Stonefly	NA	**18,000**	Clubb et al., 1975
Perlodidae	Stonefly	30	**5,130**	Evs Environment, 1996
Rhithrogena hageni	Mayfly	40-50	**10,500**	Brinkman & Johnson, 2008
Rhithrogena sp	Mayfly	21	**50**	Windward, 2002

Insects are quite responsive to metals in nature

Unfortunately……the lab and field tell us different things

Review

The sensitivity of aquatic insects to divalent metals: A comparative analysis of laboratory and field data

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[b] RSMAS, University of Miami 4600 Rickenback Cswy, Miami, FL 33149, United States
[c] Windward Environmental 200 West Mercer Street, Suite 401 Seattle, WA 98119, United States
[d] Rio Tinto 8315 West 3595 South Magna, UT 84044, United States

Using Biodynamic Models to Reconcile Differences Between Laboratory Toxicity Tests and Field Biomonitoring with Aquatic Insects

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Environmental Science & Technology

Viewpoint

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Four Reasons Why Traditional Metal Toxicity Testing with Aquatic Insects Is Irrelevant

Monica D. Poteat and David B. Buchwalter*

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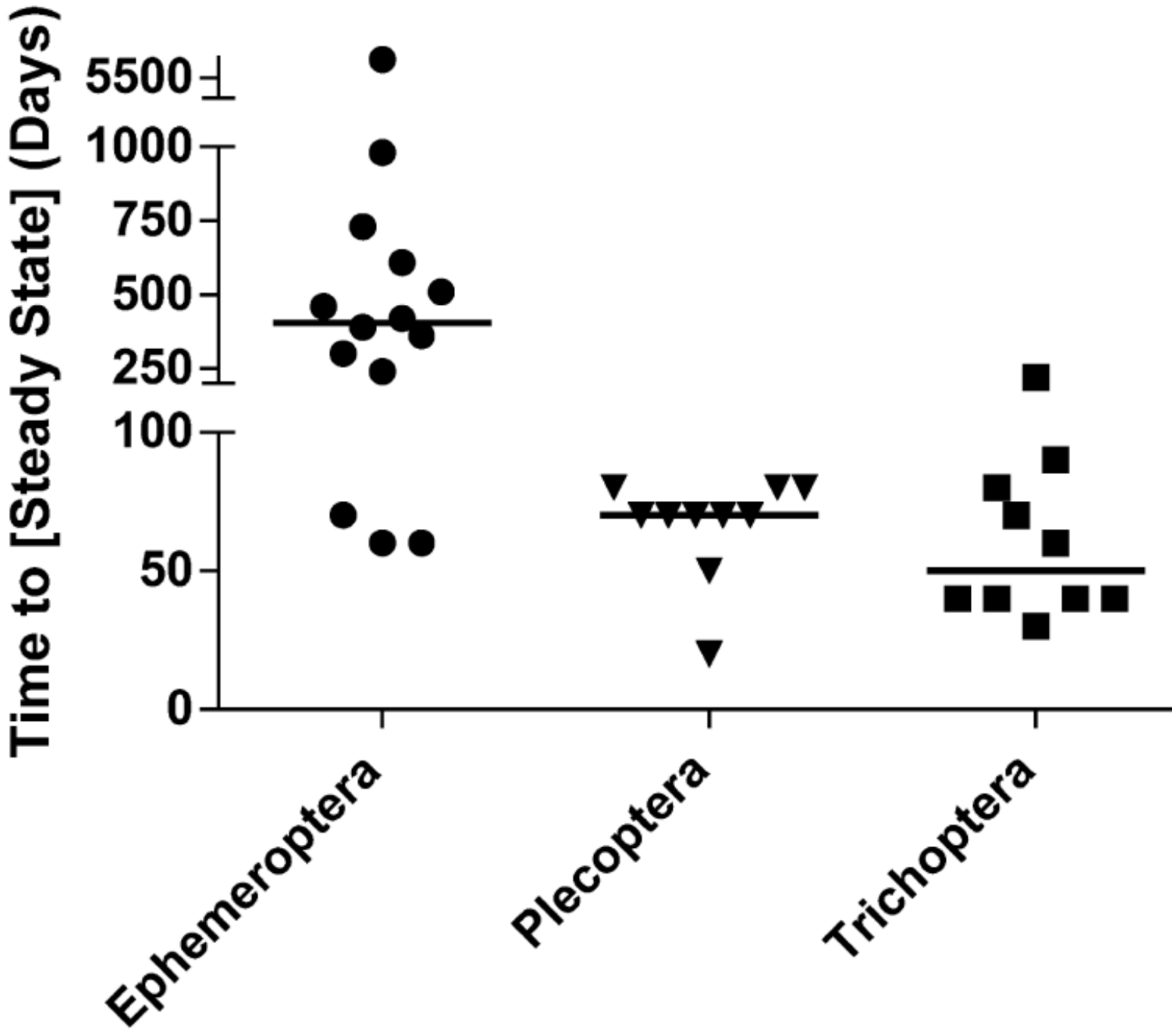
Reason 1: Time



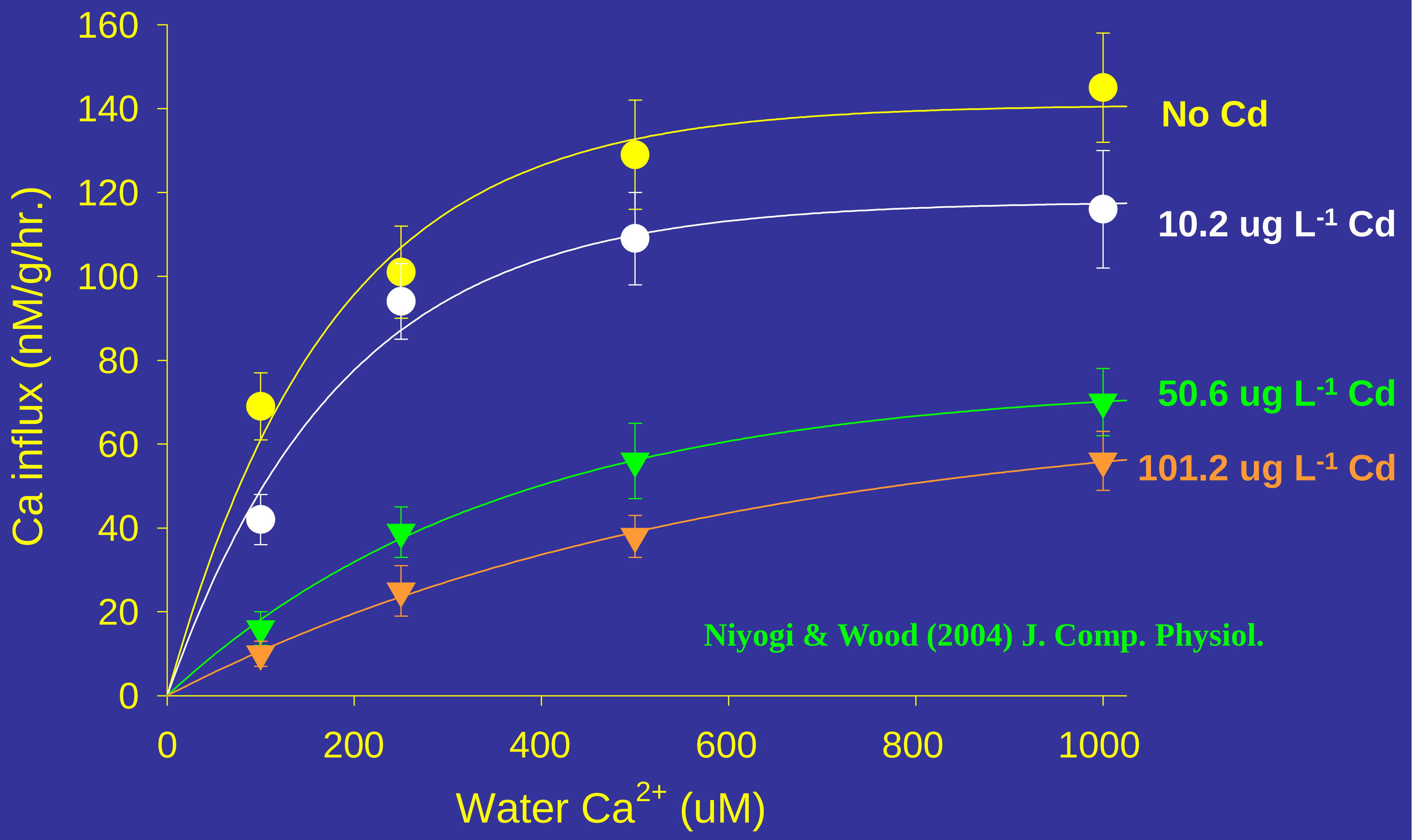
Reason 2: Mechanisms of toxicity: (limited evidence for metals causing ionoregulatory disturbance in insects)

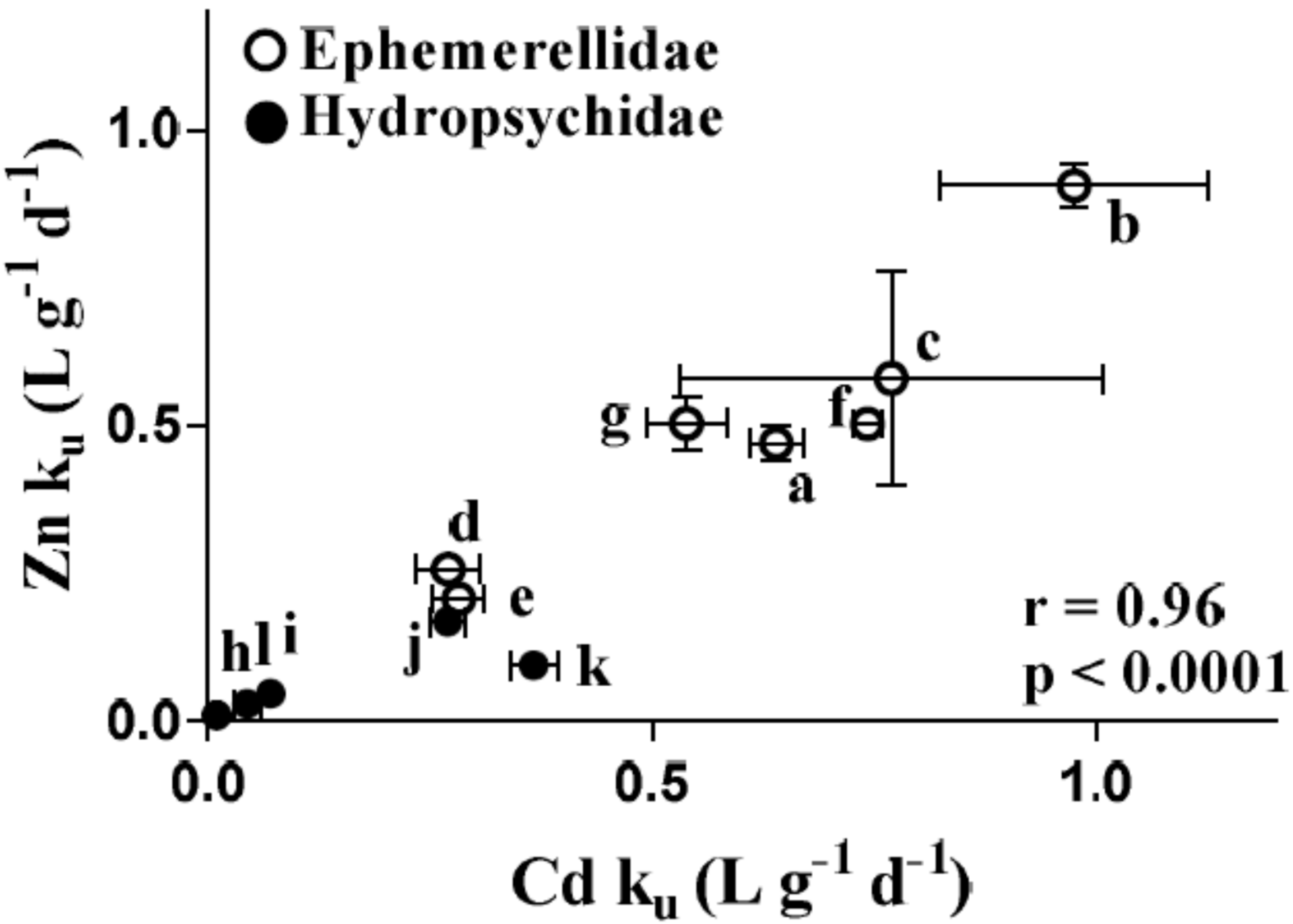
- In fish and crustaceans, there is good evidence that metals target the transport of physiologically important ions.

- Calcium transport: affected by Zn, Cd, Pb

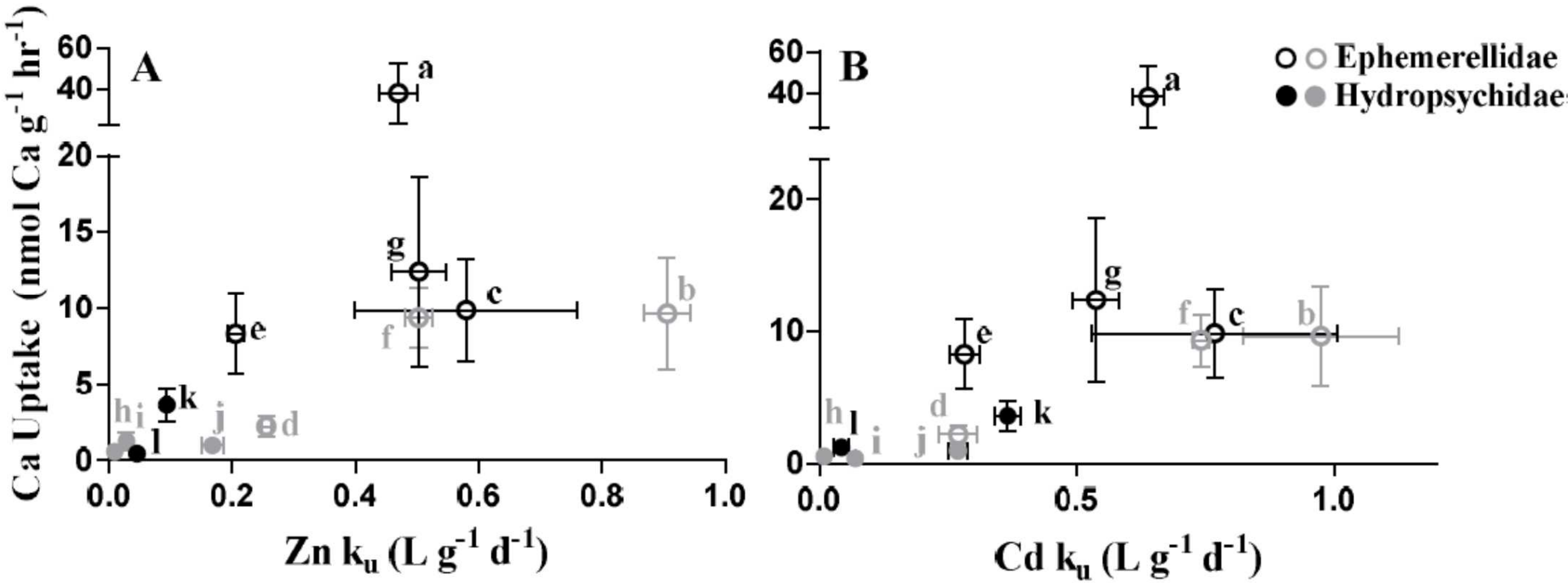
- Sodium transport: affected by Cu and Ag

Effect of Cd on Branchial Ca Influx in Rainbow Trout





Ephemerellidae
Hydropsychidae
Zn k_u (L g^{-1} d^{-1})
Cd k_u (L g^{-1} d^{-1})
0.0
0.5
1.0
a
b
c
d
e
f
g
h
i
j
k
l
r = 0.96
p < 0.0001



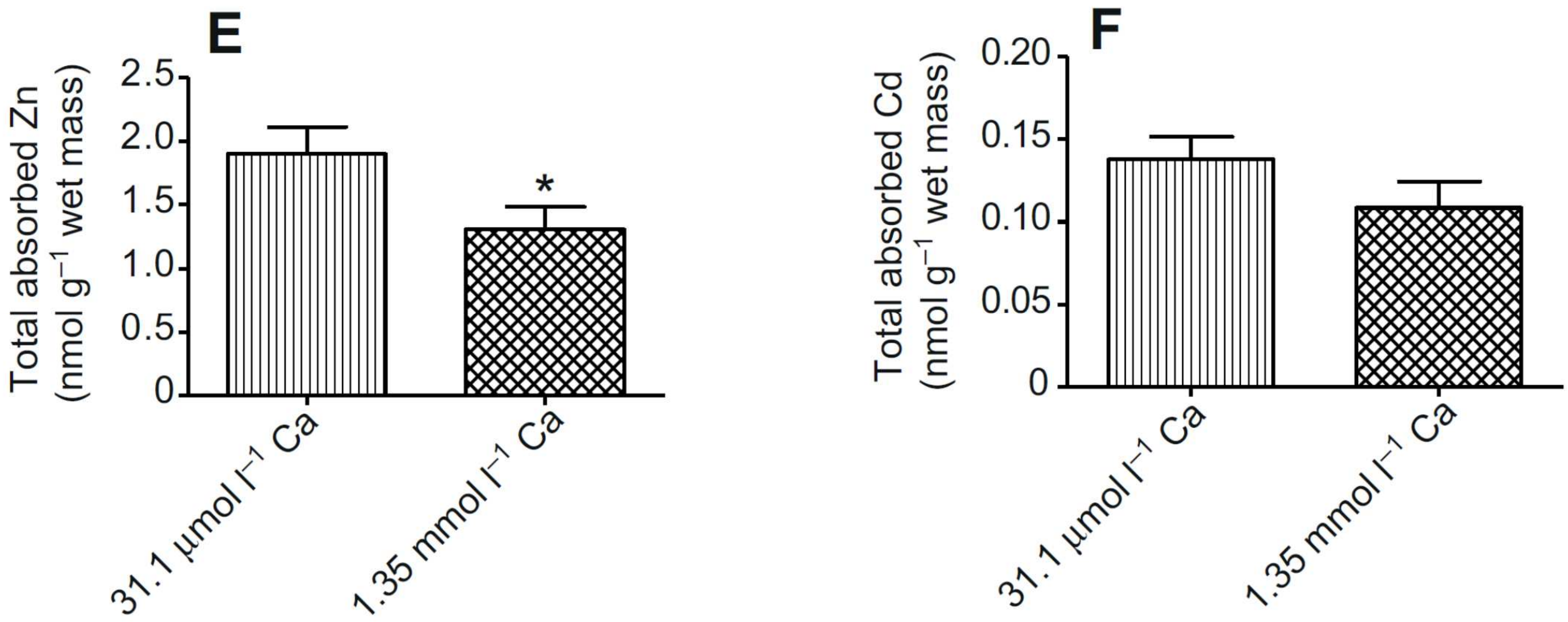
A
B
Ca Uptake (nmol Ca g-1 hr-1)
Zn ku (L g-1 d-1)
Cd ku (L g-1 d-1)
Ephemerellidae
Hydropsychidae
0
5
10
15
20
40
60
0.0
0.2
0.4
0.6
0.8
1.0
0.5
a
b
c
d
e
f
g
h
i
j
k
l

RESEARCH ARTICLE

Divalent metal (Ca, Cd, Mn, Zn) uptake and interactions in the aquatic insect *Hydropsyche sparna*

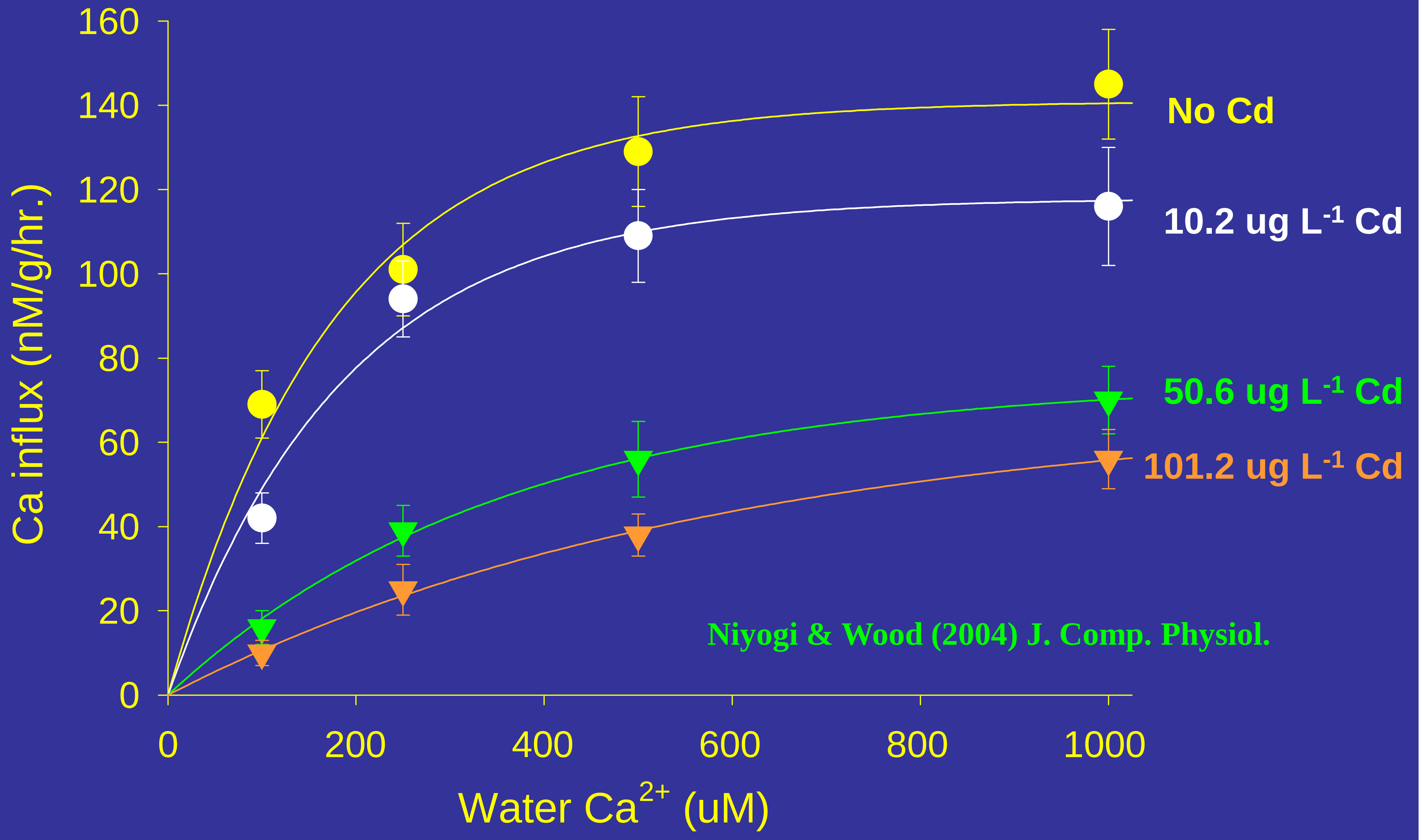
Monica D. Poteat[1], Mauricio Díaz-Jaramillo[2] and David B. Buchwalter[1,*]

The Journal of Experimental Biology 215, 1575-1583



A 43-fold increase in calcium concentration had modest (Zn) to no (Cd) effects on metal uptake rates

Effect of Cd on Branchial Ca Influx in Rainbow Trout



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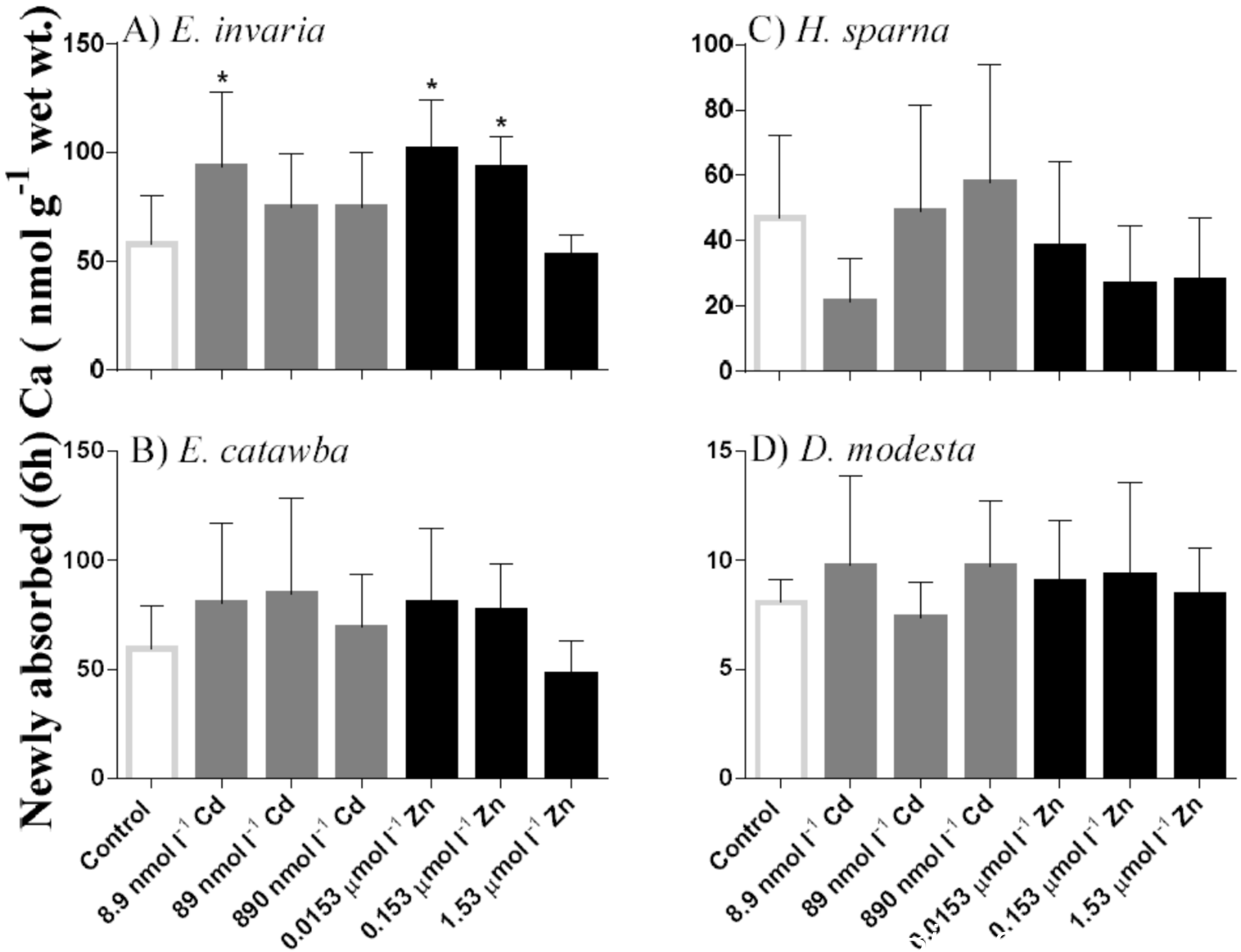
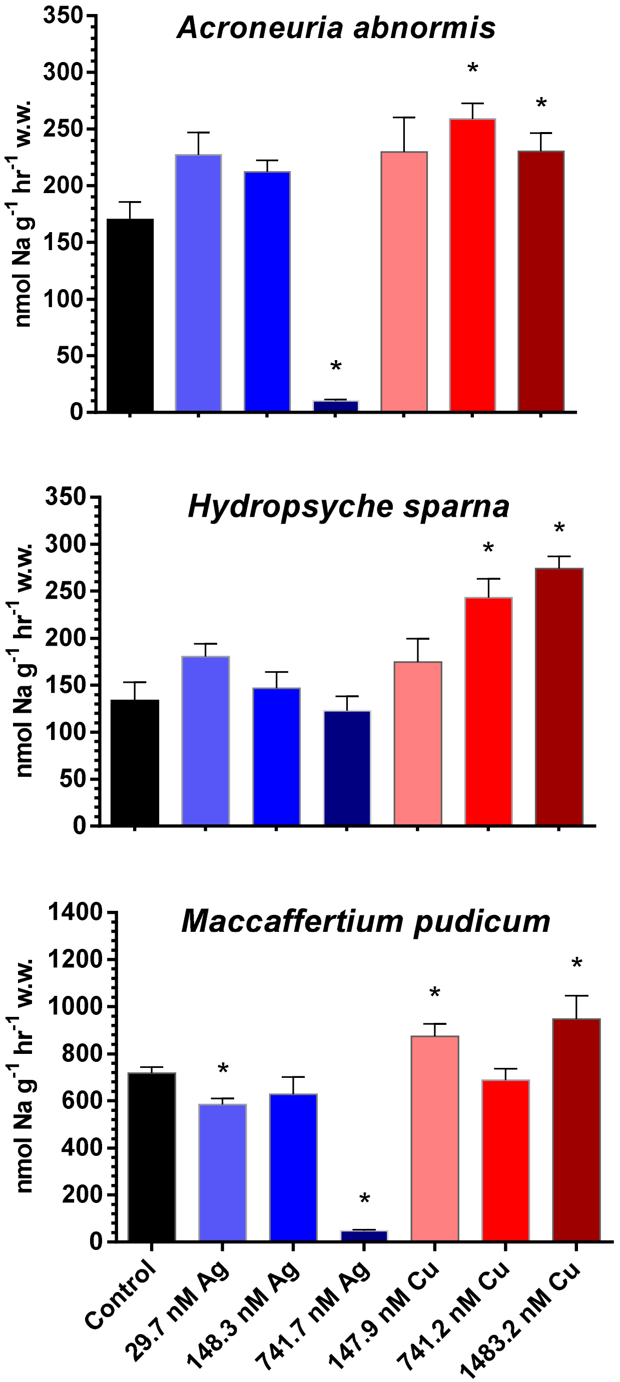
RESEARCH ARTICLE

Calcium uptake in aquatic insects: influences of phylogeny and metals (Cd and Zn)

Monica D. Poteat and David B. Buchwalter*





Silver and copper effects on Na uptake rates

Scheibener and Buchwalter, in prep

Reason 3: Dietary exposures are very important

- Aquatic insects may receive the majority of their tissue metal burdens from their food
  - (Martin and Buchwalter, ES&T, 2007).

Periphyton is a major sink for many metals

- Cd: Xie et al, Environmental Pollution, 2010
- Zn: Kim et al, Ecotoxicology, 2012
- Se: Conley et al papers

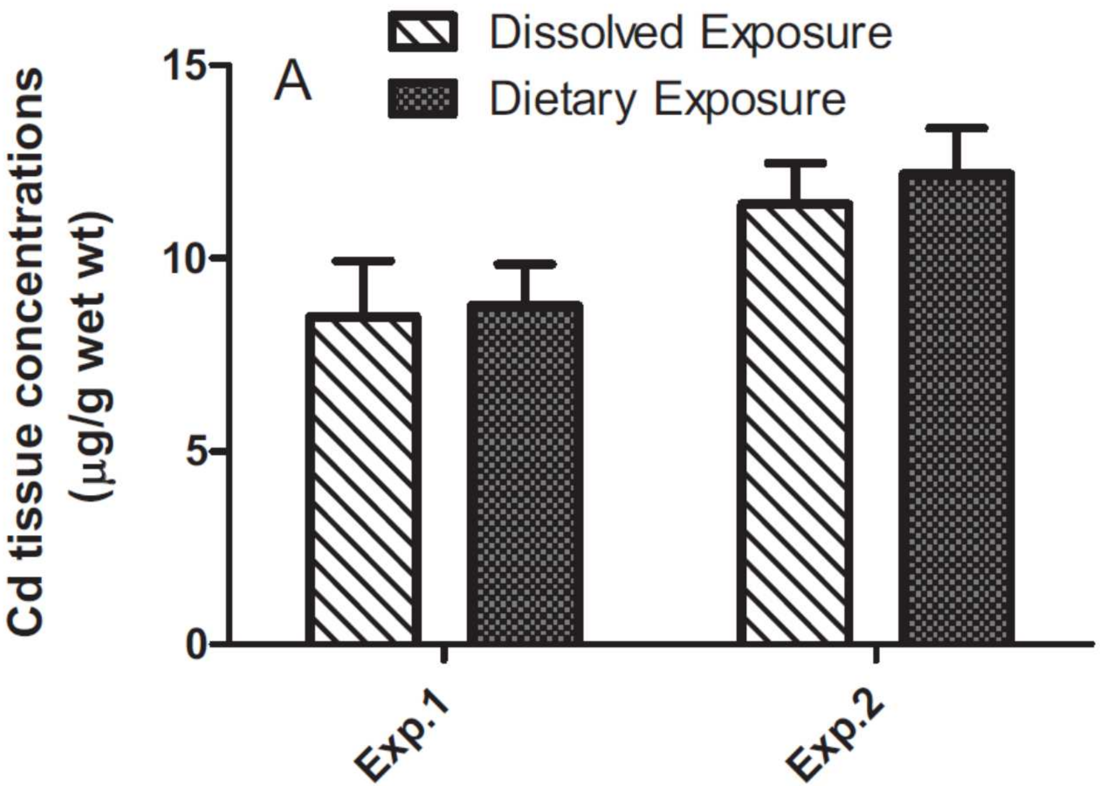
USGS (2009)

There is scientific consensus: Dietary metal exposures are extremely important in invertebrates

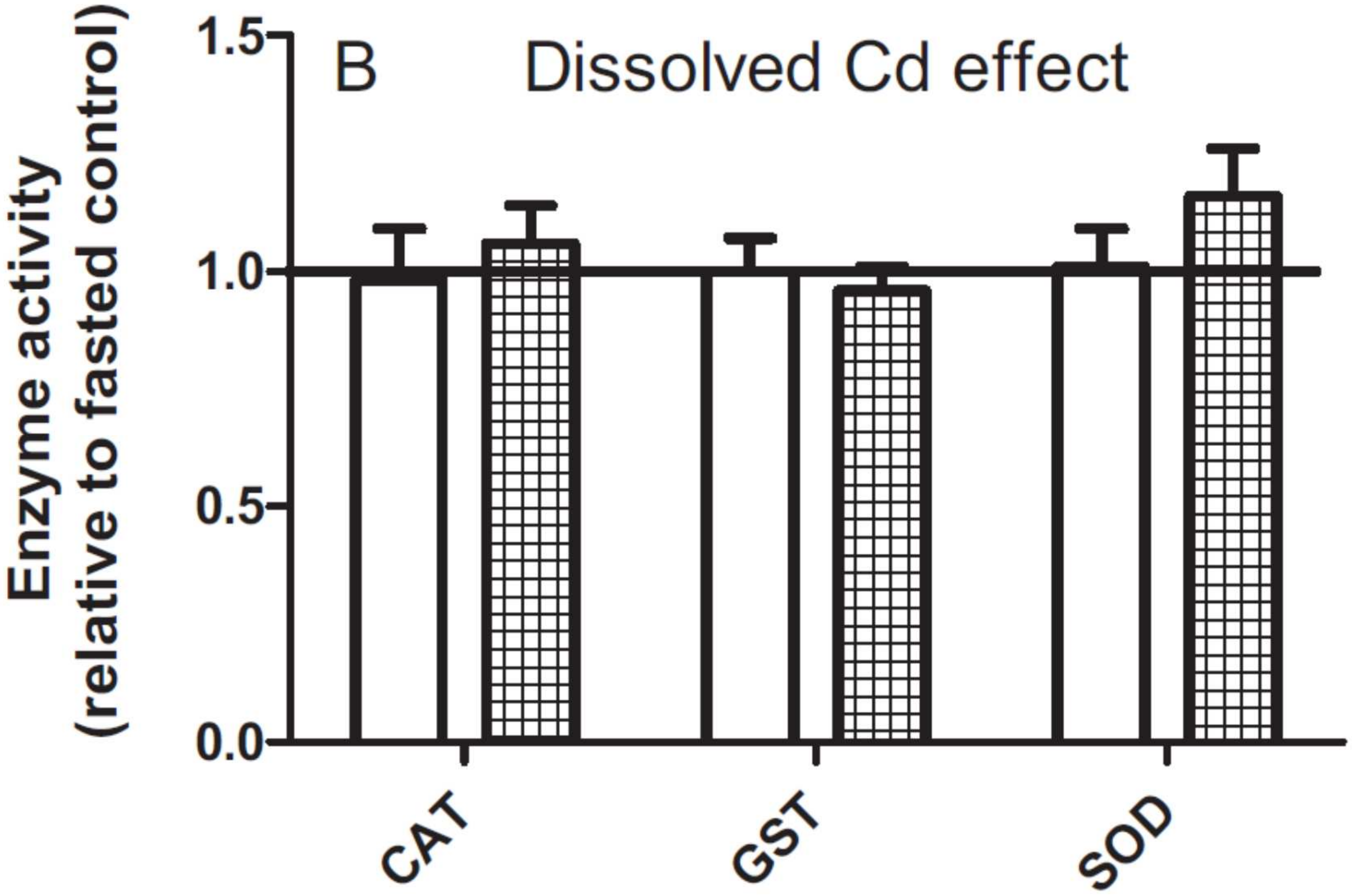
- Luoma
- Fisher
- Rainbow
- Wang
- Cain
- Croteau
- Hare

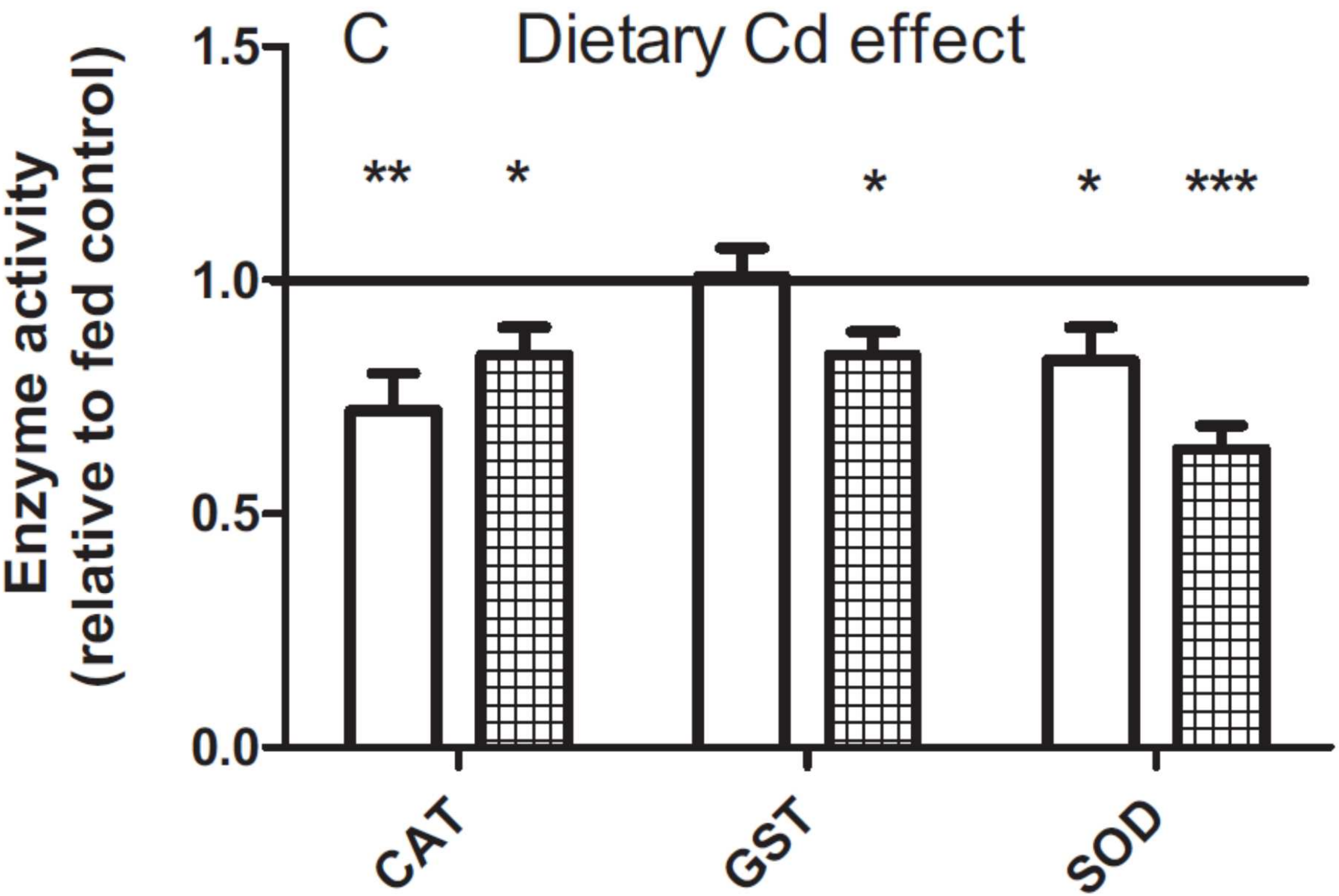
4. Reason: Dietary Exposures are Challenging

Neocloeon triangulifer



Aquatic Toxicology 105 (2011) 199–205


B
Dissolved Cd effect
Enzyme activity
(relative to fasted control)
1.5
1.0
0.5
0.0
CAT
GST
SOD



Aquatic Toxicology 105 (2011) 199–205

Why traditional toxicity tests fail:

– Test durations are insufficient
– Assumptions of mechanisms of dissolved exposures are not supported
– Dietary routes of exposure are ignored
– Dietary exposures may be <u>more</u> challenging than aqueous exposures to aquatic insects

Paths forward

Developing a laboratory model: *Neocloeon triangulifer*


-Parthenogenetic – relatively easy to culture
-Non-diapausing eggs – clonal offspring
-Highly fecund – (temperature and nutrition dependent)

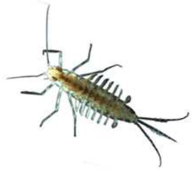
Genetic (gene sequence data and qPCR tools being developed

Neocloeon triangulifer use is expanding

Laboratory approaches

Full life cycle exposures

Ability to incorporate both dissolved and aqueous exposures



-Cadmium
-Zinc
-Selenium

Dietary transfer is very important

-Manganese – lost during molting

-Arsenic – apparently little trophic transfer from periphyton

Crustaceans are not always good surrogates for insects

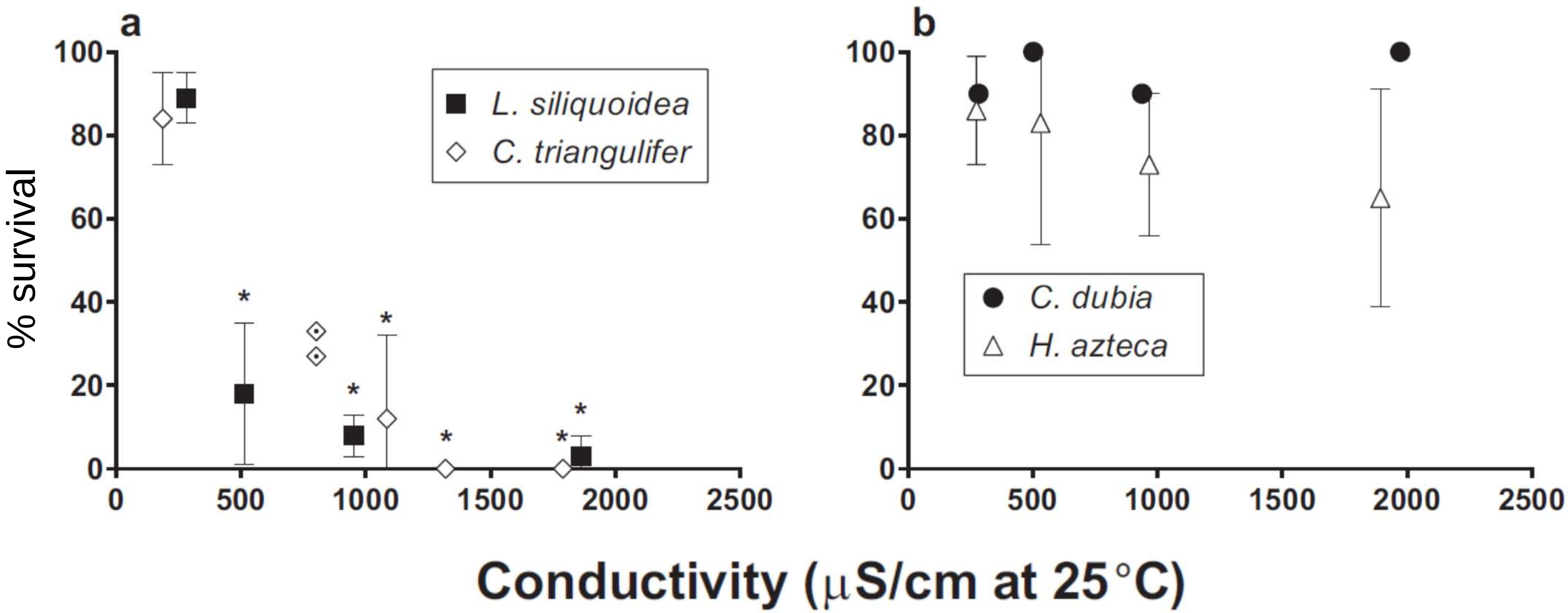
Insects are secondarily aquatic and have different biology/physiology than crustaceans and other aquatic forms with a more proximate marine origin

In some cases, insects may be more sensitive than the crustaceans thought to represent sensitive invertebrates

Example: Total Dissolved Solids

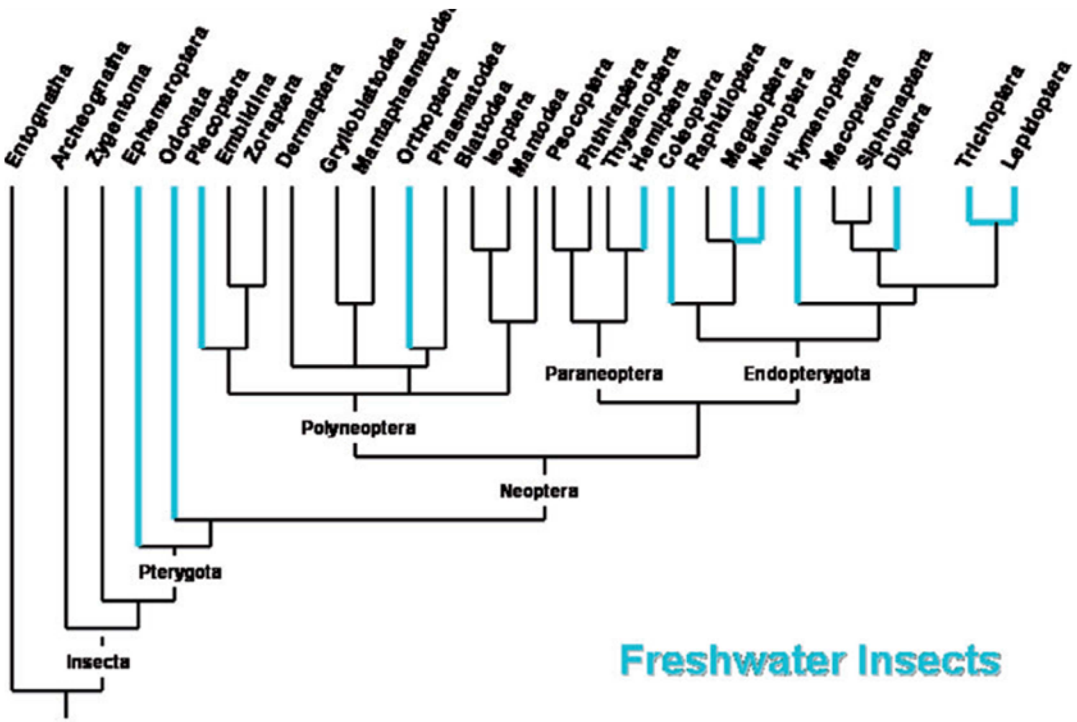
USE OF RECONSTITUTED WATERS TO EVALUATE EFFECTS OF ELEVATED MAJOR IONS ASSOCIATED WITH MOUNTAINTOP COAL MINING ON FRESHWATER INVERTEBRATES

JAMES L. KUNZ,*† JUSTIN M. CONLEY,‡ DAVID B. BUCHWALTER,‡ TERESA J. NORBERG-KING,§ NILE E. KEMBLE,†
NING WANG,† and CHRISTOPHER G. INGERSOLL†



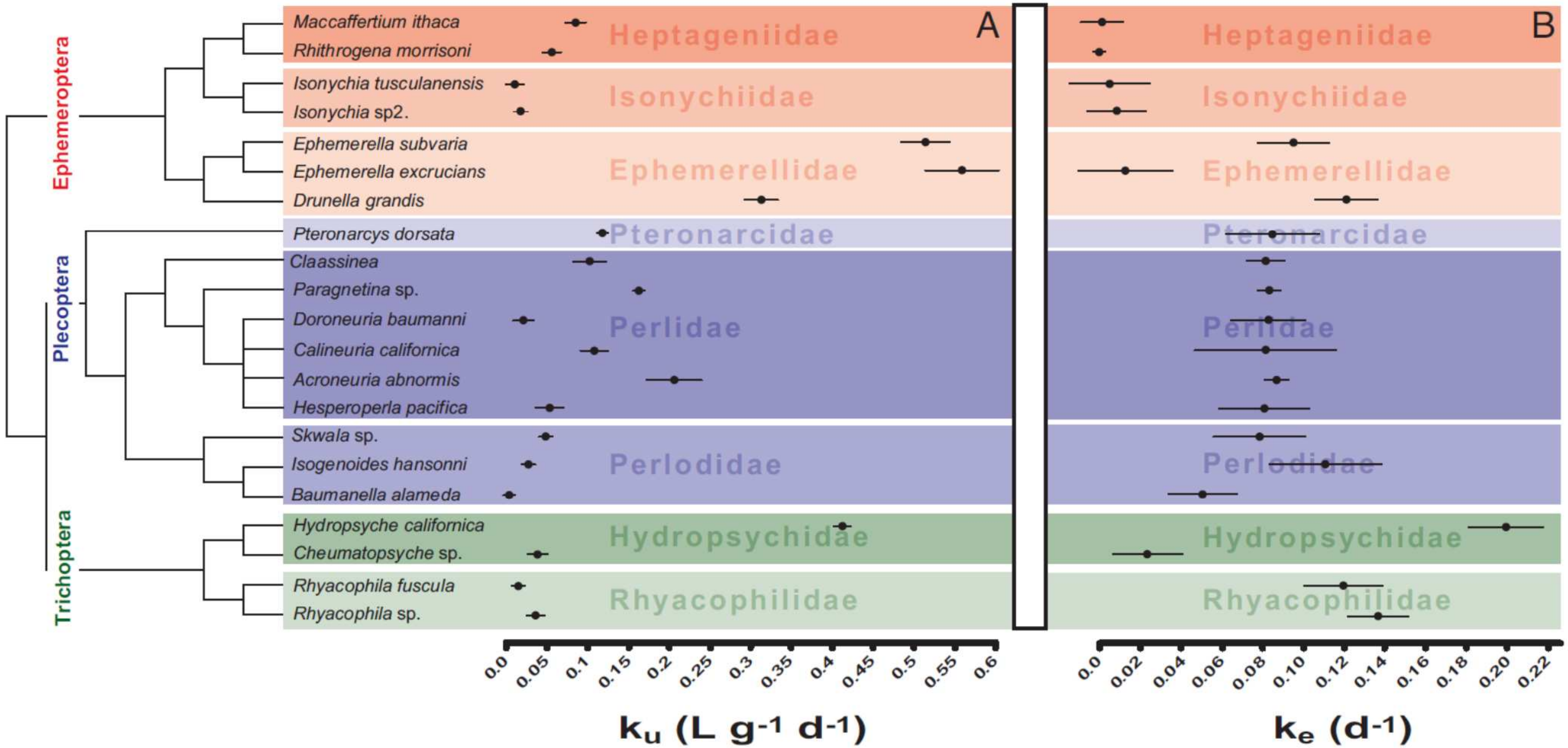
Phylogenetic signal and extrapolation

Terrestrial ancestry vs marine ancestry



- Species groups have solved the problems of successful transitions from land to water differently
- Species groups have been aquatic for different lengths of time (~375M – mayflies)
- Rates of evolution and speciation vary among species groups
- Massive differences in the physiology of organisms living in the same place (a rock, riffle, stream reach….)

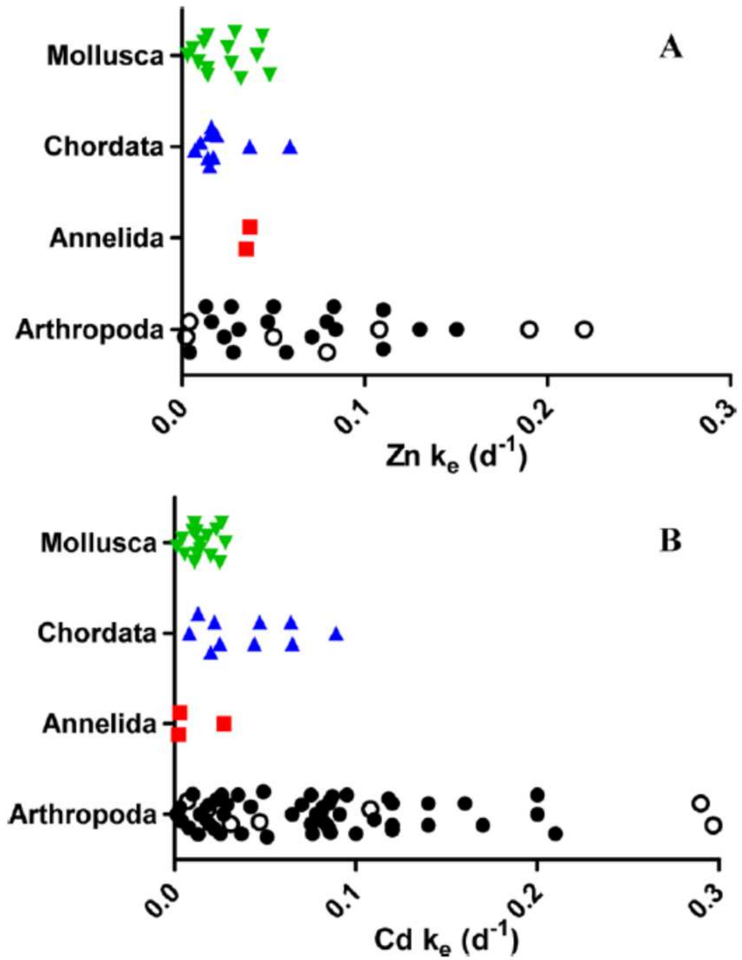
Phylogenetic signal exists in bioaccumulation data



Aquatic insect ecophysiological traits reveal phylogenetically based differences in dissolved cadmium susceptibility

David B. Buchwalter*[†], Daniel J. Cain[‡], Caitrin A. Martin*, Lingtian Xie*, Samuel N. Luoma[‡], and Theodore Garland, Jr.[§]

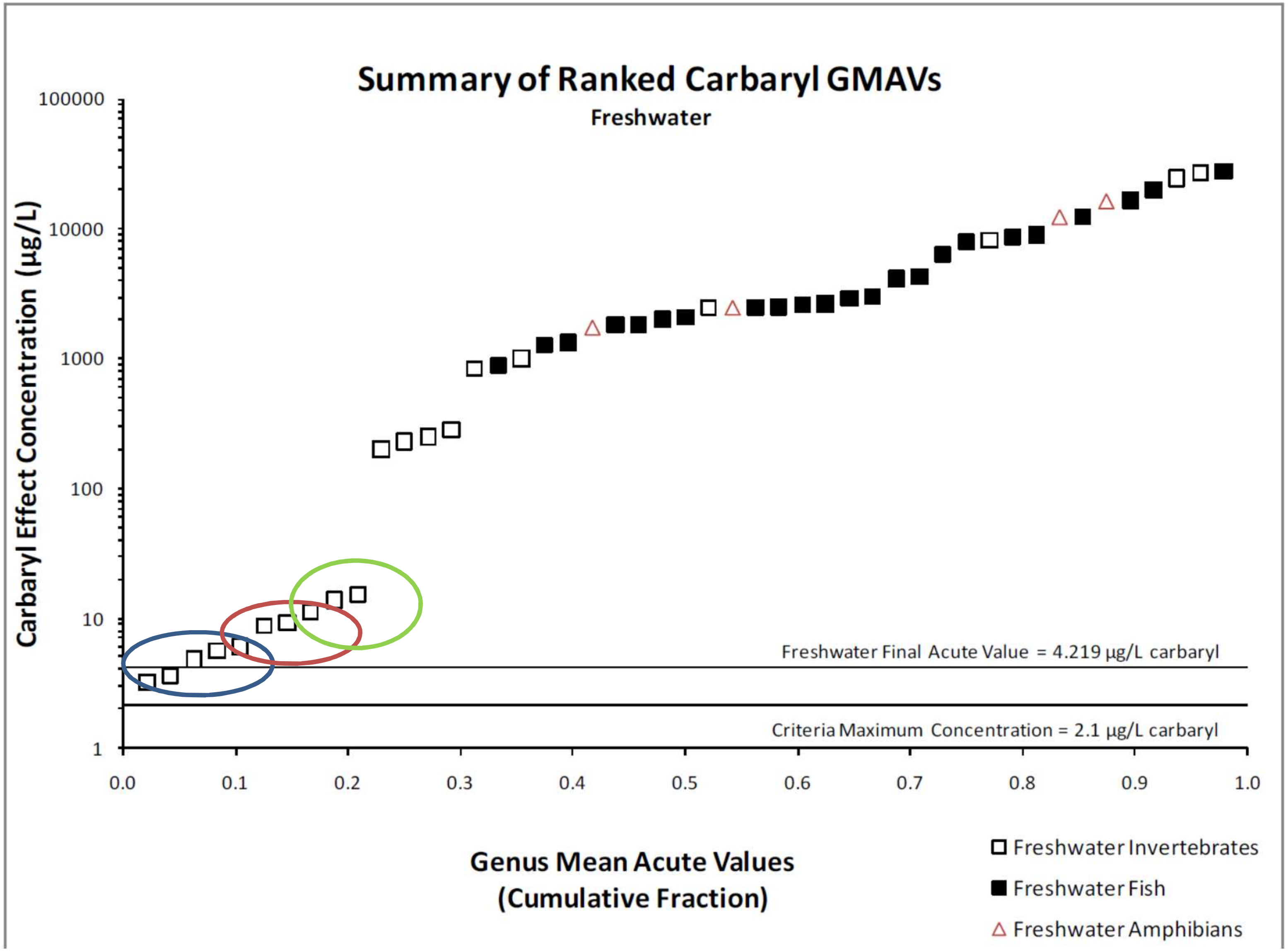
Phylogenetic signal exists in bioaccumulation data



Evolutionary Patterns in Trace Metal (Cd and Zn) Efflux Capacity in Aquatic Organisms

Monica D. Poteat,[†] Theodore Garland, Jr.,[‡] Nicholas S. Fisher,[§] Wen-Xiong Wang,[||] and David B. Buchwalter[*,†]

Phylogenetic signal exists in tox data



Can phylogenetics be used to predict or extrapolate toxicity?

Can extrapolations create SSDs that reflect the biodiversity of freshwater ecosystems?


Thank you!

North American Freshwater Biodiversity

- Fish: ~1,200
- Invertebrates: ~10,000 – 15,000
  - Crustacea: ~1384
    - Mysidacea: 4
    - Amphipoda: 150
    - Copepoda: 230
    - Decapoda: 350
    - Isopoda: 130
    - Ostracoda: 300
    - Cladocera: 150
    - Others: ~70

North American freshwater invertebrates

from Thorp and Covich 1991

Taxon	Common Name	No. of Known Species
Turbellaria	Flatworms	>200
Gastropoda	Snails	~350
Bivalvia	Mussels and clams	>250
Oligochaeta	Worms	~150
Hirudinea	Leeches	~80
Acari	Water mites	>1500
Insecta		
Ephemeroptera	Mayflies	~575
Odonata	Dragonflies and damselflies	~415
Plecoptera	Stoneflies	~550
Heteroptera	True bugs	324
Coleoptera	Beetles	>1100
Trichoptera	Caddisflies	>1340
Diptera	True flies	>2000[a]
	Total	~8834

[a]Estimate is for the Nearctic region (Coffman and Ferrington 1996).