The Application of Long-term Monitoring Approaches to Evaluate Restoration Effectiveness

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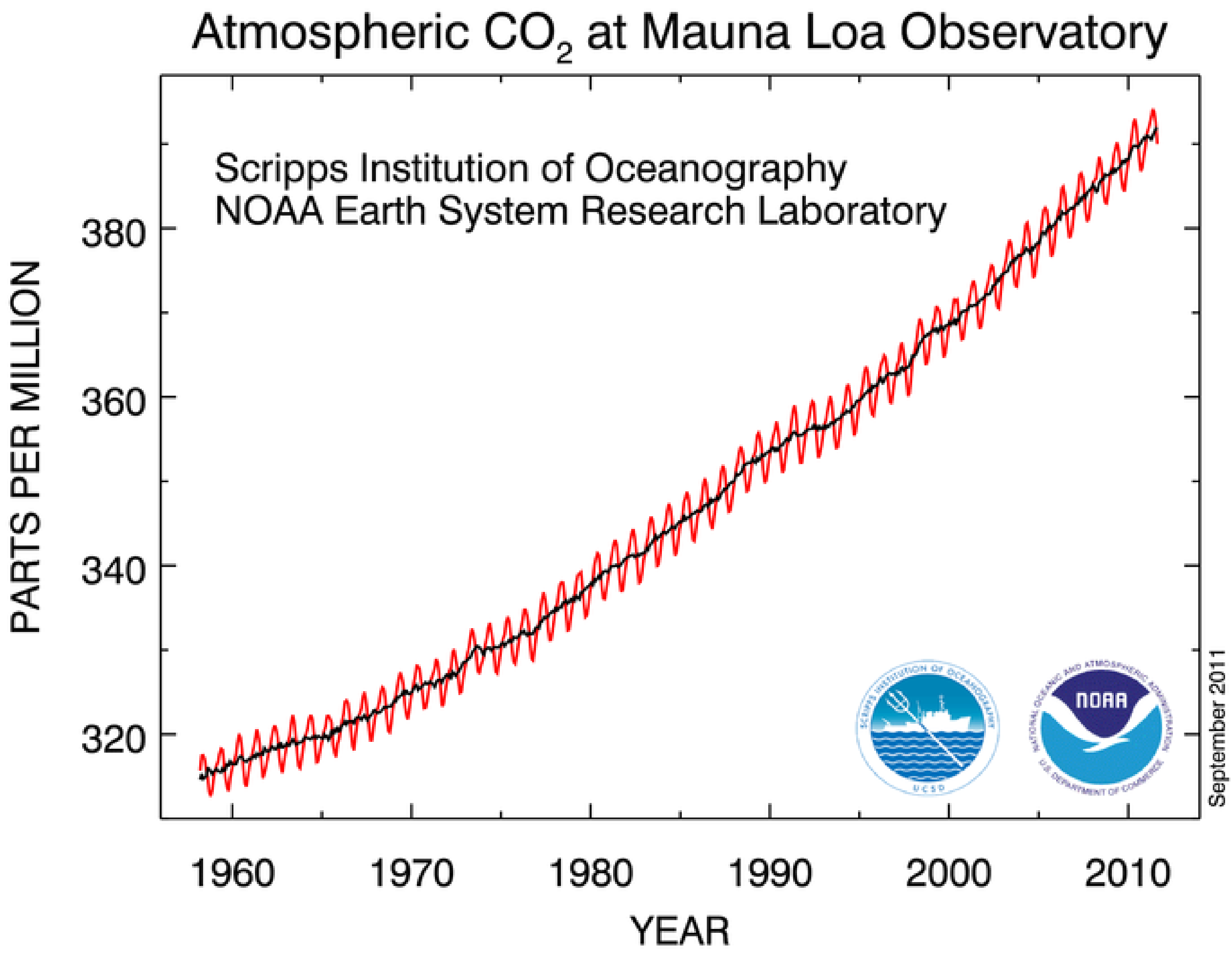
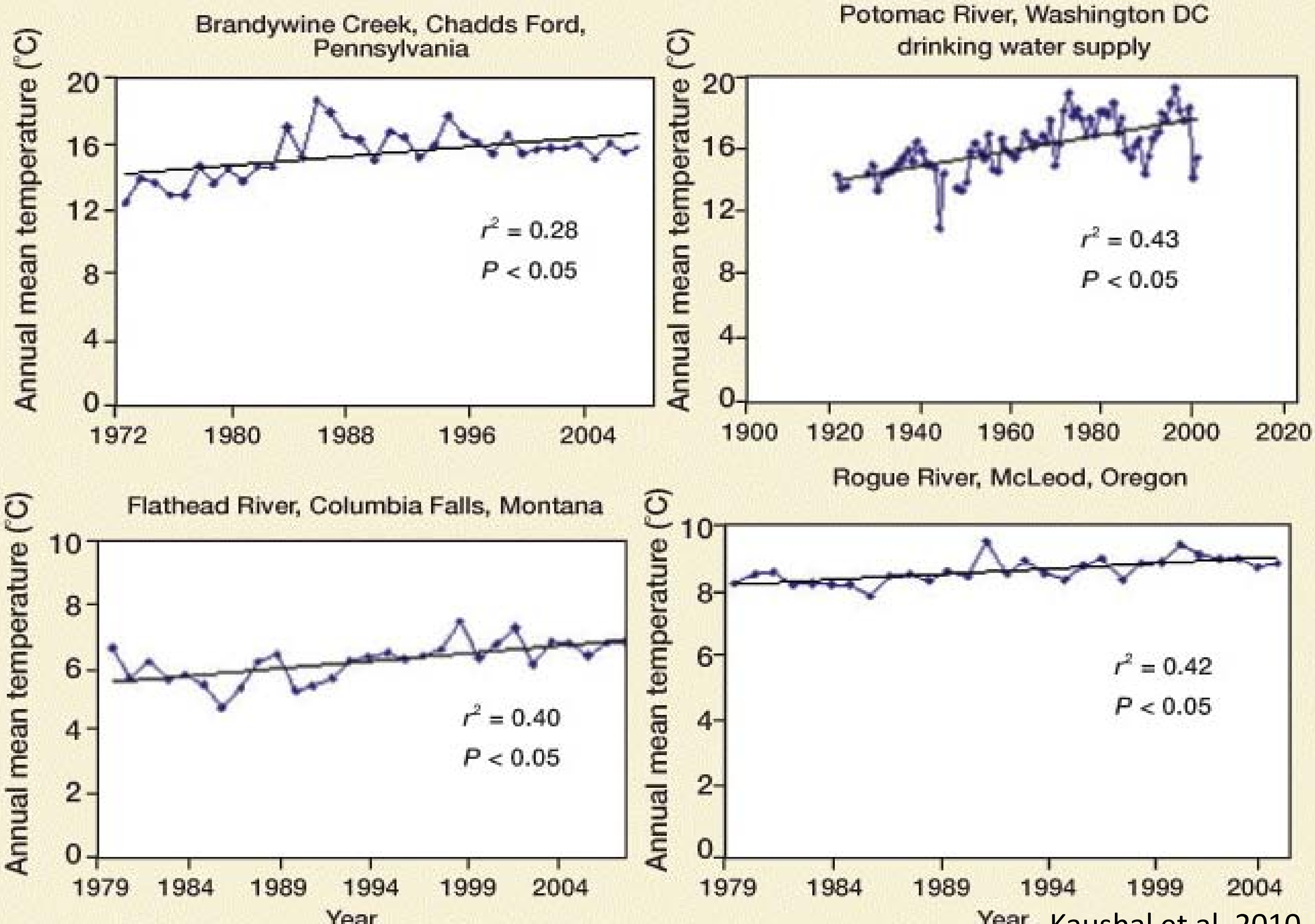
Overview

- What we can learn from long-term monitoring
- Results of the Arkansas River NRDA
- Limitations and the need for integrated descriptive and experimental approaches
- Evaluating long-term recovery in the context of climate change


Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
320
340
360
380
1960
1970
1980
1990
2000
2010
YEAR
September 2011

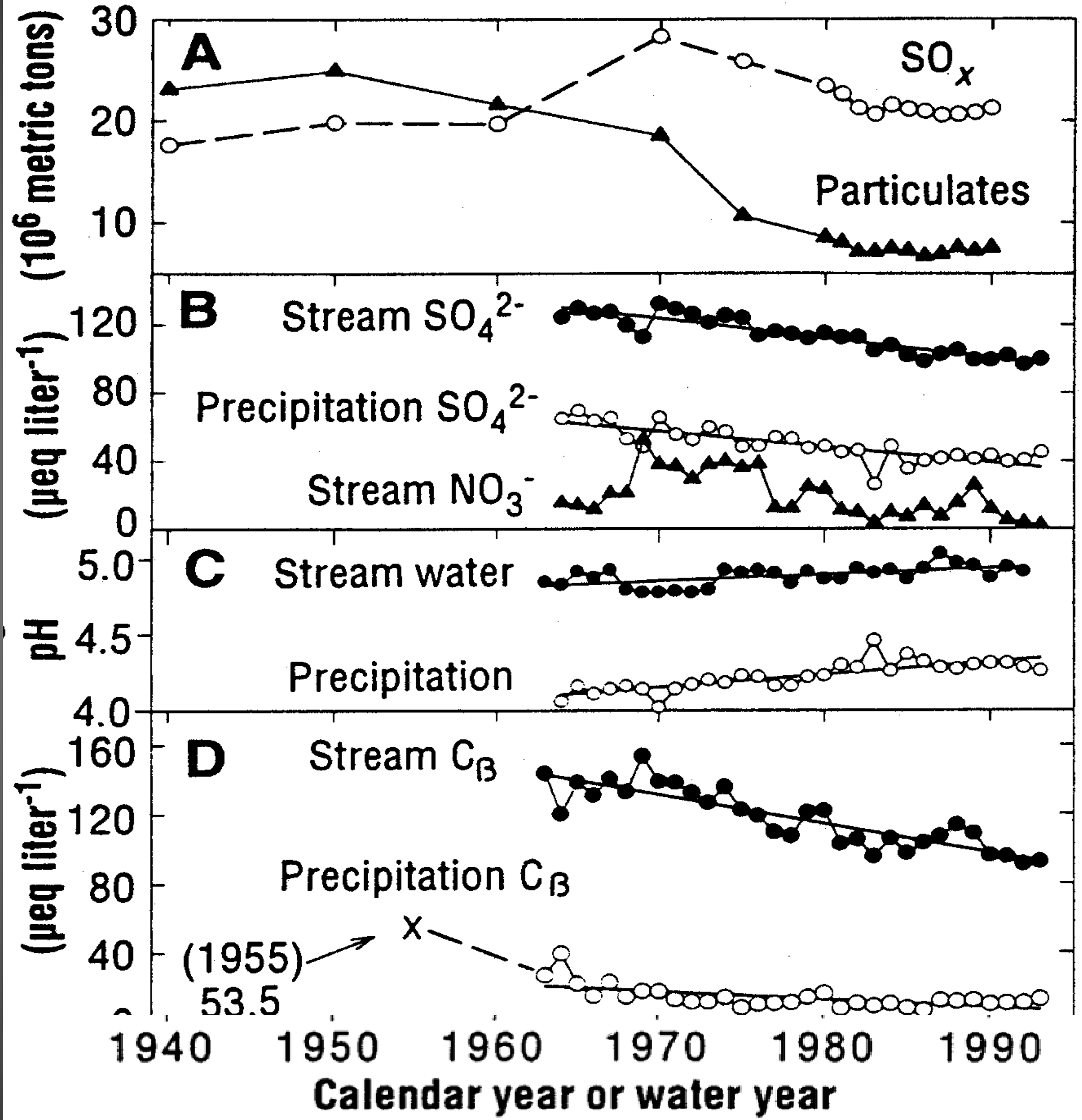


Kaushal et al. 2010

NSF Long-Term Ecological Research (LTER) Program

Hubbard Brook Experimental Forest

(Likens et al. 1996)



- Average duration of "long-term" biological monitoring in aquatic ecosystems is 9 y (Jackson & Füreder 2006)

  → insufficient to evaluate restoration effectiveness or recovery

- Meta-Analysis: Failure to observe recovery attributed to short duration of monitoring (Jones & Schmitz, Plos, 2009)

Criticism of U.S. stream restoration efforts:
→ insufficient post-restoration monitoring

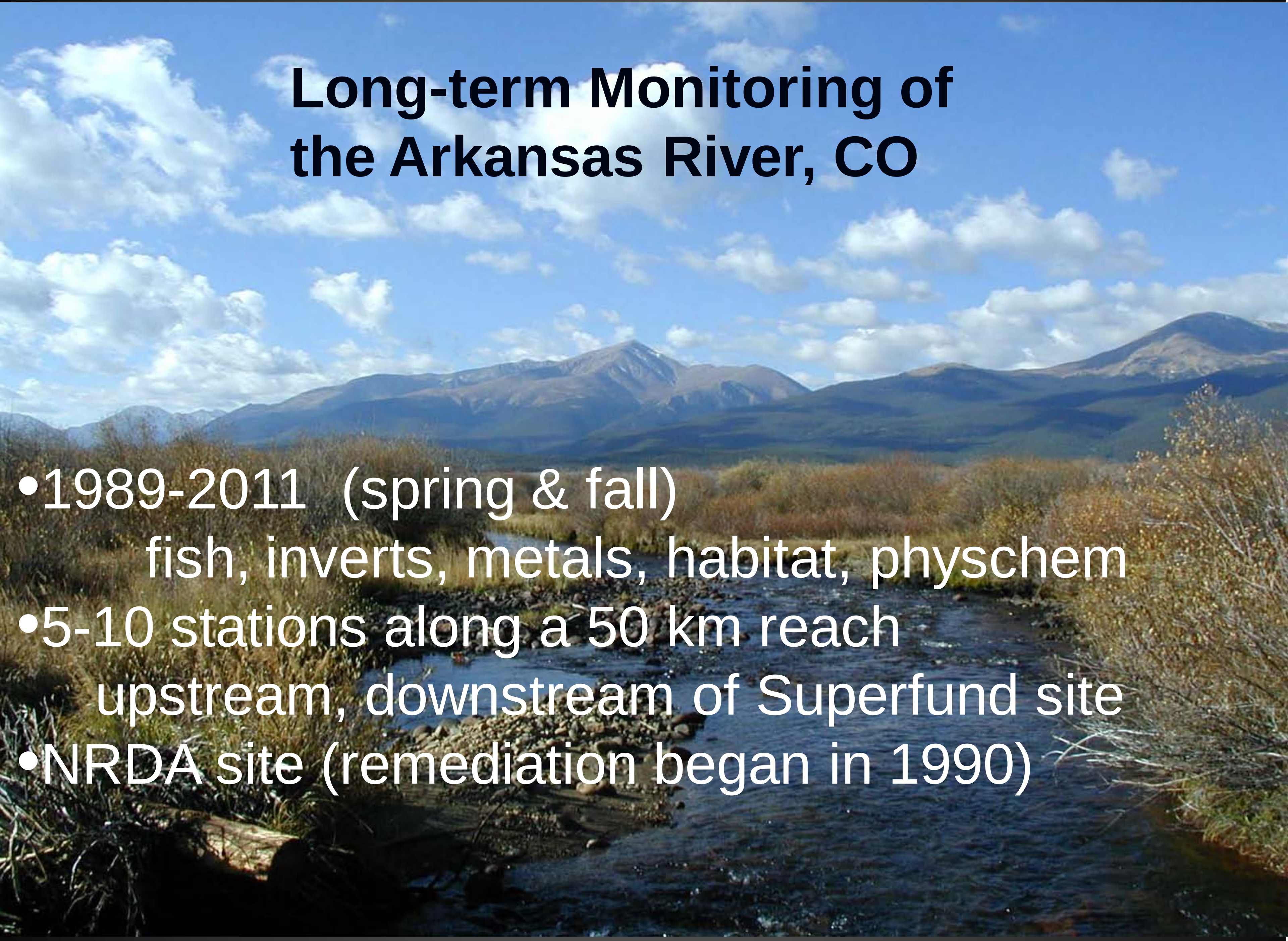
"Comprehensive assessment of restoration progress for the U.S., or even individual regions, is not possible with the *piecemeal* information currently available"

Bernhardt 2005

Sediment Dredging at Superfund Megasites NRC, 2008

"It was often not possible to evaluate long-term remedy performance relative to remedial action objectives because of insufficient post-remediation data…."

Black Lagoon, Detroit River



Long-term Monitoring of the Arkansas River, CO

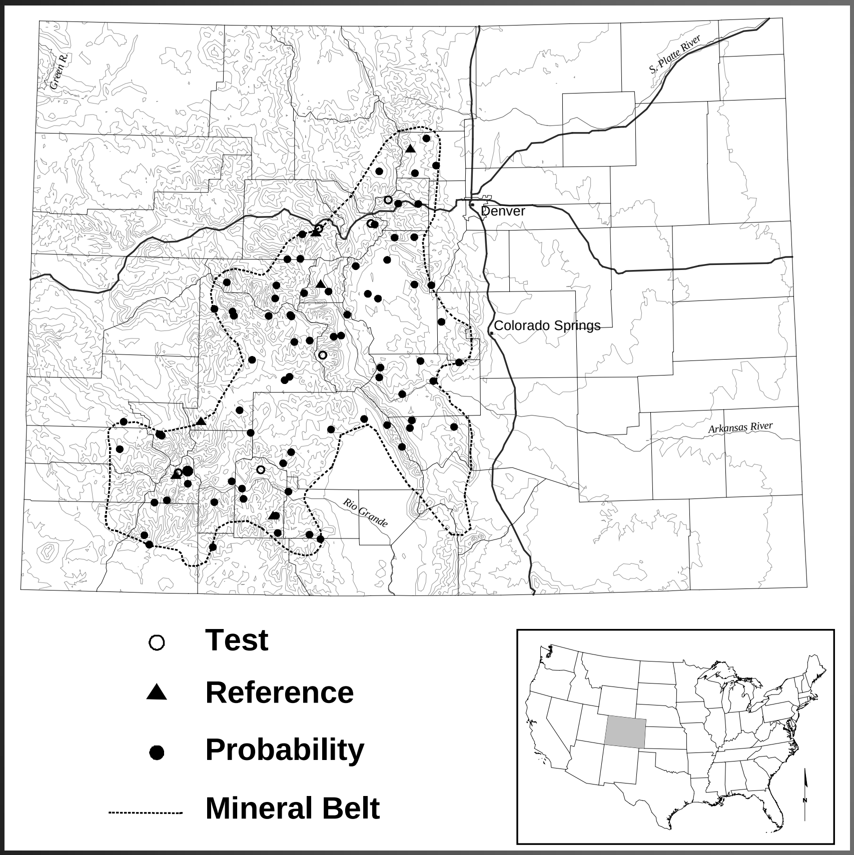
- 1989-2011 (spring & fall)
  fish, inverts, metals, habitat, physchem
- 5-10 stations along a 50 km reach
  upstream, downstream of Superfund site
- NRDA site (remediation began in 1990)

Unique Features of the Dataset

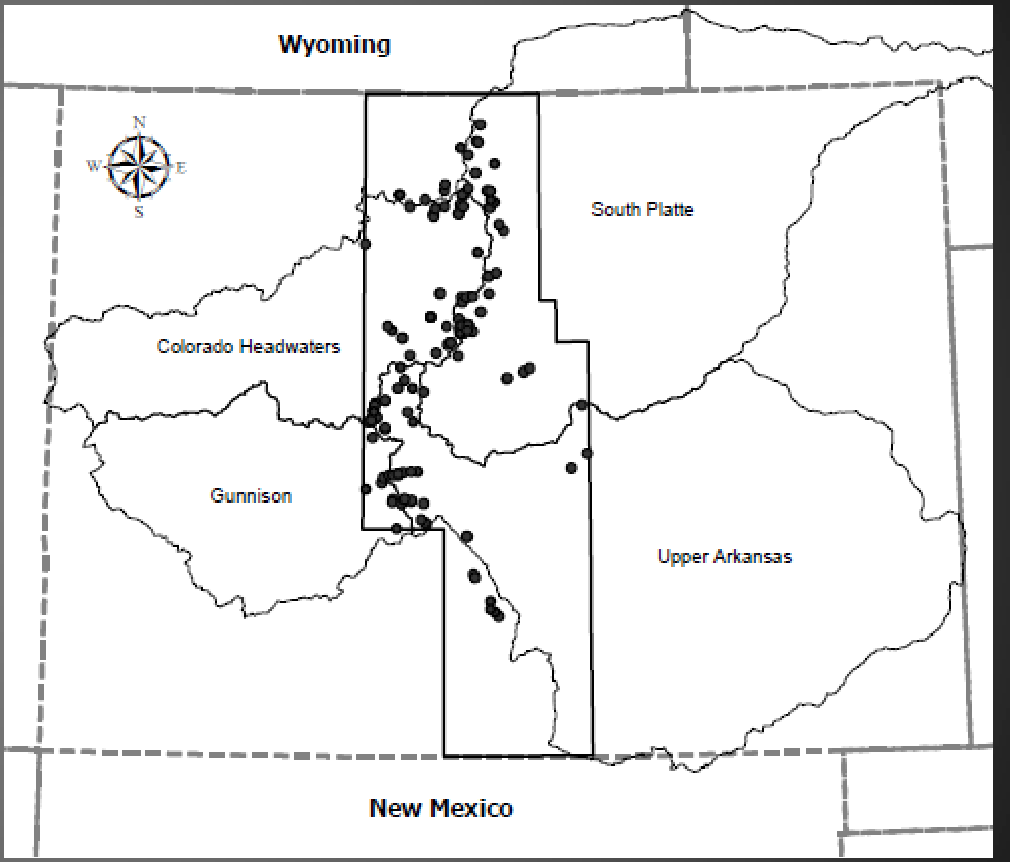
- 22 year record of chemical, physical, biological data
- All data collected by same investigator
  →consistent methods
- Response to restoration treatments
- Influence of long-term climatic changes

2 Spatially extensive field surveys in Colorado

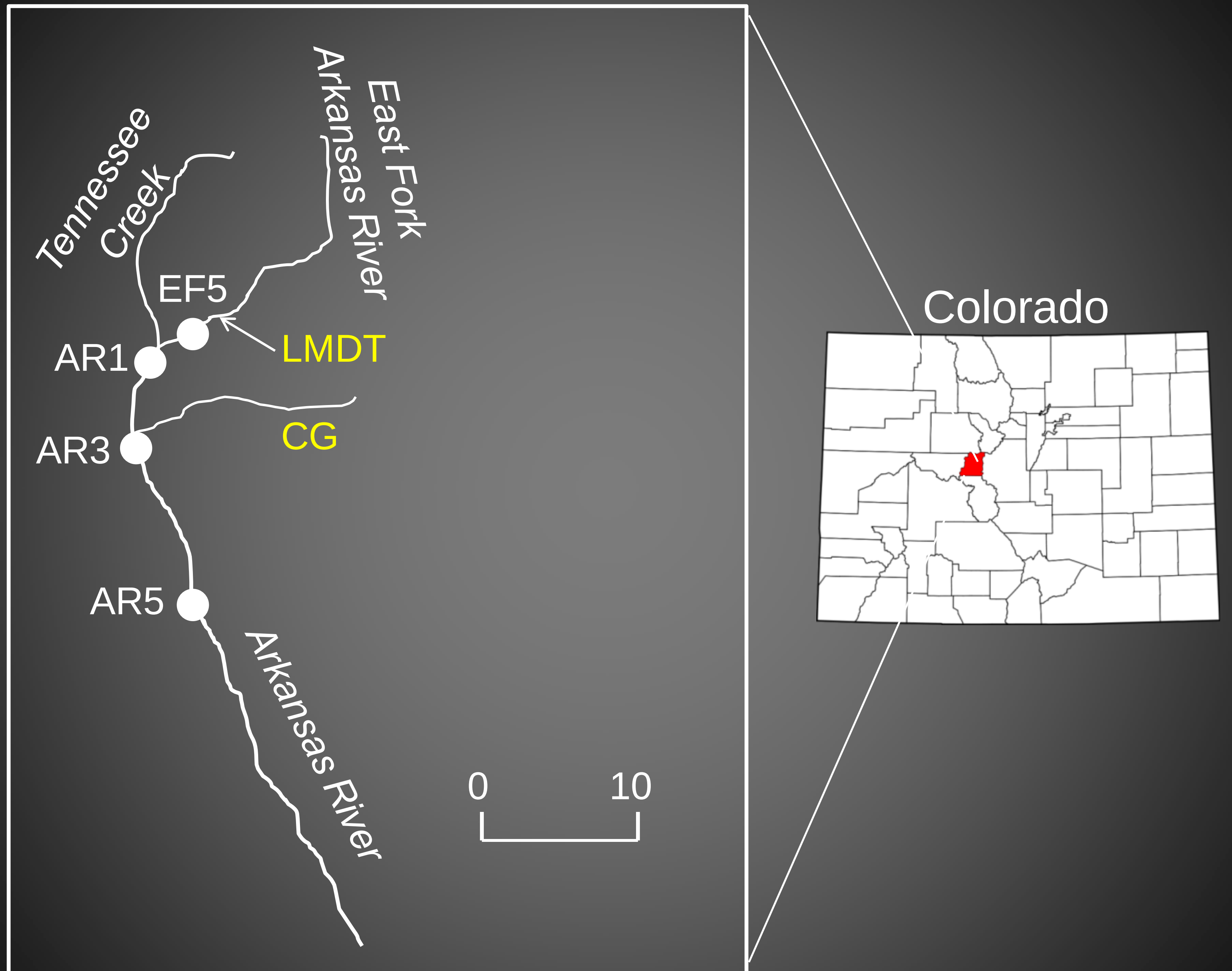
EPA EMAP (n = 95)



USGS & CSU (n = 154)



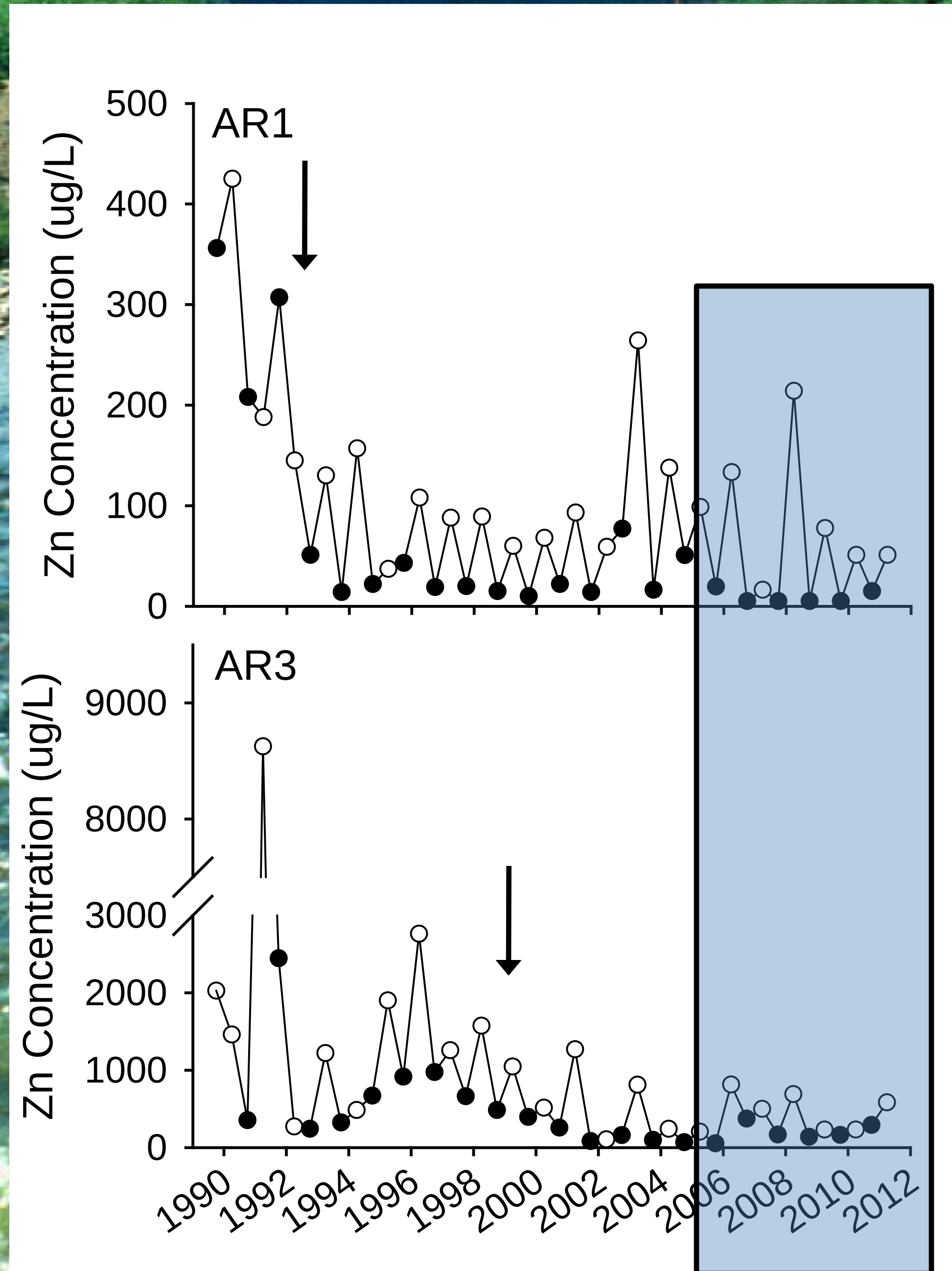
Interpret results within the context of ~250 other streams in Colorado

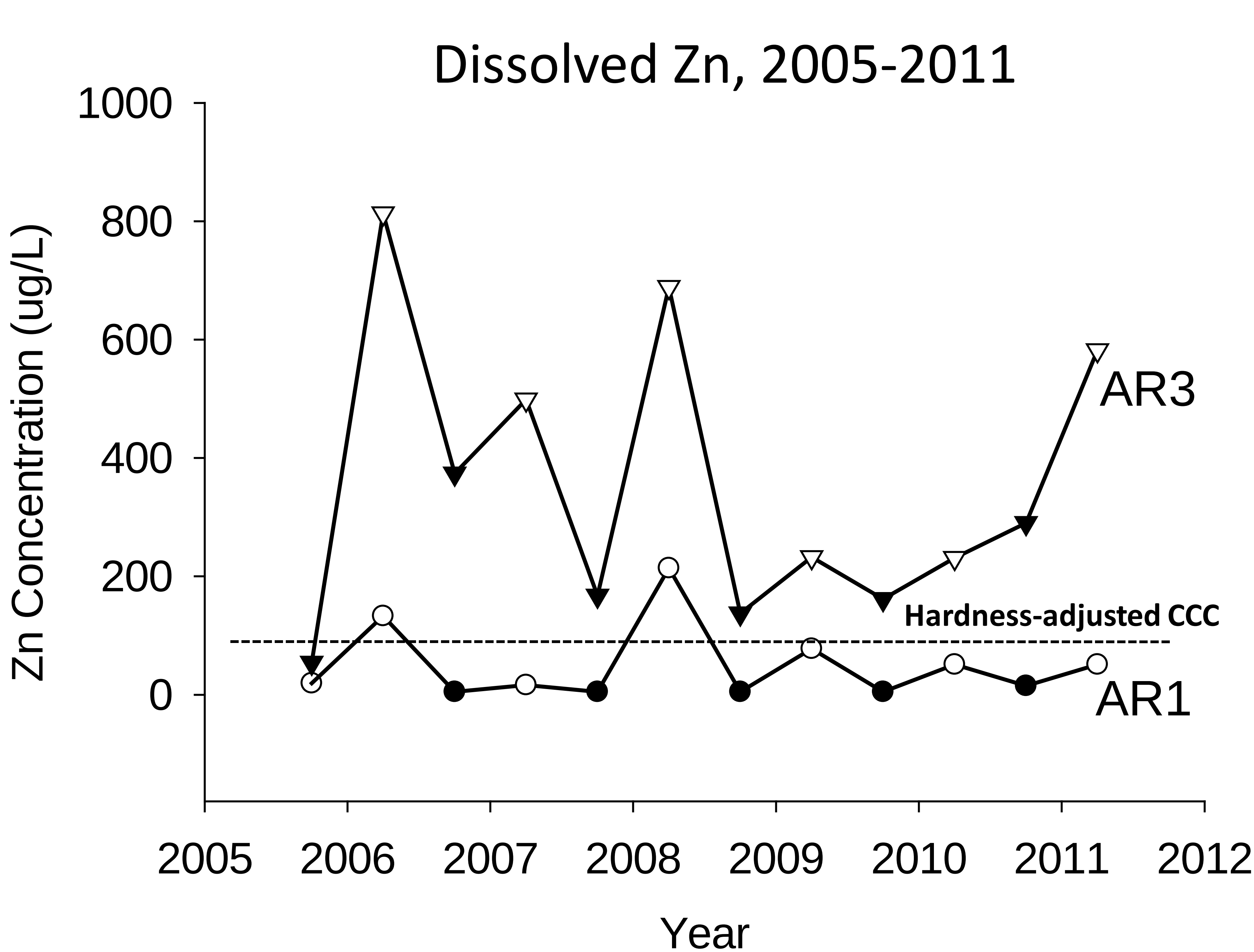


Tennessee Creek
East Fork Arkansas River
EF5
AR1
LMDT
AR3
CG
AR5
Arkansas River
0
10
Colorado

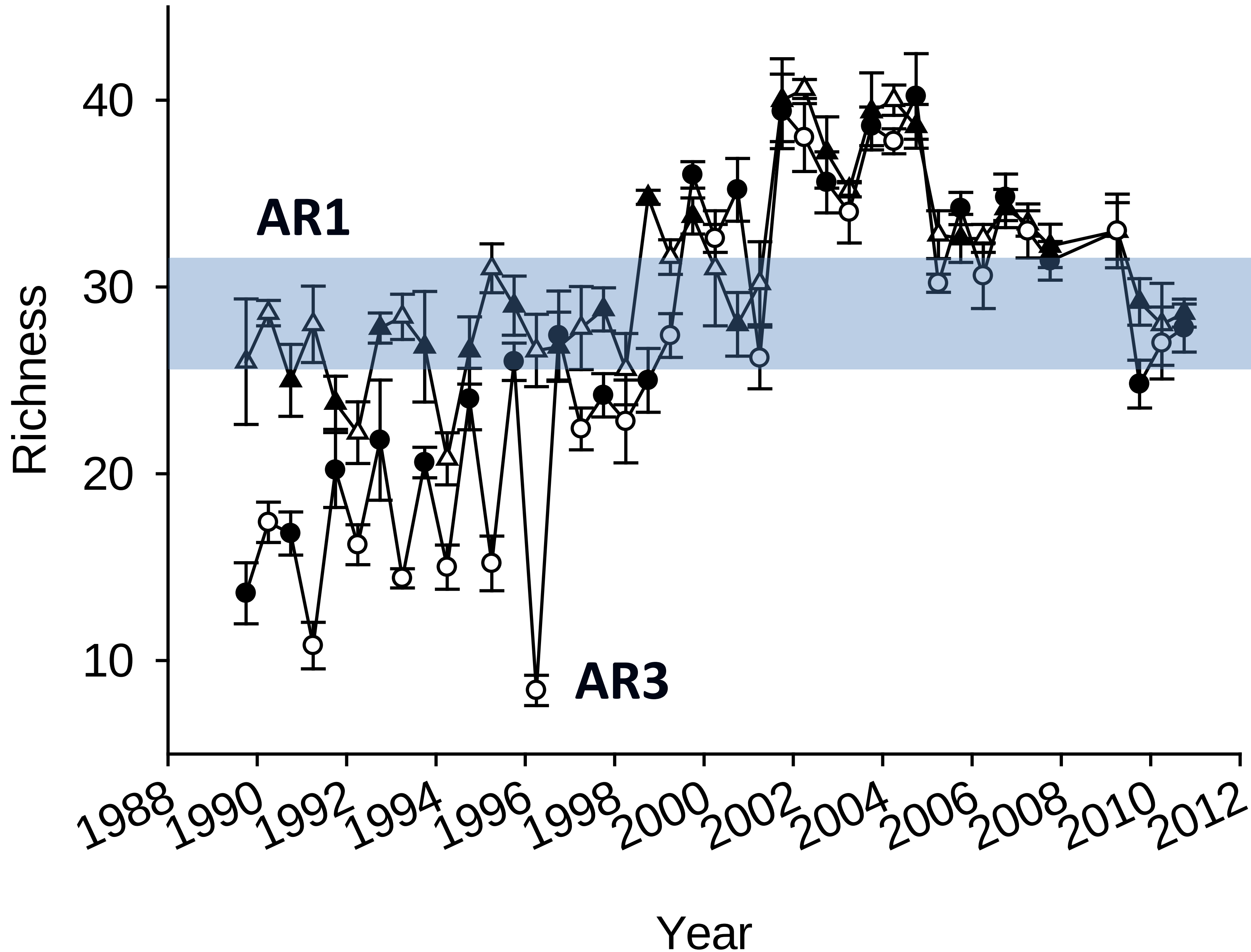
Restoration area	Remediation Treatments	Date
Starr Ditch, Stray Horse & Evans Gulch	Removed 150,000 m^3 mine waste; revegetate	1990
Leadville Mine & Yak Drainage Tunnels	Captured & treated metal-contaminated water	1990-1992
Lower California Gulch	Removed fluvial tailings; revegetate	1995-1997
Fluvial tailings & floodplain	Stabilized river channel; remove and/or amend contaminated soil; revegetate	1993-1999
Habitat restoration	Improve habitat structure; add woody debris; revegetate	2011-2016

Arkansas River (AR3), summer 1996

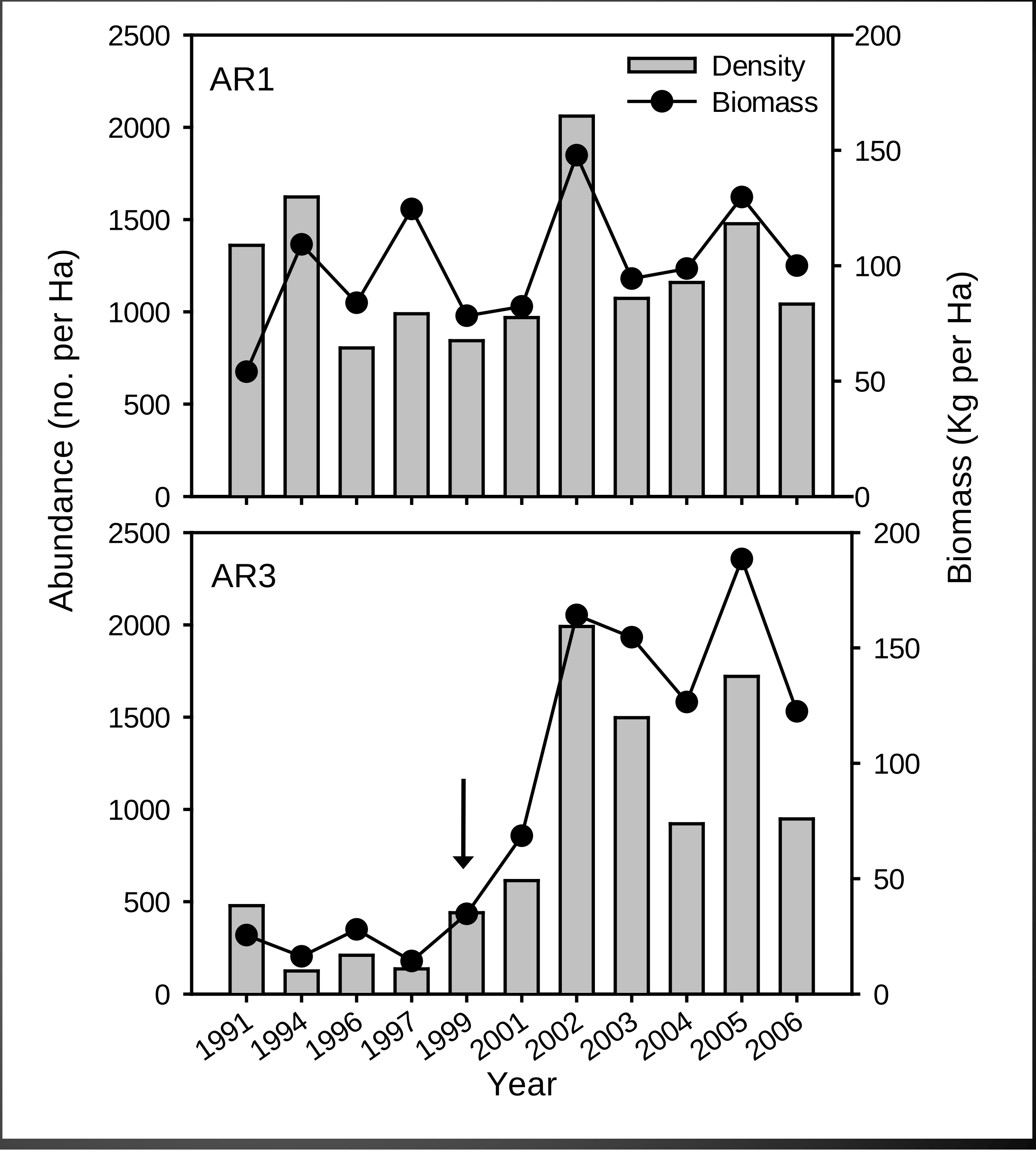


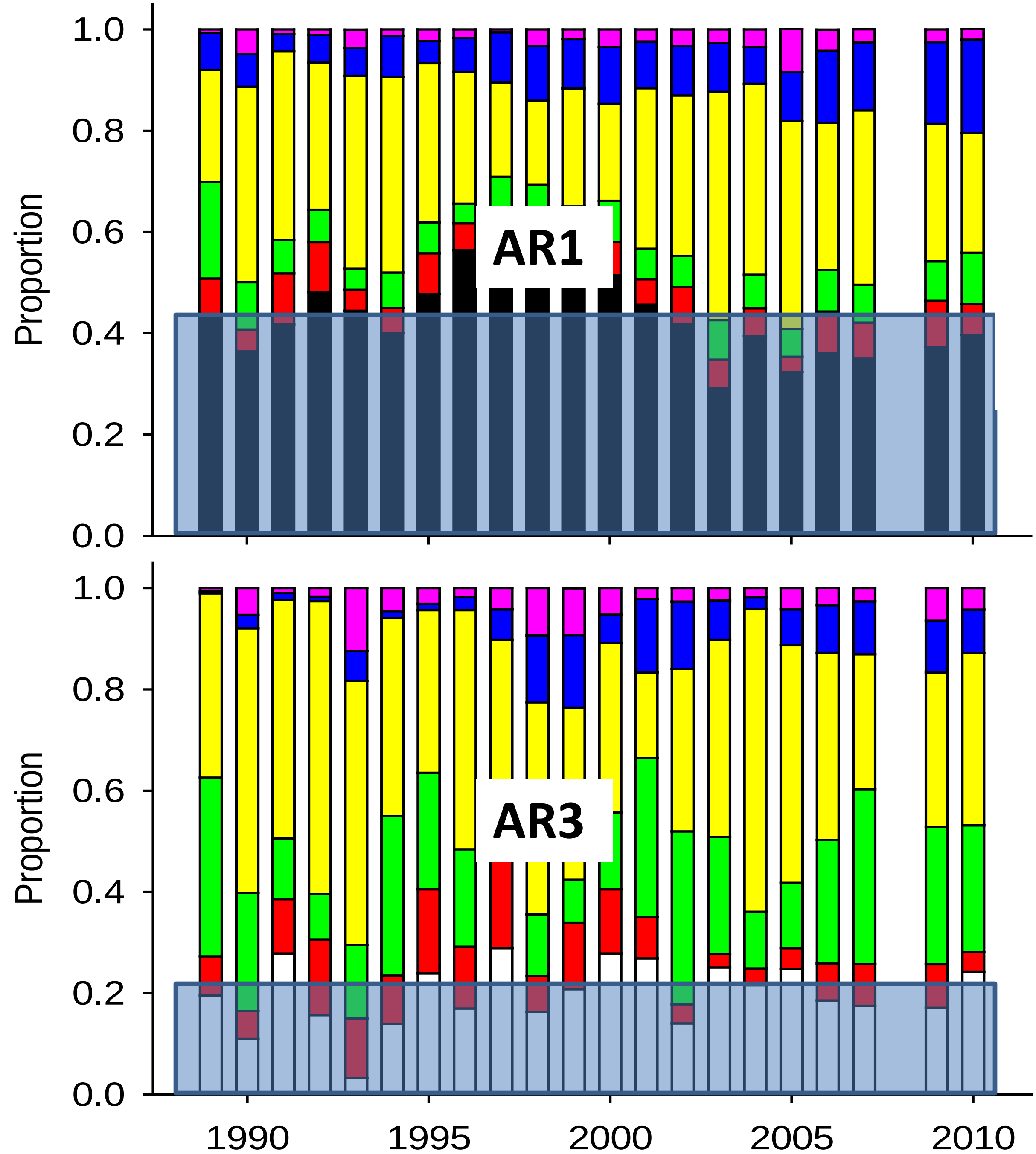

Dissolved Zn, 2005-2011
1000
800
600
400
200
0
Zn Concentration (ug/L)
AR3
Hardness-adjusted CCC
AR1
2005
2006
2007
2008
2009
2010
2011
2012
Year

Macroinvertebrate Species Richness



Brown Trout Biomass & Density





Large surface area of gills for gas exchange

- High permeability
- Metal accumulation

Summary of Long-Term Data

- Metal concentrations declined significantly due to restoration treatments
  → elevated during spring runoff

- Macroinvertebrate richness and brown trout biomass/density similar among sites

- Community composition is very different
  → low abundance of metal-sensitive taxa

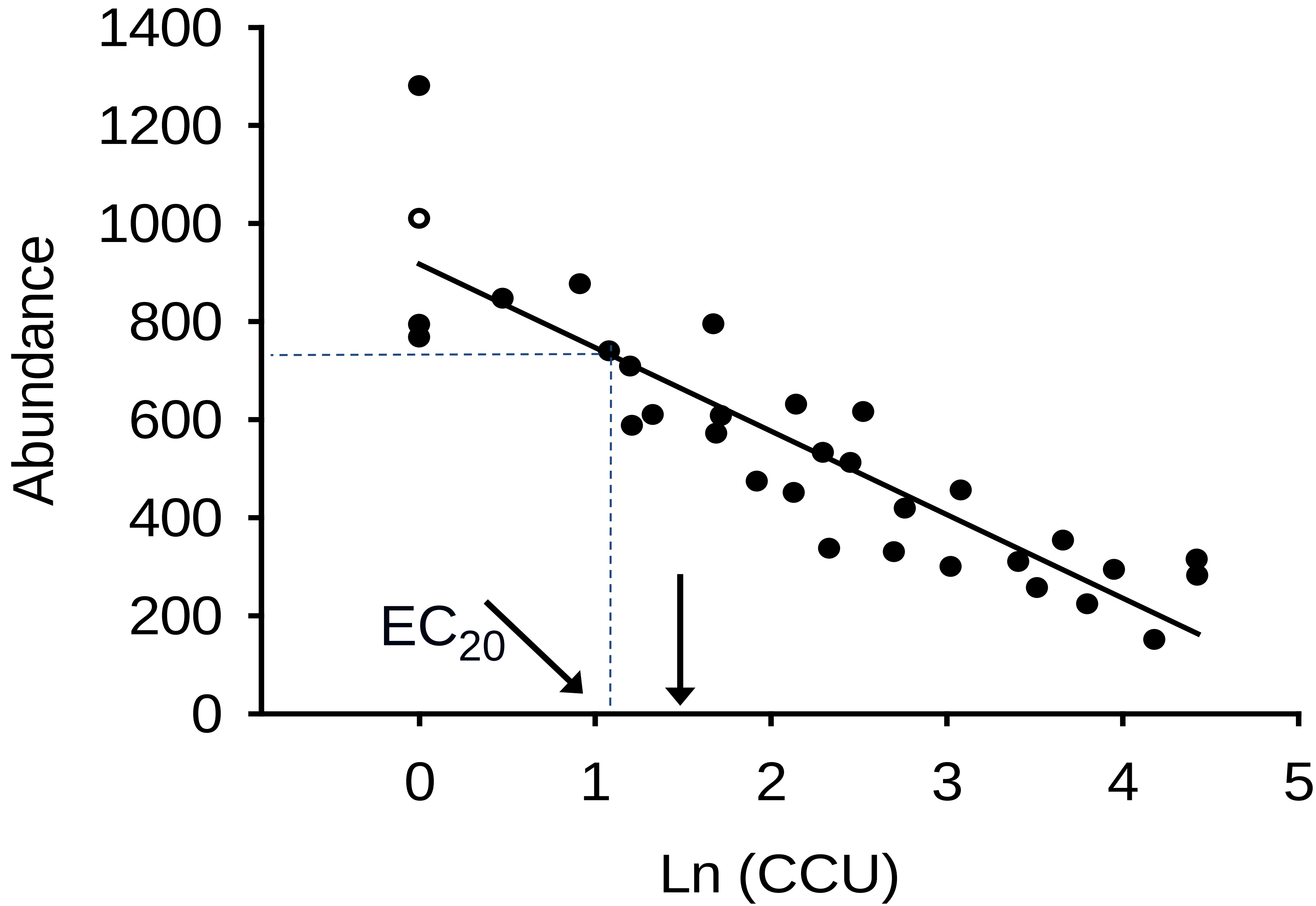
Specific questions:

- Are metals responsible for observed differences in community composition?
- What is a safe concentration of metals to protect aquatic communities?
- Are metal-tolerant communities more susceptible to other stressors?
- How will recover be influenced by climate change?

Stream Microcosms Experiments

Date	Metals	Reference
Oct 1991	Zn	Kiffney & Clements 1994
Jul 1992	Cd, Cu, Zn	Kiffney & Clements 1994
Sep 1992	Cd, Cu, Zn	Kiffney & Clements 1996
Nov 1993	Zn	Kiffney & Clements 1996
Aug 1996	Zn	Clements 2004
Aug 1997	Cd, Cu, Zn	Courtney & Clements 2000
Sep 1997	Cd, Cu, Zn	Clements 1999
Oct 1998	Cd, Zn	Clements 2004
Oct 1999	Cd, Cu, Zn	Clements, unpublished
Nov 1999	Cd, Cu, Zn	Clements 2004
Aug & Oct 2000	Cd, Cu, Zn	Clements, unpublished
Jul 2002 & May 2003	Cd, Cu, Zn	Clark & Clements, 2006
Sep 2003	Zn	Kashian & Clements, 2004
Aug 2003	Cd, Cu, Zn	Kashian & Clements, 2007
September, 2007	Cu	Cadmus & Clements, unpubl.
October, 2007	Cu, Zn	Cadmus & Clements, unpubl.
October, 2010 & Aug 2011	Fe	Cadmus & Clements, unpubl.

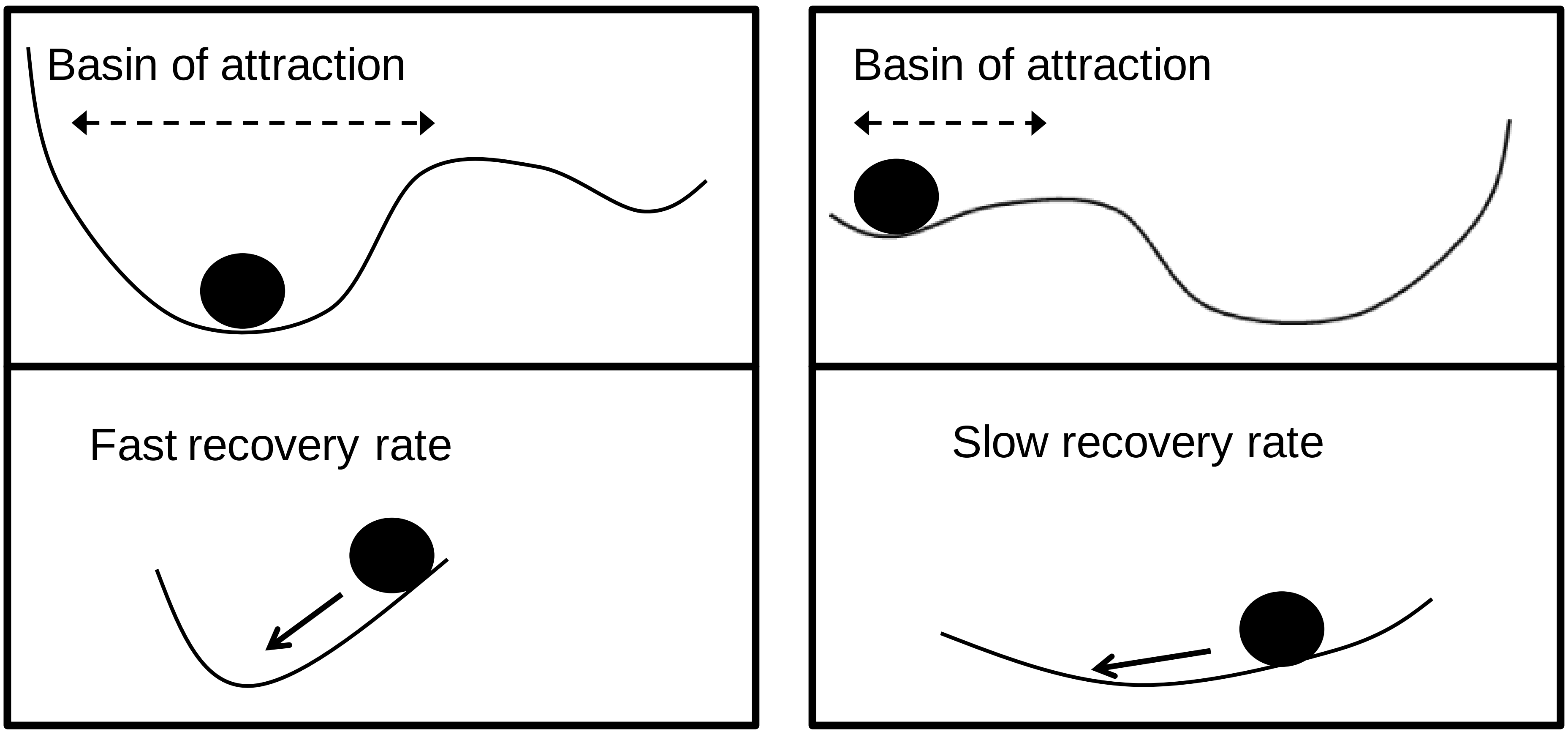
What is a safe concentration of metals that will protect benthic communities?



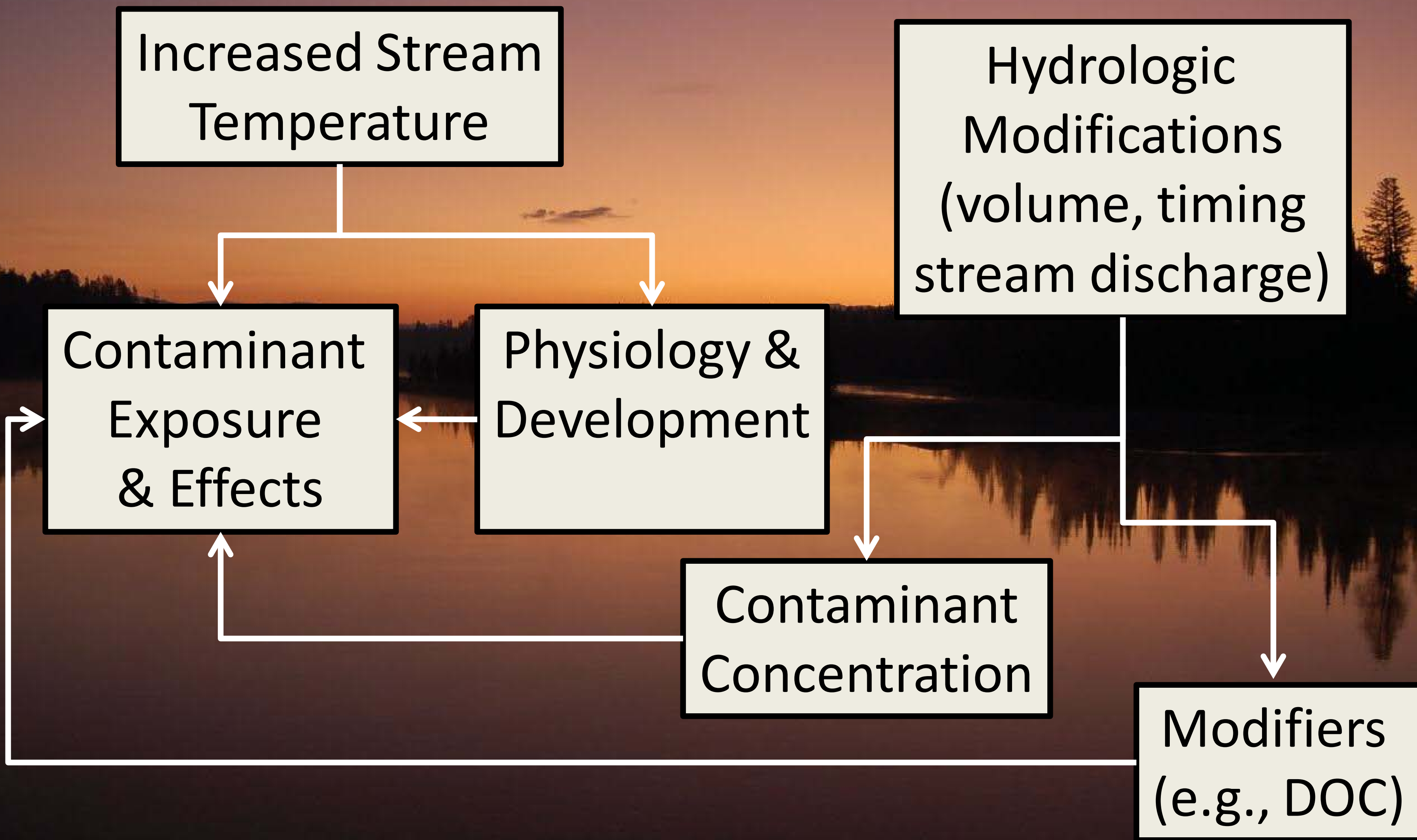
Are metal-tolerant communities more susceptible to other stressors?

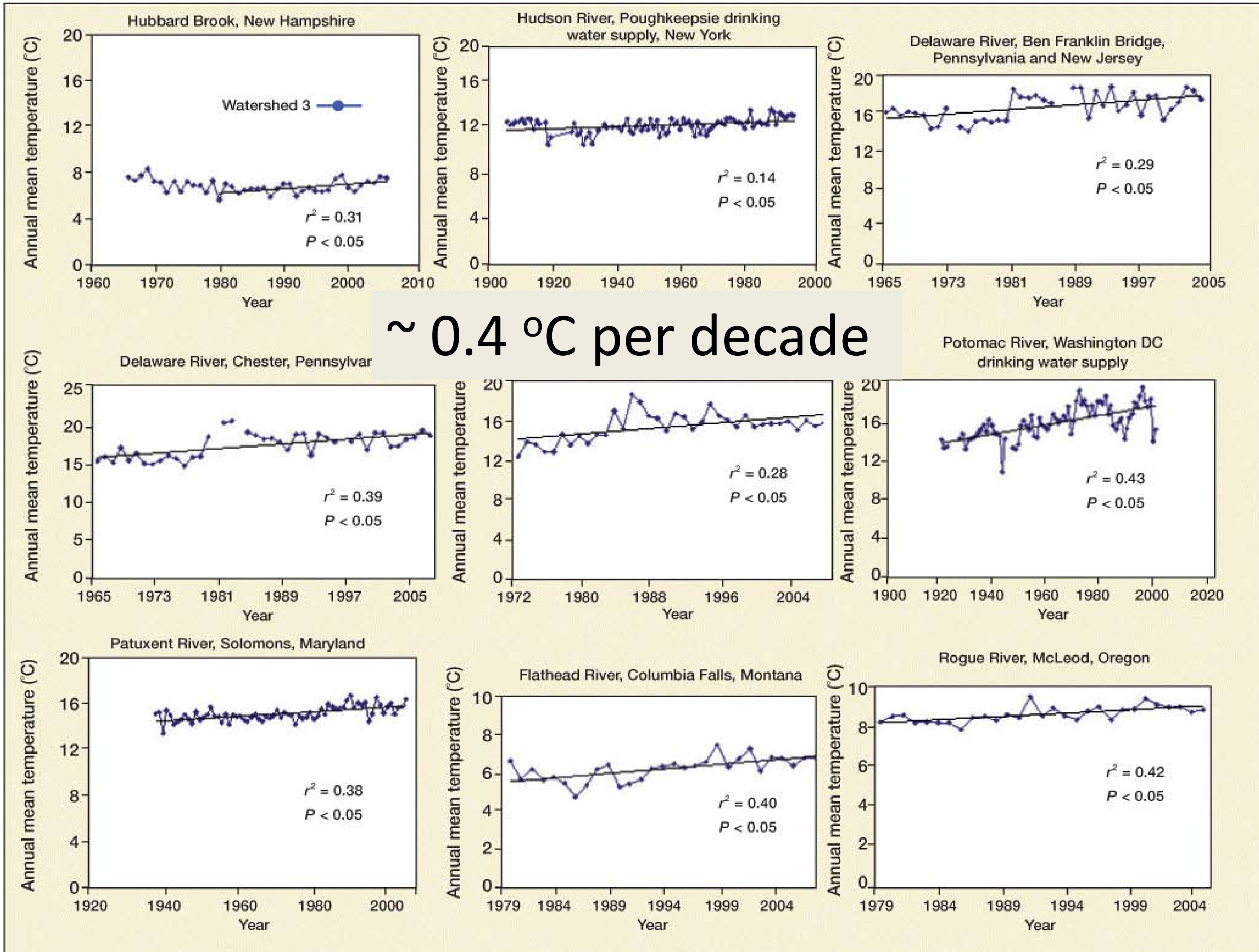
Reference Communities:
High resistance/resilience

Disturbed Communities:
Low resistance/resilience



Will Climate Change Influence Recovery?

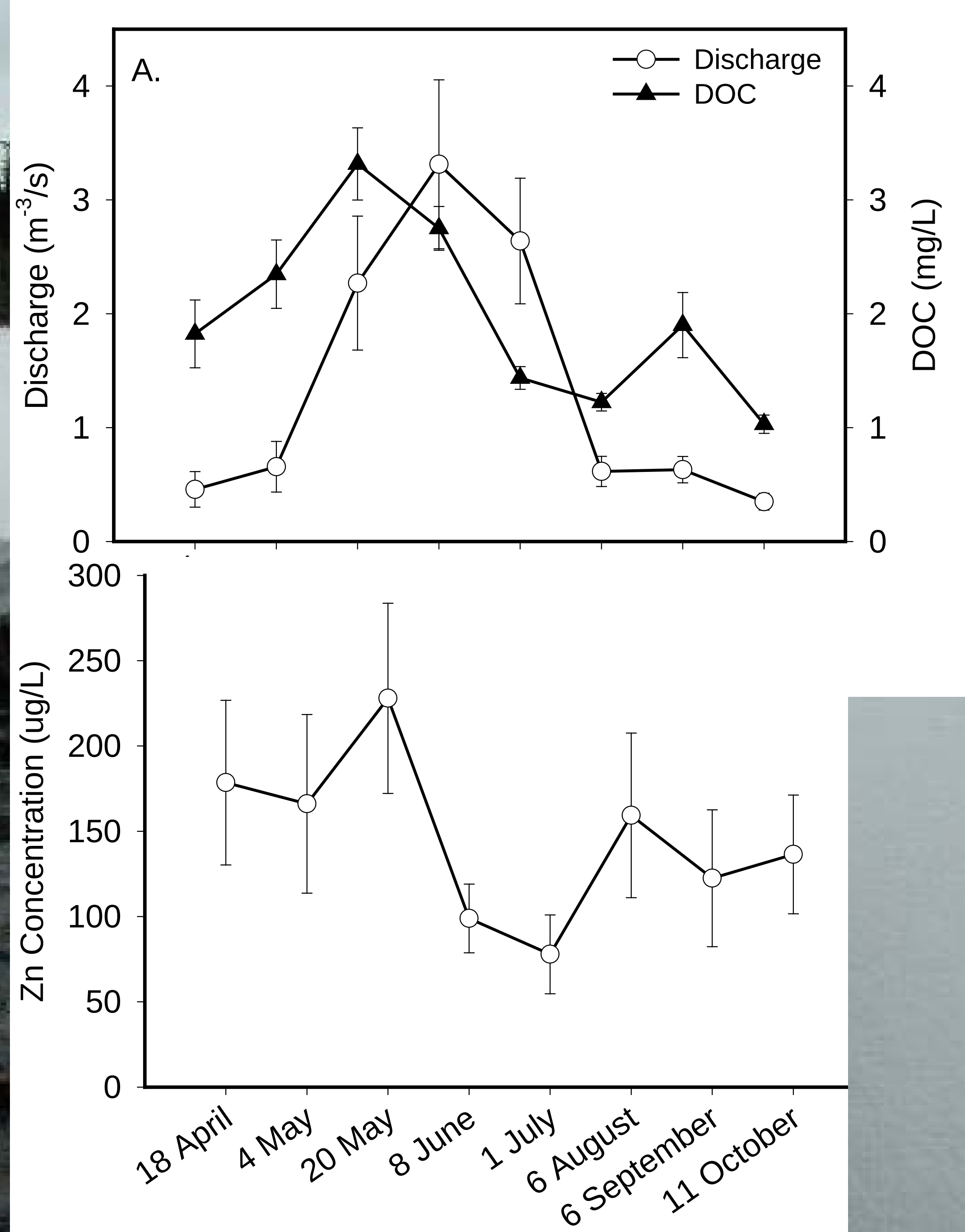


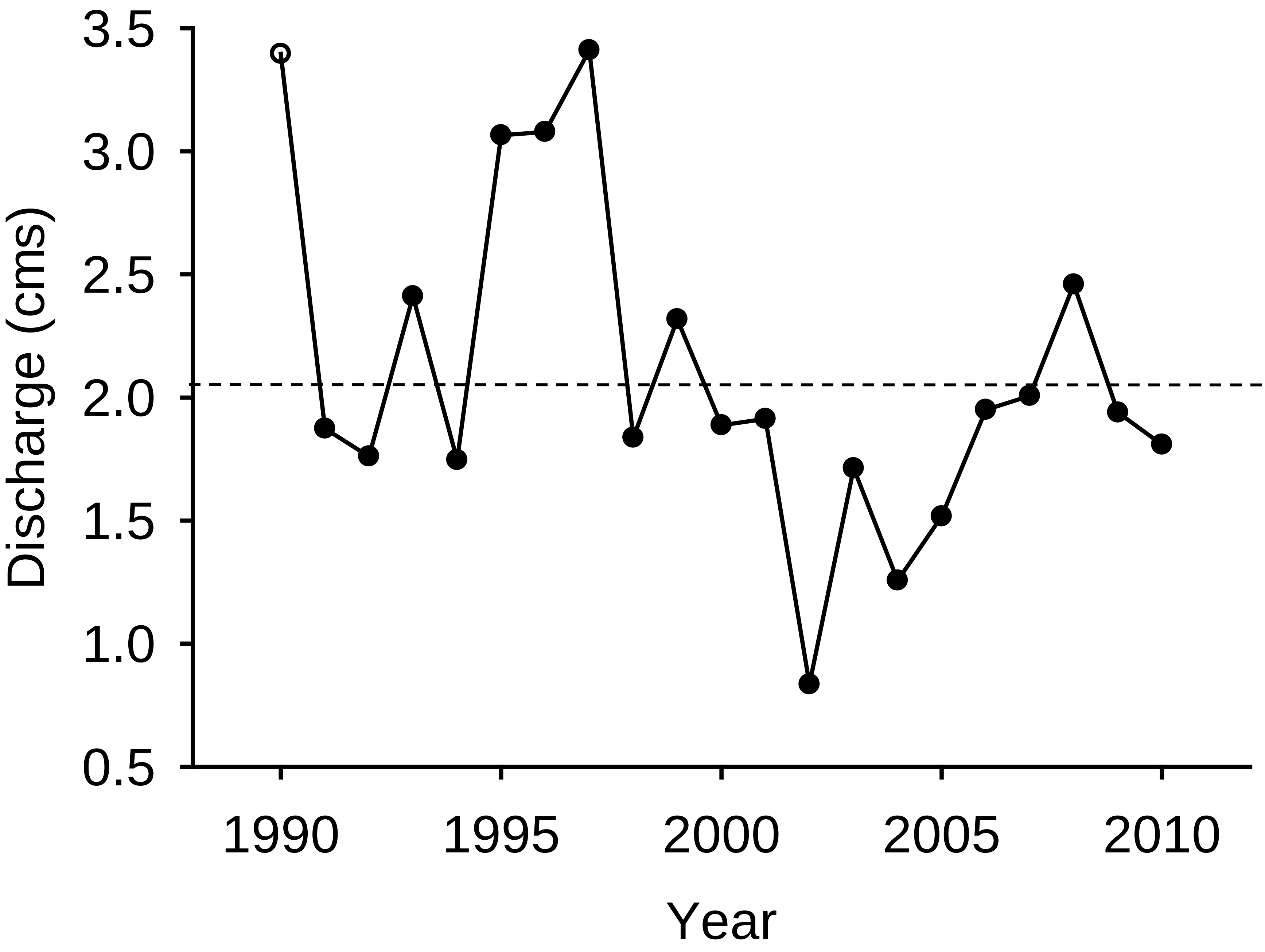


~ 0.4 °C per decade

Kaushal et al. 2010

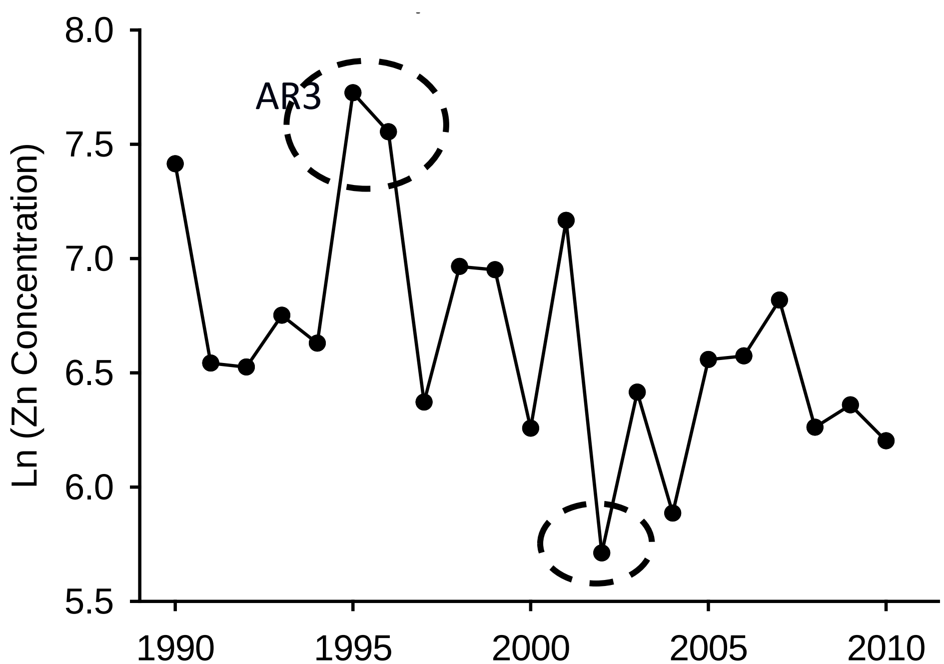
Hydrologic Characteristics



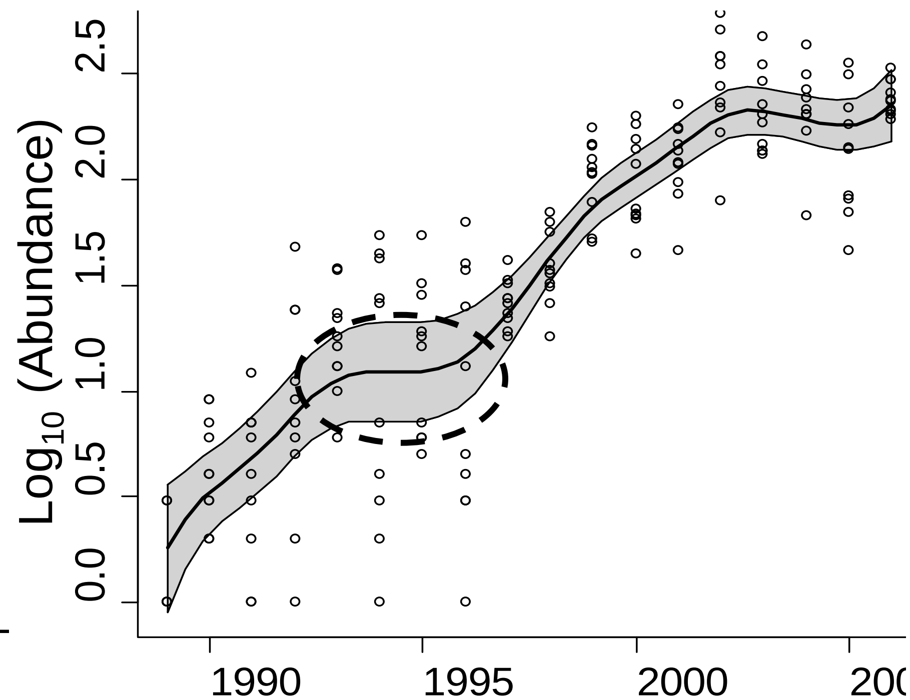


3.5
3.0
2.5
2.0
1.5
1.0
0.5
Discharge (cms)
1990
1995
2000
2005
2010
Year

Metal Uptake by Caddisflies



Recovery of Sensitive Species



Assessment of recovery and restoration effectiveness requires a long-term perspective

Recommendations and Lessons Learned

- Maintain consistent methods
- Start “big” and scale back as necessary
  → sampling freq, spatial scale, endpoints
- Monitoring alone may not be sufficient
  → experiments
- Use regional reference conditions
- Consider long-term climatic trends

Thanks!

>100 CSU graduate & undergraduate students

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