Strategies for integrating ecosystem science into ecotoxicology

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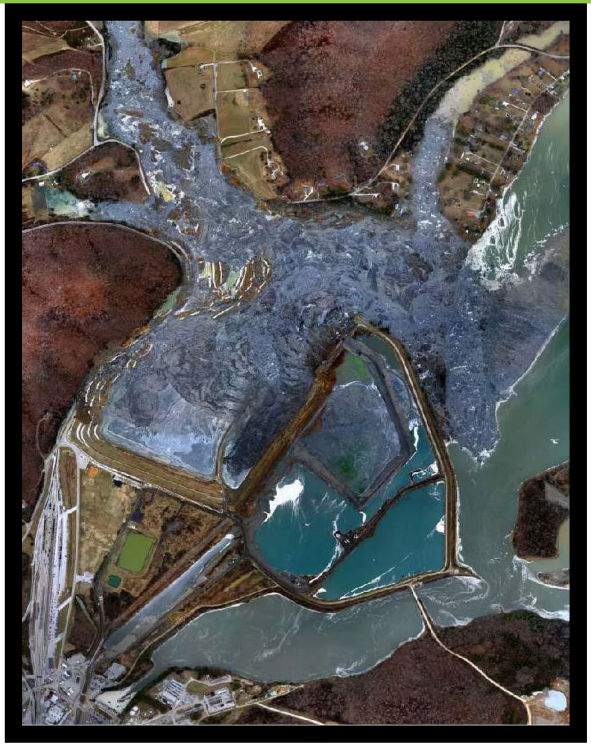
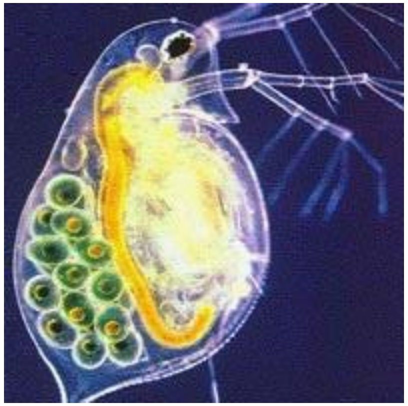
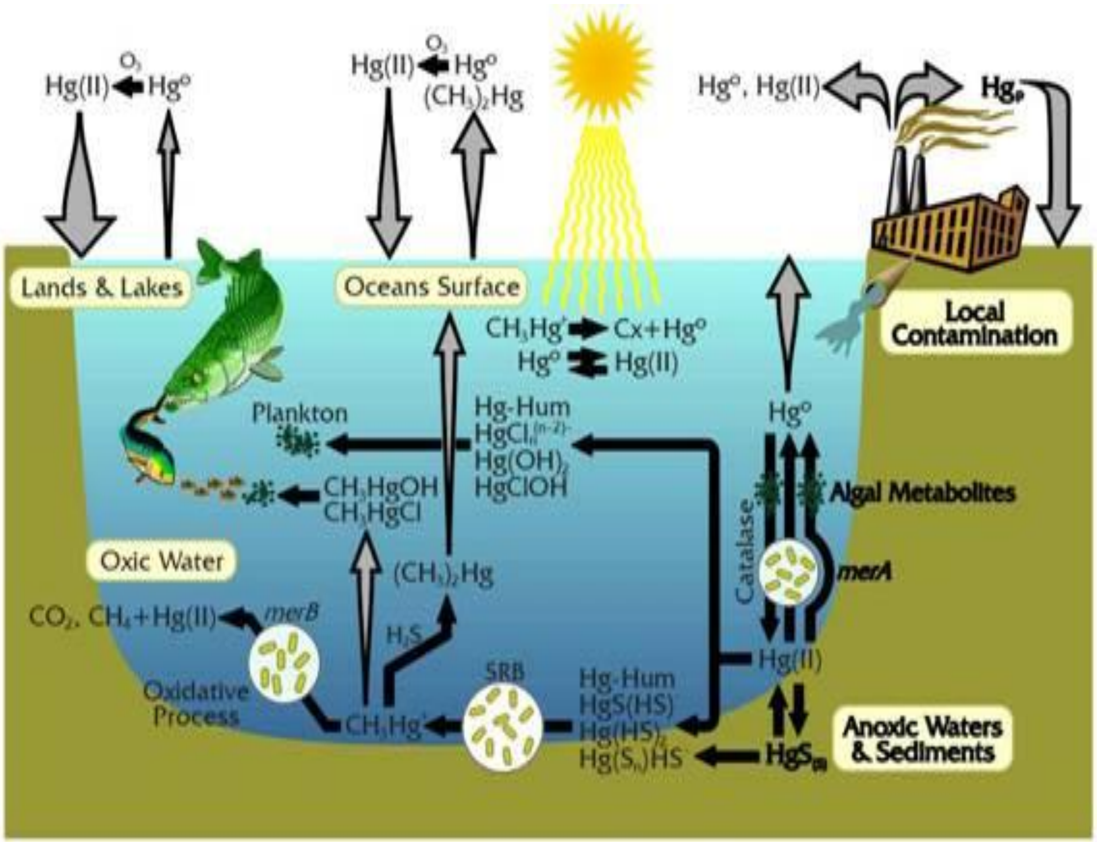
Challenges to incorporating ecosystem science into ecotoxicology

- Ecosystems are complex and difficult to study
- Measurements of toxicity are often on organism or (sub)organism level
- Toxicity standards and bioaccumulation models often consider individual contaminant
- What baseline do we compare impacted ecosystems to?



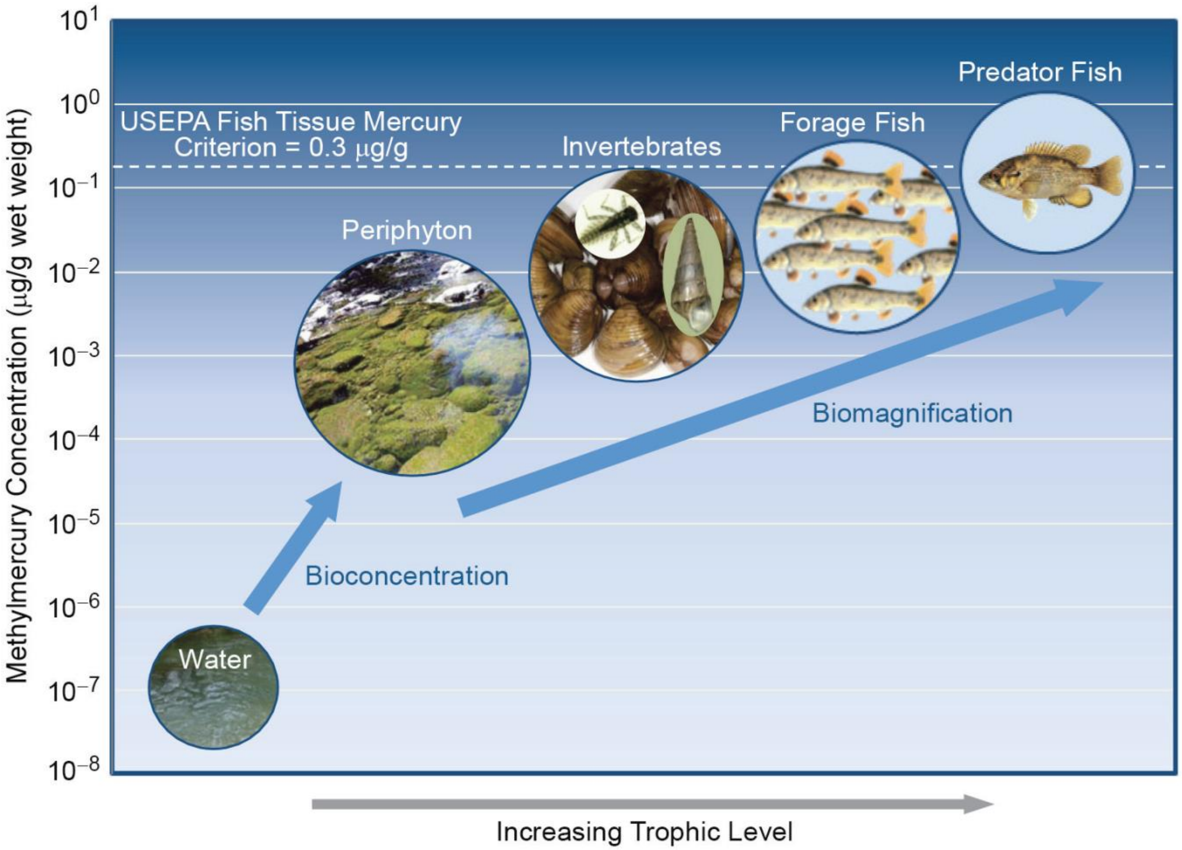


Global biogeochemical cycle for mercury



- Multiple chemical forms or “species”
- *Methylmercury is most toxic form
- Methylmercury builds up in aquatic food chains
- *Mercury toxicity is intimately linked with aquatic ecosystems

Mercury in living organisms

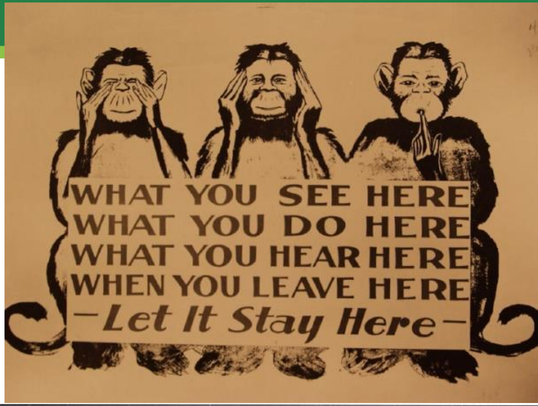


- Mercury biomagnifies as it is transferred up the food chain, leading to high Hg concentrations in fish

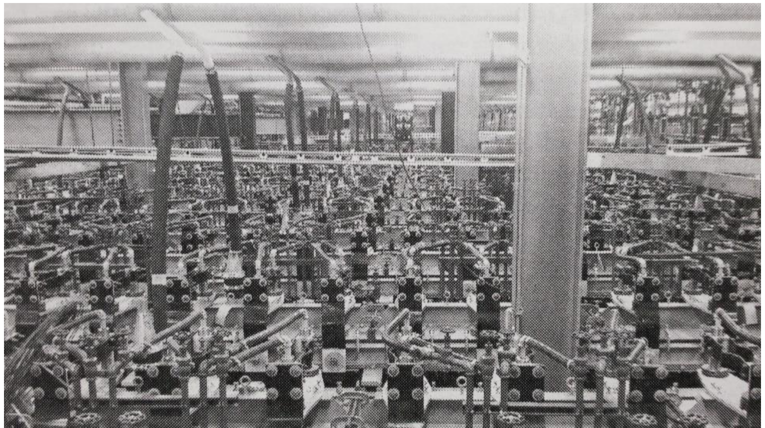
- This means that relatively low aqueous Hg concentrations can lead to hazardous concentrations in fish

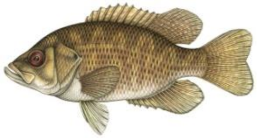
History of mercury contamination in Oak Ridge

- Large amounts (> 10 million kg) of inorganic Hg were used for industrial processes in 50’s and 60’s
- Spills and releases of Hg contaminated creeks, floodplains, and downstream sediments
- Hg remediation has focused on source control (water treatment systems, sewer relining, pipe re-routing, soil removal)
- Biological monitoring
  - Ensure effluent limits are protective of aquatic life
  - Assess ecological impacts, identify causes, and evaluate effectiveness of pollution abatement actions
  - Monitor ecological recovery




Hg flasks arriving at Y-12 (1955)

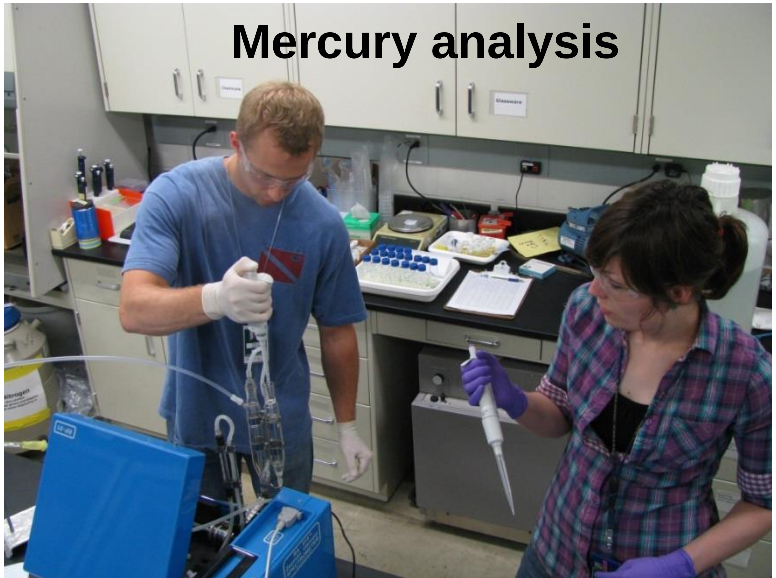





Mercury Cycling in East Fork Poplar Creek
City of Oak Ridge
Clinch River
Y12 National Security Complex
Direct Input
N
Inorganic Mercury
Mercury Methylation
Fork
lar
eek
Upstream Inputs
Streambank Inputs
Floodplain Inputs
Bioaccumulation
Sediment Inputs

Biological monitoring

1. Water quality & Bioaccumulation

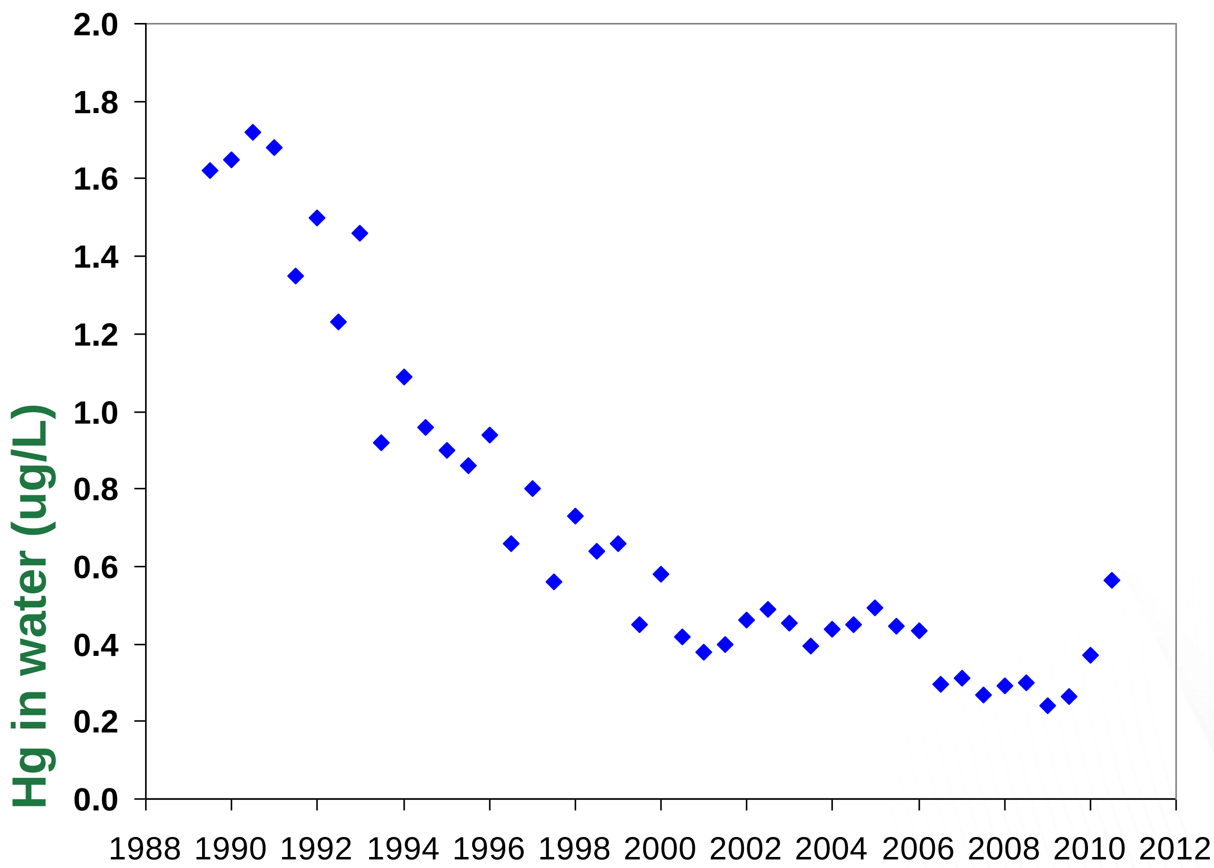


Biological monitoring

2. Ecological studies: Fish and Invertebrate communities

Remediation progress in East Fork Poplar Creek

Despite drastic reductions in aqueous Hg concentrations,

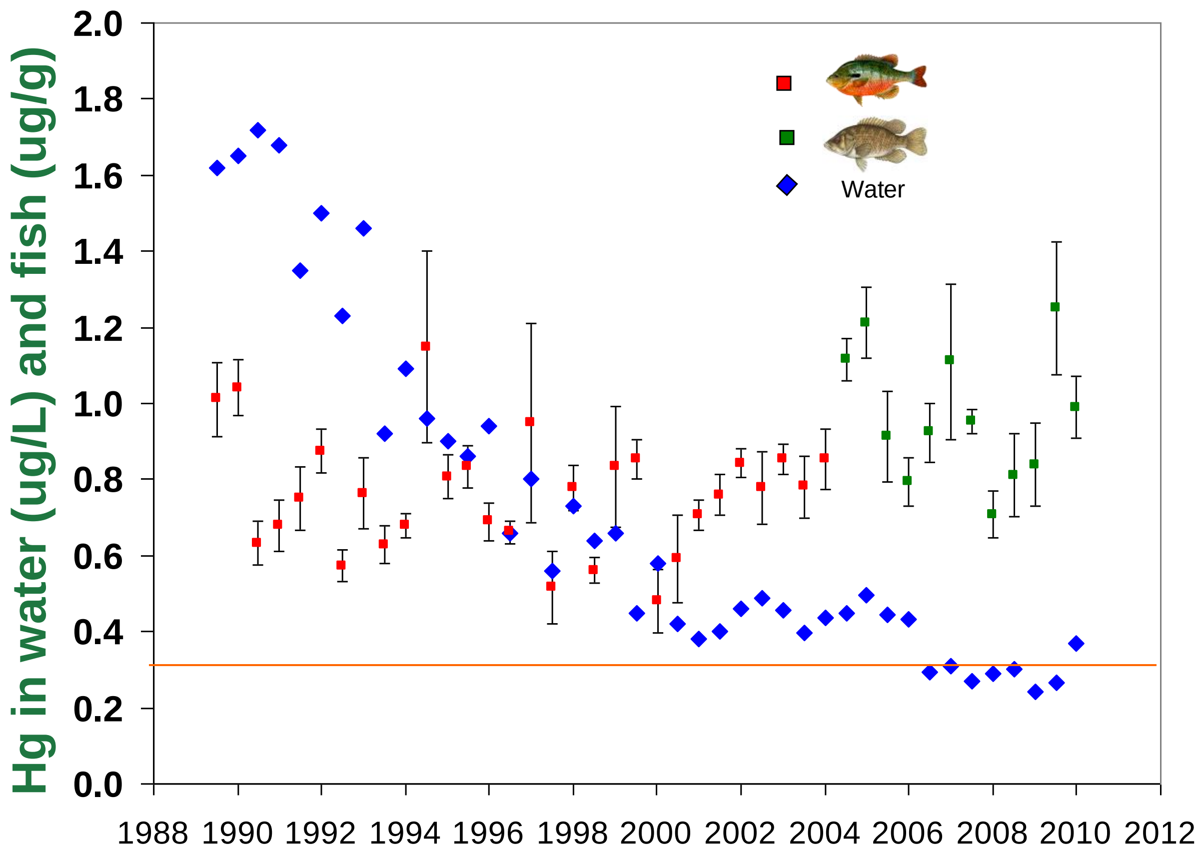


EVENT:				Pond replaced				Dechlorination				Flow management		Pond bypassed			Bank stabilized		
YEAR:	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003

Remediation progress in East Fork Poplar Creek

Despite drastic reductions in aqueous Hg concentrations,

Hg in fish remains elevated

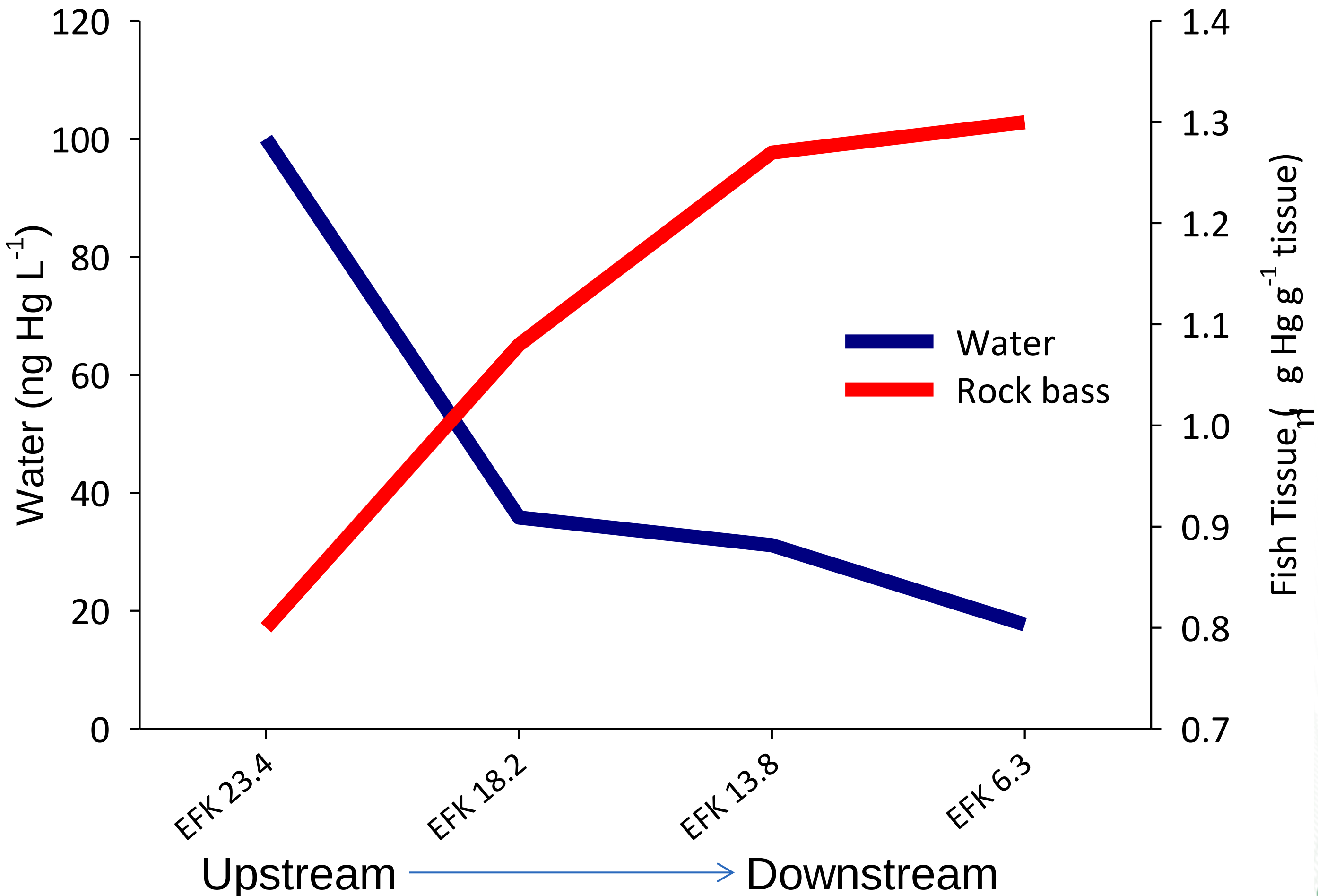


EVENT: Pond replaced ⟷ Dechlorination ⟷ Flow management ⟷ Pond bypassed ⟷ Bank stabilized ⟷

YEAR: 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003

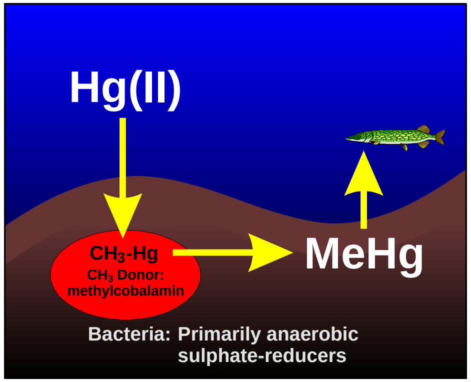
Puzzling trends in mercury concentrations

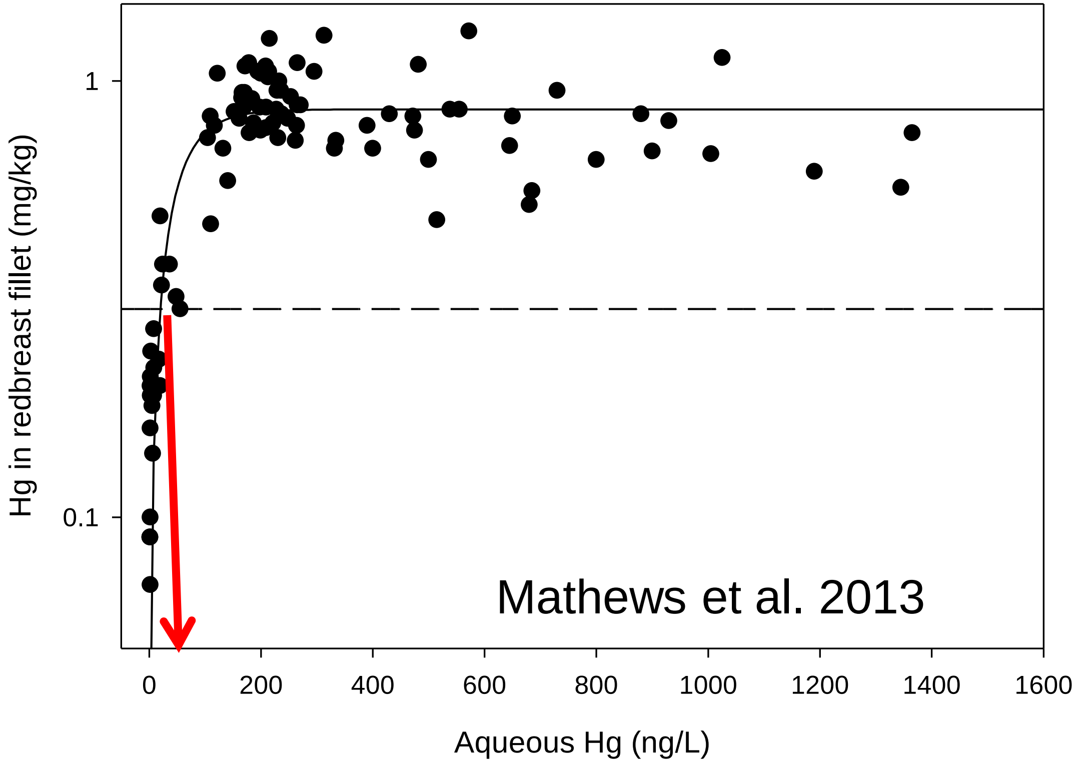
Mercury concentrations in water decrease further away from source, but fish tissue concentrations increase!



What is an appropriate remediation target?

- Non linear response; threshold concentration?
- MeHg is controlling fish concentrations but Hg methylation is difficult to predict and control





Can food web ecology help us understand and control MeHg bioaccumulation in fish?

Aquatic invertebrates are important to the stream ecosystem…

- Crucial link in food webs
  - High 2° production
  - Different feeding strategies
    - Accumulating Hg from different sources

Scraper

Collector-Gatherer

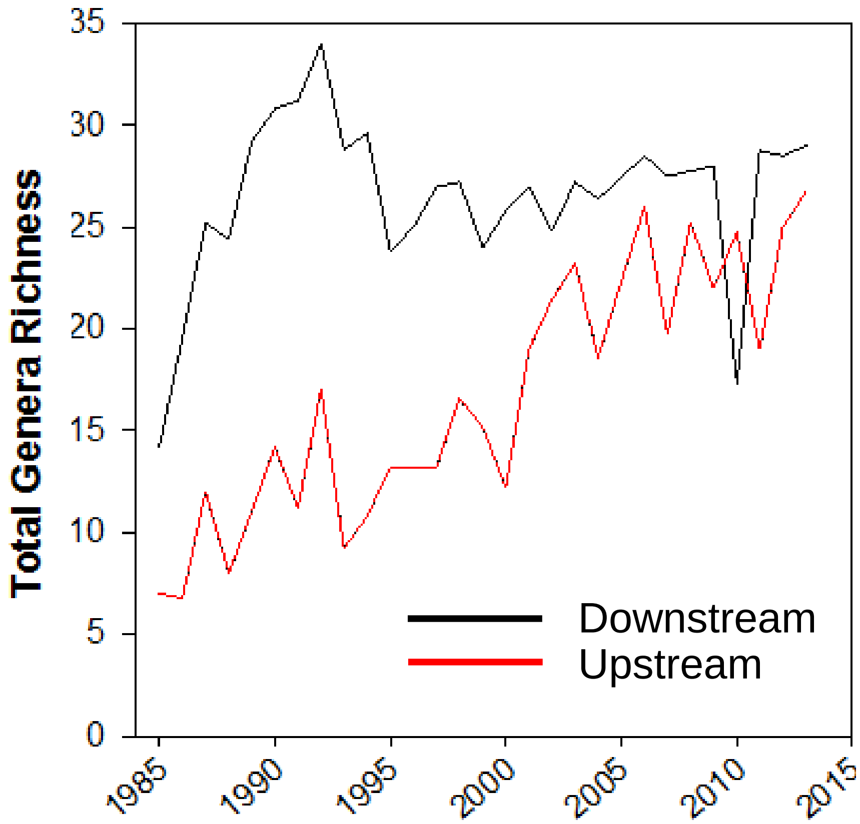
Collector-Filterer

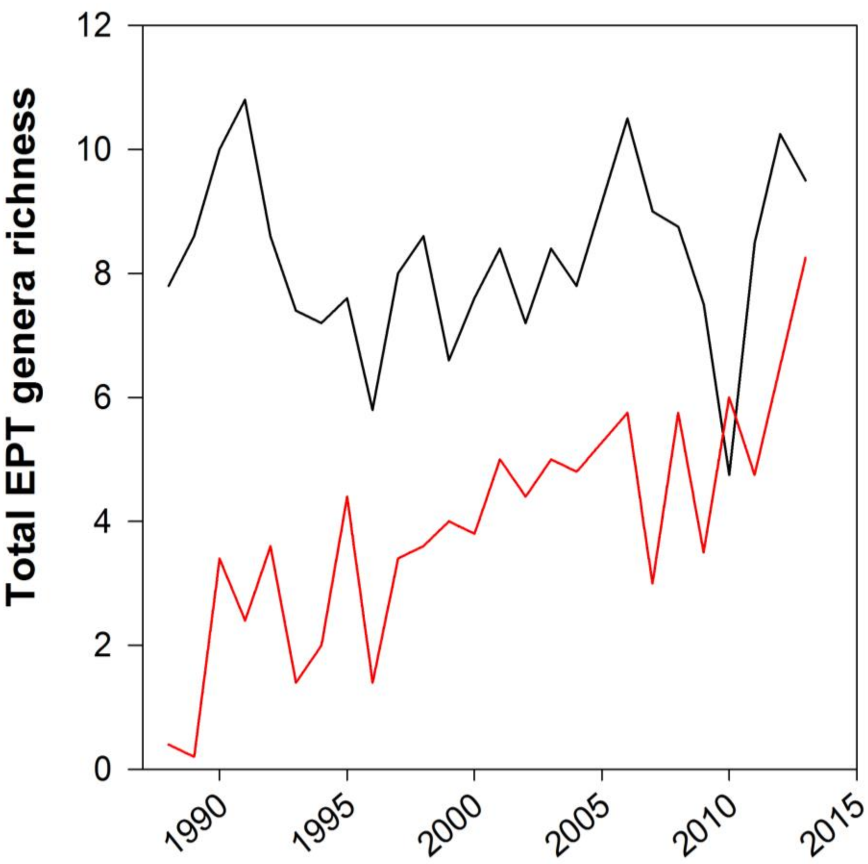
Predator

…they are also useful to us.

- Used as ecological indicators of stream health
  - Abundant
  - Easily sampled
  - Sedentary
  - Different sensitivities!

Diversity over time (1986-2014)





- Taxa richness has increased over time, especially at upstream site

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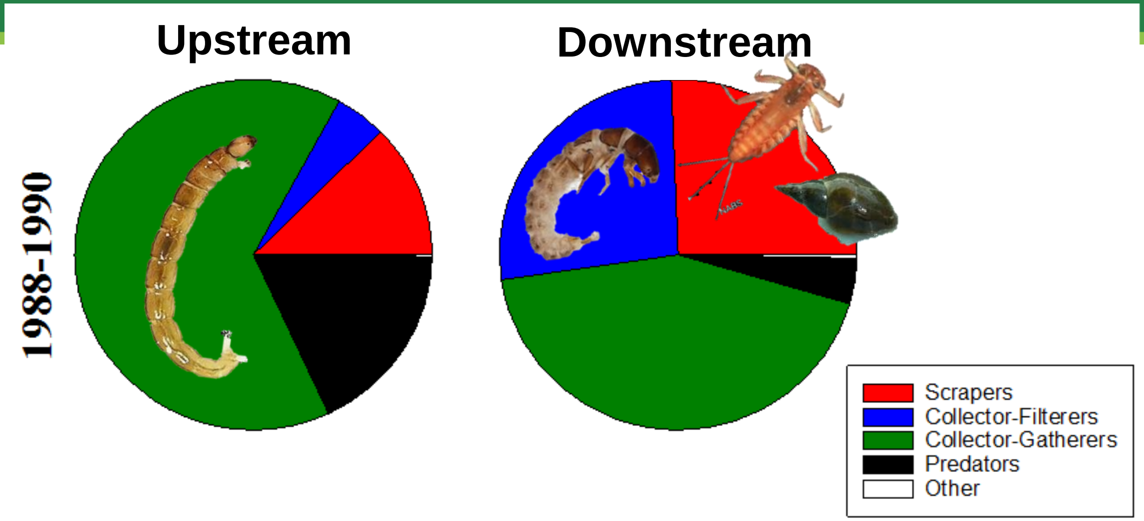
Trophic and Community Structure



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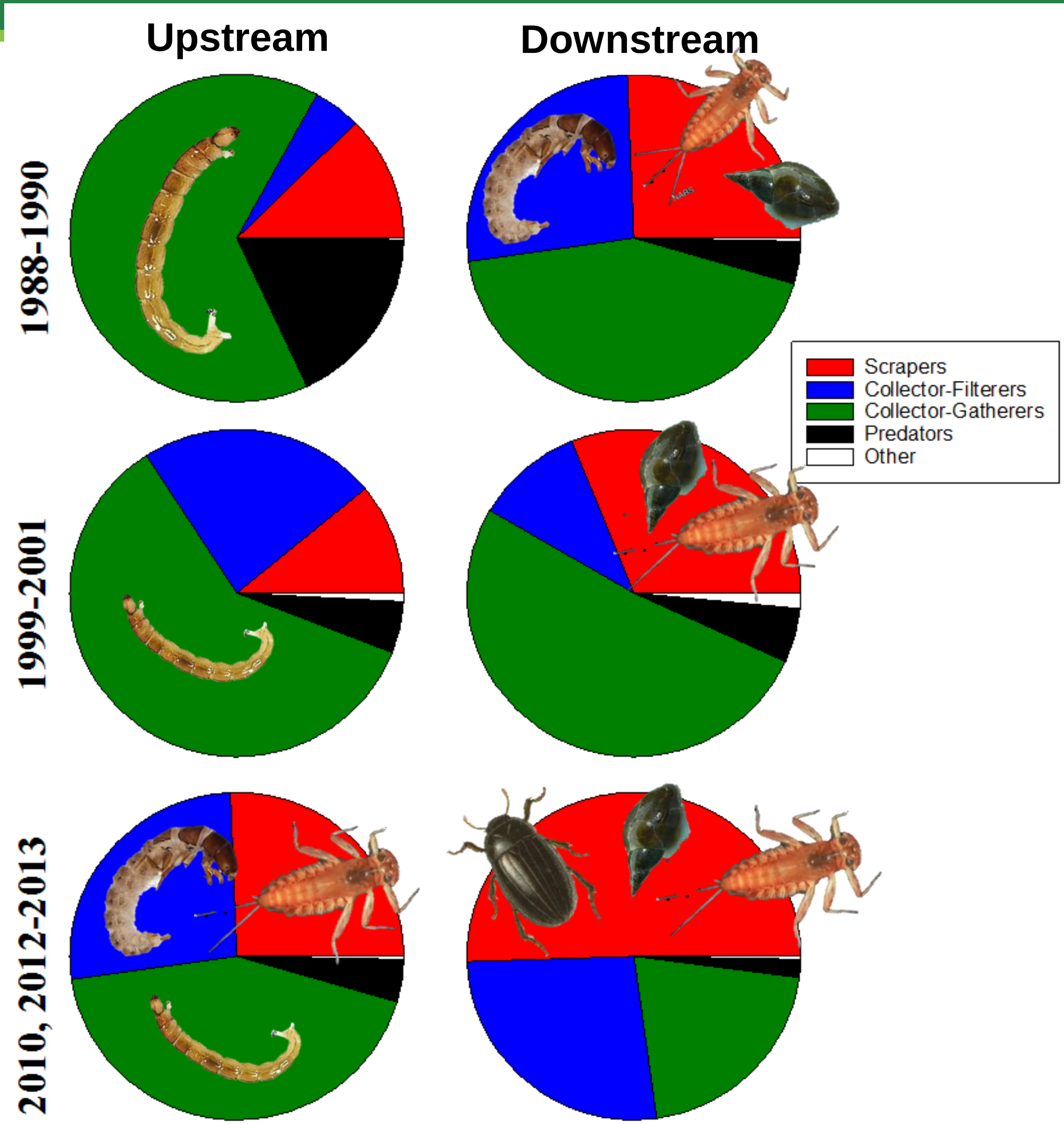
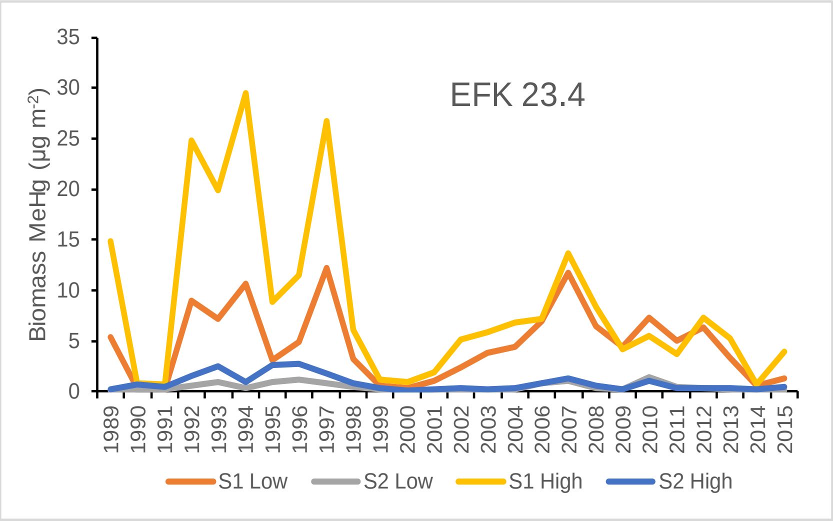
Trophic and Community Structure

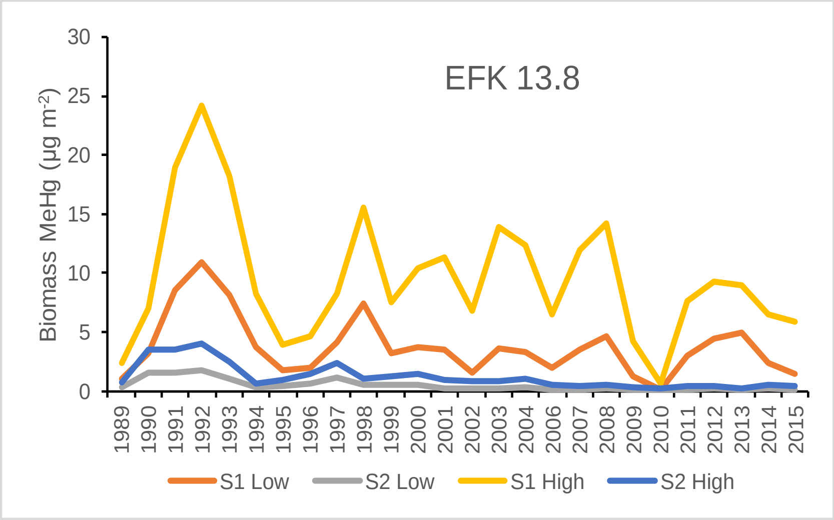


Hindcasting mercury inventories using community data

- Using mercury concentrations in invertebrates measured in 2015 and invertebrate community data we estimated what the inventories of mercury might have looked like

- This will be used to understand how mercury transfer to fish has changed over time





McManamay

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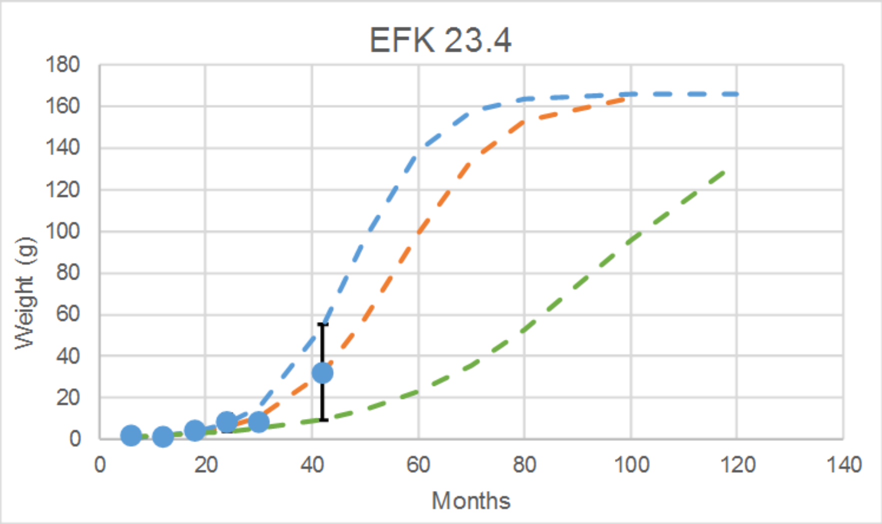
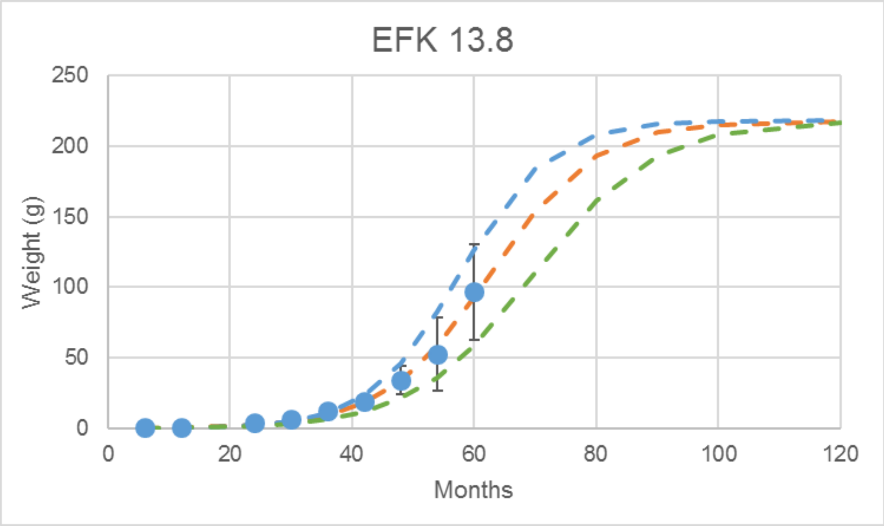
Bioenergetics modeling using population data

- Using fish community data (length-weight) we were able to assign age groups to fish based on size and estimate growth at age
- Average weight-at-age relationships provided the needed information to develop growth curves specific to each EFPC site.
- Data suggests rapid growth early in life history of fish at upstream site

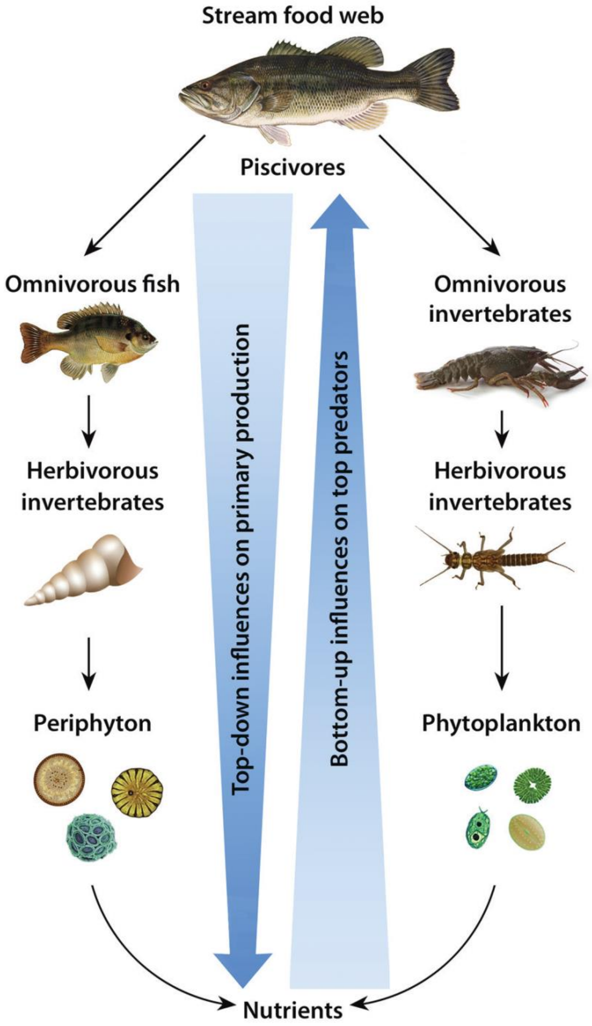




McManamay

All trophic levels are interconnected

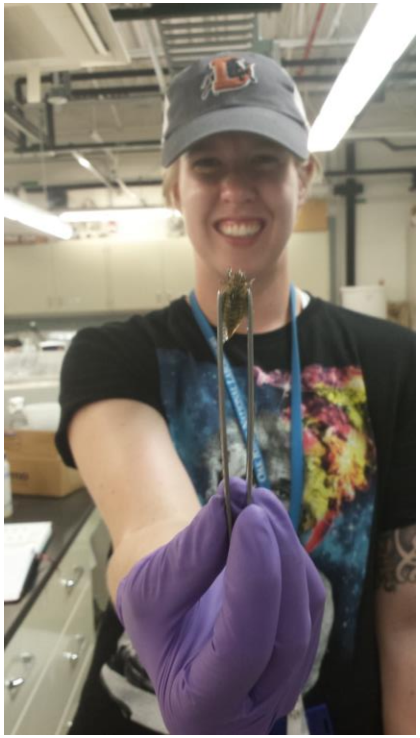
If we identify key trophic linkages, we can manipulate the food web to decrease Hg bioaccumulation in upper trophic level fish



Summary and Conclusions

- Much progress has been made over the past 30 years to reduce mercury inputs to East Fork Poplar Creek but fish tissue concentrations remain above guidelines
- Species richness (both fish and invertebrate) has increased in response to remediation actions, leading to longer food chains and greater opportunities for Hg biomagnification
- Conventional remediation options may not be successful at meeting fish tissue guidelines for years
- Ecological manipulation may be a cost effective and sustainable option to meet guidelines until clean up is possible

Acknowledgments



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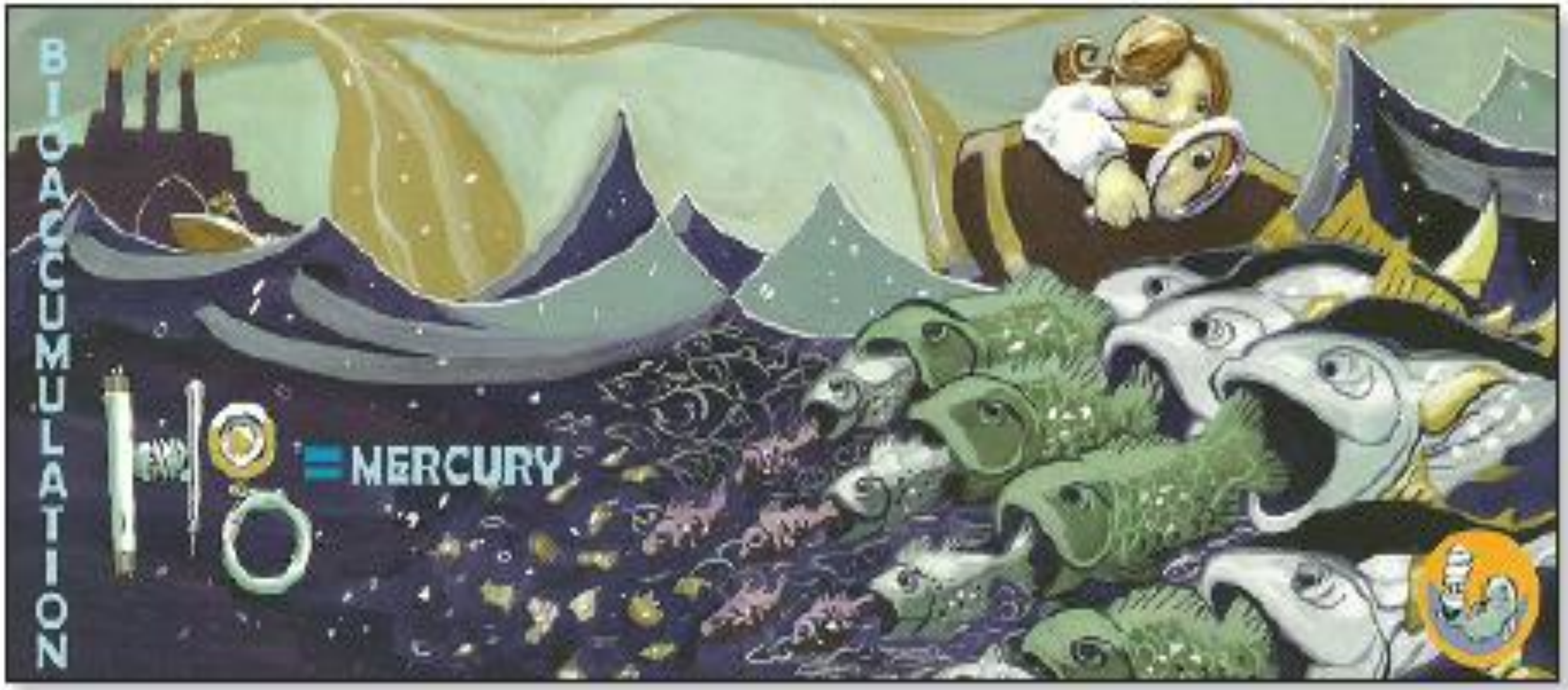
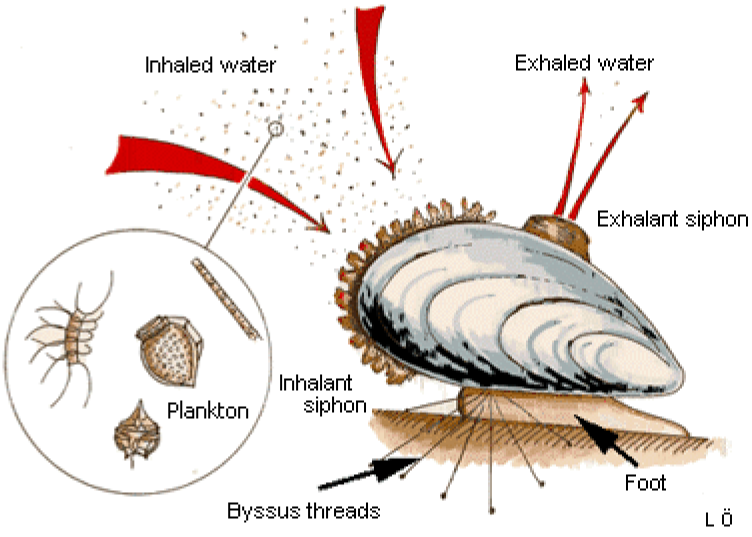
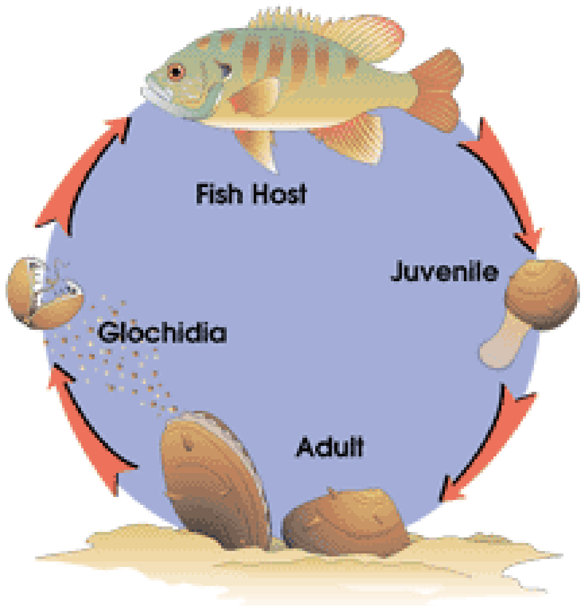
Questions?



Future work: re-introducing native mussels

- Filter feeders
- Great diversity of species, but in decline
- Complex life cycle





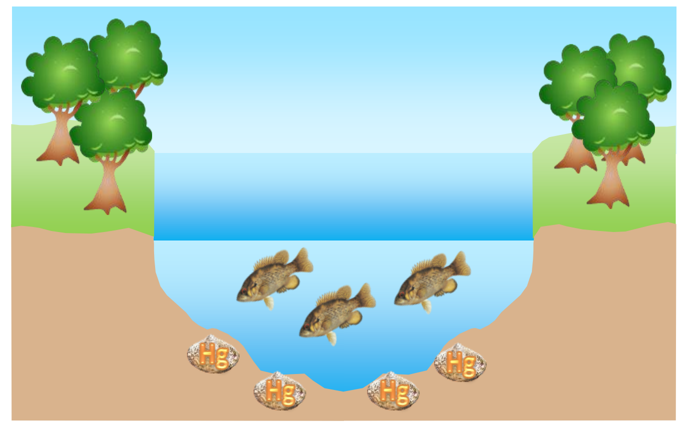
Can introduced bivalves affect Hg cycling in East Fork Poplar Creek?

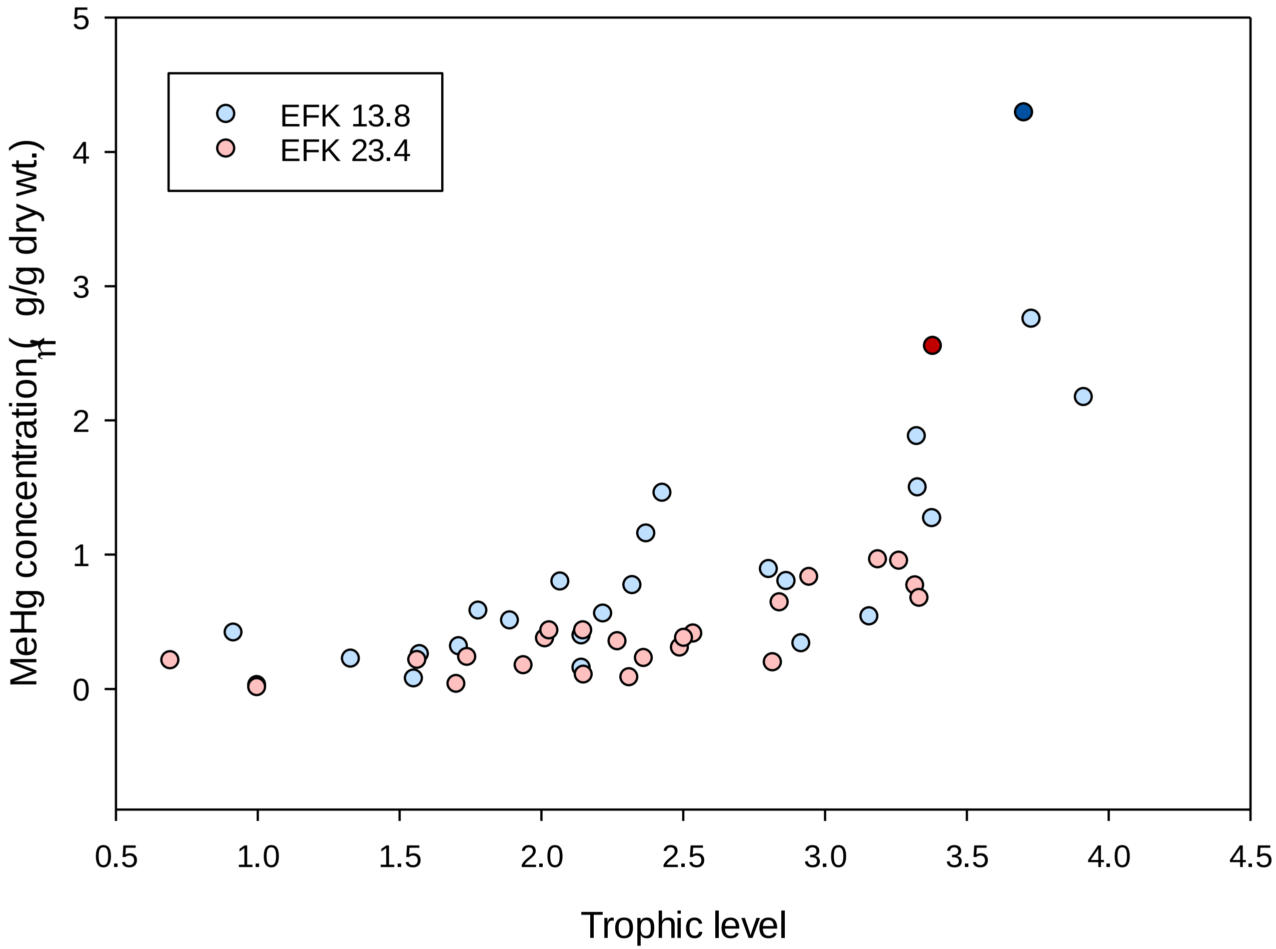
Current Conditions

Mercury available to food web

Manipulations & Hypothesized Response

Increase filter-feeder (clam) biomass
Decrease mercury available to food web





EFK 13.8
EFK 23.4
MeHg concentration (µg/g dry wt.)
Trophic level
0
1
2
3
4
5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

Name	Family	Maximum size (mm)	Habitat	Known host fish suitable for EFPC	Status (1993)
Actinonaias ligamentina[a] "Mucket"	Unionidae	140	Main channels in runs and riffles; depth of 3 ft or less; prefer gravel, cobble, mud	Bluegill, rock bass	Stable
Amblema plicata "Threeridge"	Unionidae	170	Small streams to big rivers; prefer clay, mud, sand, and gravel; most common in 1–3 ft of water	Bluegill, rock bass	Stable
Eliptio dilatata "Spike"	Unionidae	120	Reservoirs; less than 2 ft of water in upper Clinch River; prefer firm substrate of course sand and gravel; moderately strong current	Banded sculpin, rock bass	Stable
Lampsilis cardium "Plain pocketbook"	Unionidae	140	Moderate to strong current; tolerant to pollution; prefer coarse gravel and sand; between 2 and 20 ft of water	Bluegill	Special concern
Lasmigona costata "Flutedshell"	Unionidae	190	Moderately strong current; prefer coarse sand and gravel; 3 ft of water or less	Bluegill, rock bass	Stable
Ligumia recta "Black sandshell"	Unionidae	160	Strong current; prefer coarse sand with gravel and cobbles; several inches to 6 ft of water	Bluegill	Special concern
Pleurobema cordatum "Ohio pigtoe"	Unionidae	80	Large rivers; 18–24 ft of water; prefer firm substrate	Bluegill	Special concern
Quadrula metanerva "Monkeyface"	Unionidae	110	Swift current; clean water; prefer gravel	Bluegill	Stable
Strophitus undulatus "Creeper"	Unionidae	90	Adaptable; high gradient to meandering or channelized rivers	Bluegill	Stable
Toxolasma parvus "Lilliput"	Unionidae	30	Small to large rivers, lakes and ponds; prefer mud, sand, and fine gravel	Bluegill	Stable
Utterbackia imbecillis "Paper pondshell"	Unionidae	100	Shallow banks; prefer fine mud and sand	Bluegill, rock bass	Stable
Villosa iris[a] "Rainbow"	Unionidae	75	Clean, well-oxygenated water; less than 3 ft of water; prefer gravel and sand; moderate to strong current	rock bass	Stable
Villosa vanuxemensis[a] "Mountain creekshell"	Unionidae	70	Small headwater creeks; very clean water; prefer gravel and sand	Banded sculpin	Special concern

Note: All information from Parmalee and Bogan 1998.

[a] Signifies specimen (alive or shell) was observed in 1997 by J. G. Smith (US DOE 1997).

Teresa Mathews

Complex Aquatic Sciences Team Lead, Environmental Sciences Div.

Ph.D. Biological Oceanography

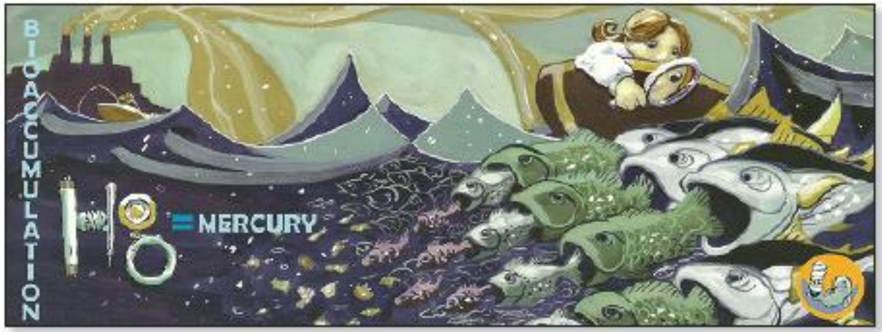
Research focus:

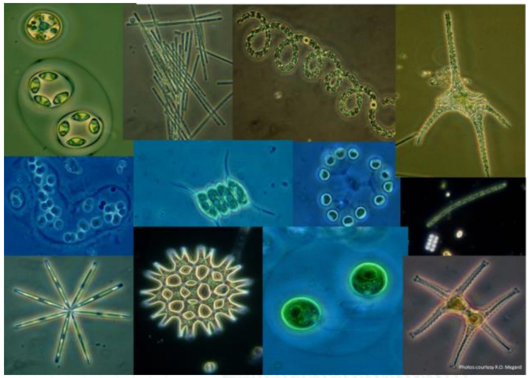
How do biological interactions affect:

- global carbon cycling
- nutrient and contaminant cycling
- ecosystem productivity

Applications:

- managing eutrophication and harmful algal blooms
- sustainable algal biomass production for biofuel
- large scale ecological manipulation for contaminant management (mercury)





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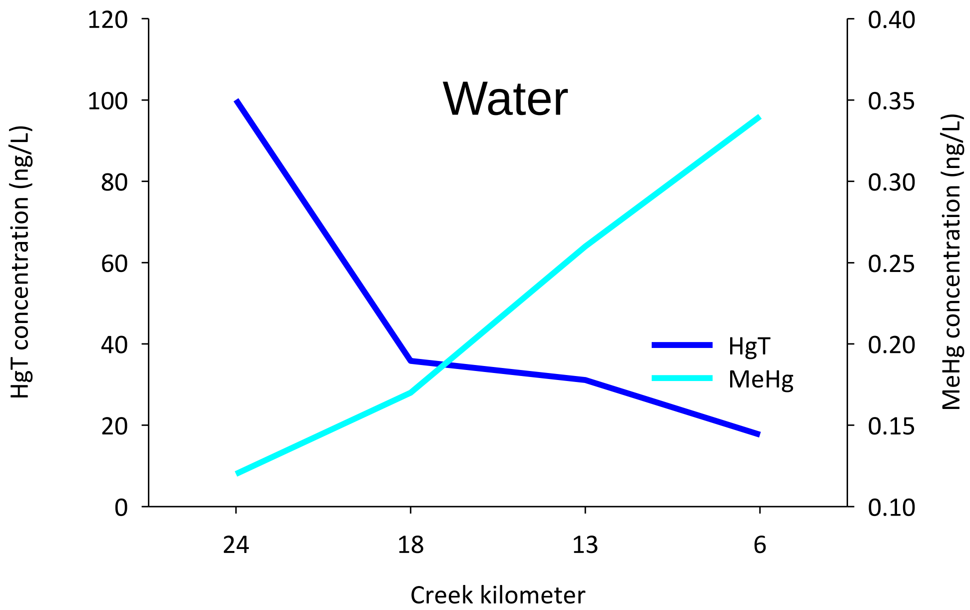
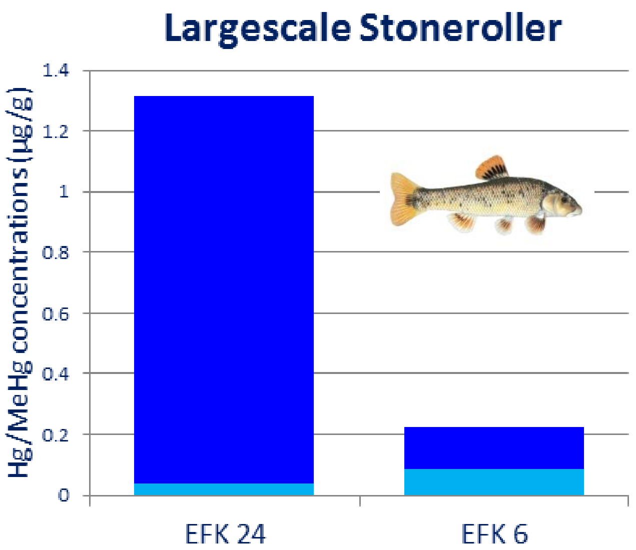
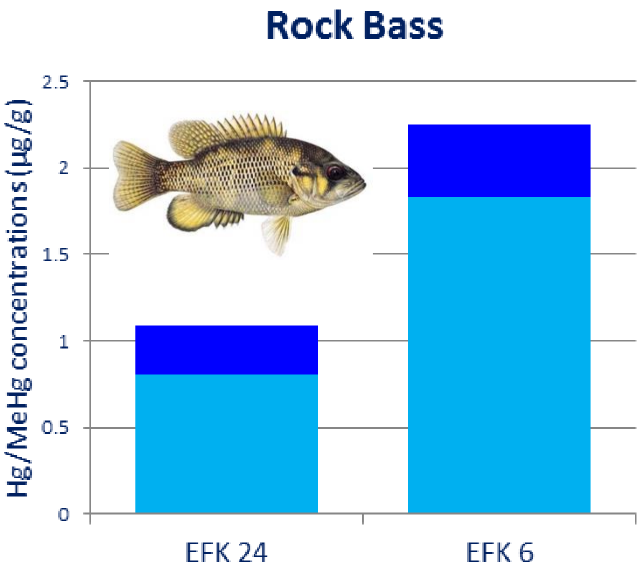
Mercury methylation is controlling fish concentrations







- While HgT concentrations decrease with further distance downstream, MeHg concentrations increase
- Hg in lower trophic level fish reflect aqueous HgT concentrations, while Hg in higher trophic level fish reflects aqueous MeHg concentrations
- Upper trophic level fish have higher MeHg concentrations downstream compared to upstream