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Further Evaluation of IDEQ 2019 Paired Fish and Surface Water Arsenic Data

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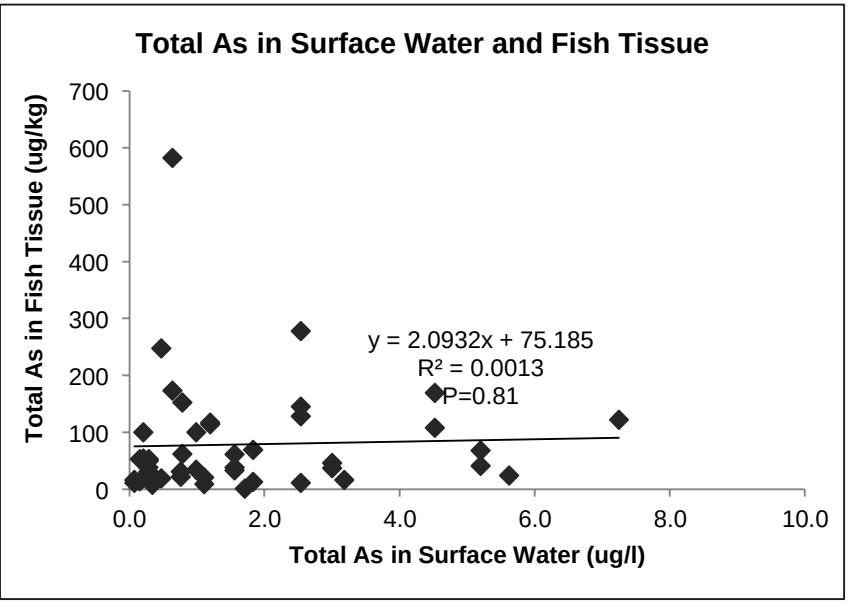
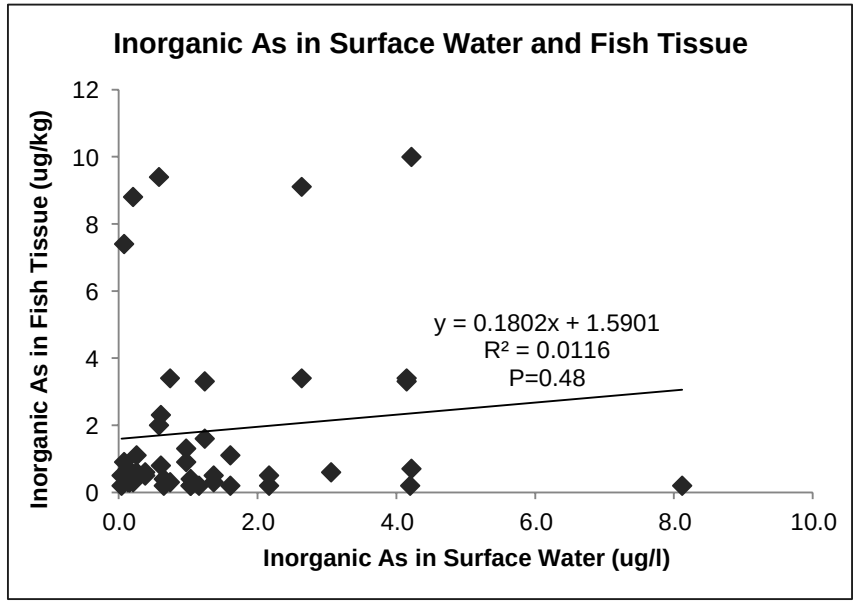
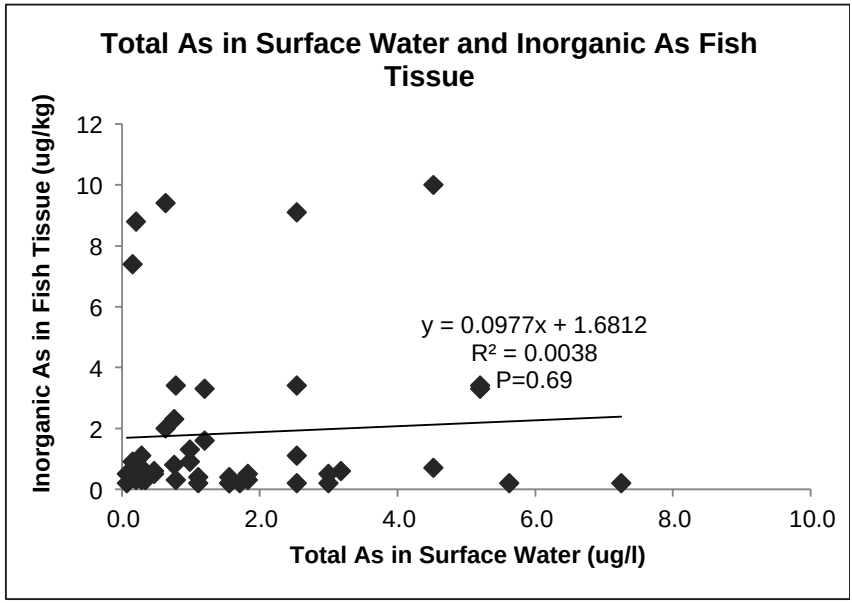
Introduction

Idaho 2019 Data - Summary of Previous Analyses

- No statistically significant relationship between arsenic in fish tissue and surface water







Additional Evaluations

- Literature Review
  - Do previously published studies help explain the 2019 Idaho paired tissue and water data?
- Additional Analyses of 2019 Idaho Data
  - Multivariate analysis to identify the parameters, if any, that have a statistically significant effect on iAs concentrations in fish tissue
  - Effect of fish body weight on tissue iAs concentration
  - Effect of fish feeding guild on the relationship between iAs concentration in tissue and surface water
  - Relationship between fish weight and trophic level on ratio of iAs to tAs
  - Effect of Idaho river basin on iAs surface water and tissue concentrations

Literature Review

Literature Review – Water/Tissue Relationship

- No relationship between As in surface water and fish tissue
- Williams et al. 2006 – compiled surface water and fish tissue total As concentrations from 8 field studies (lakes, ponds, rivers in US and Canada)

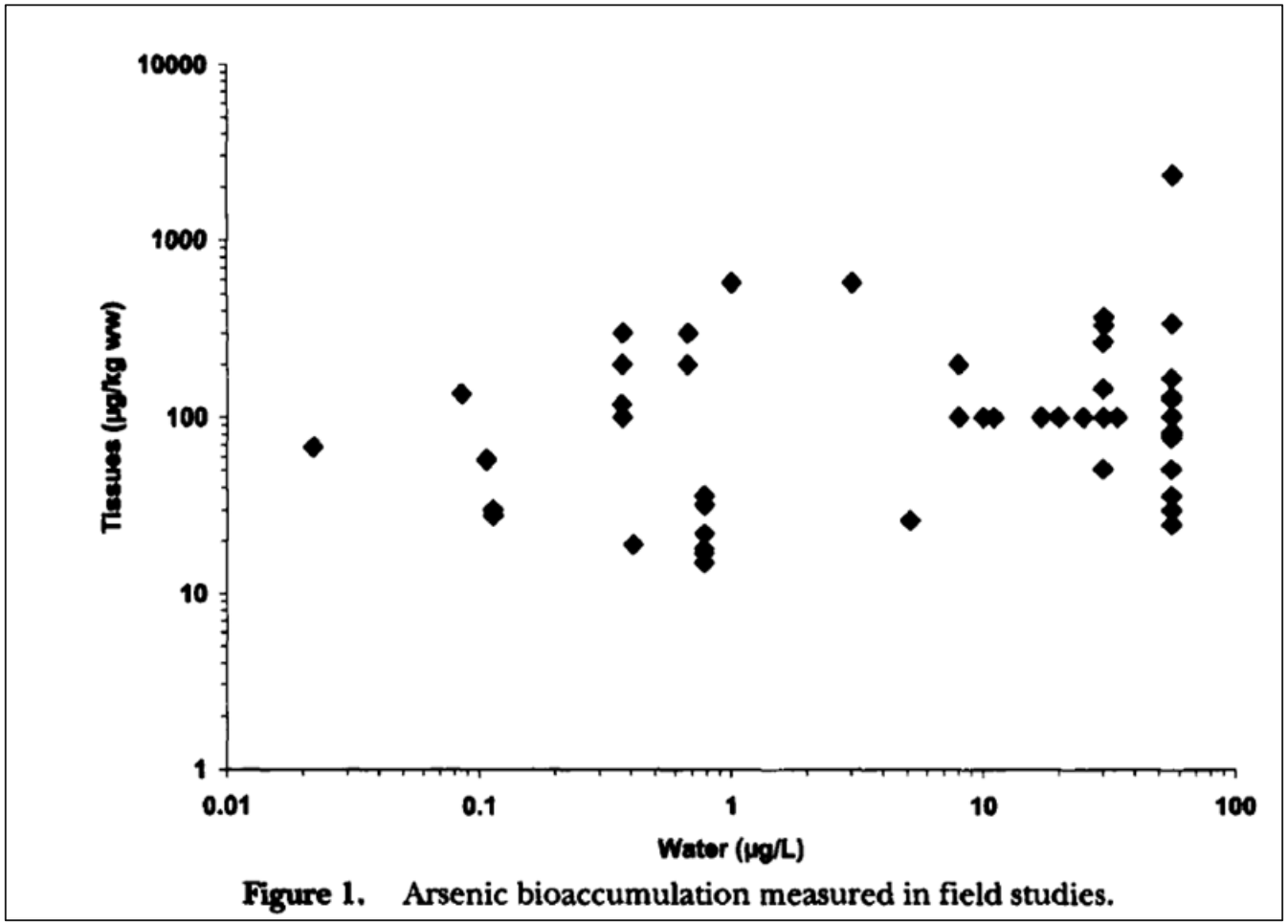


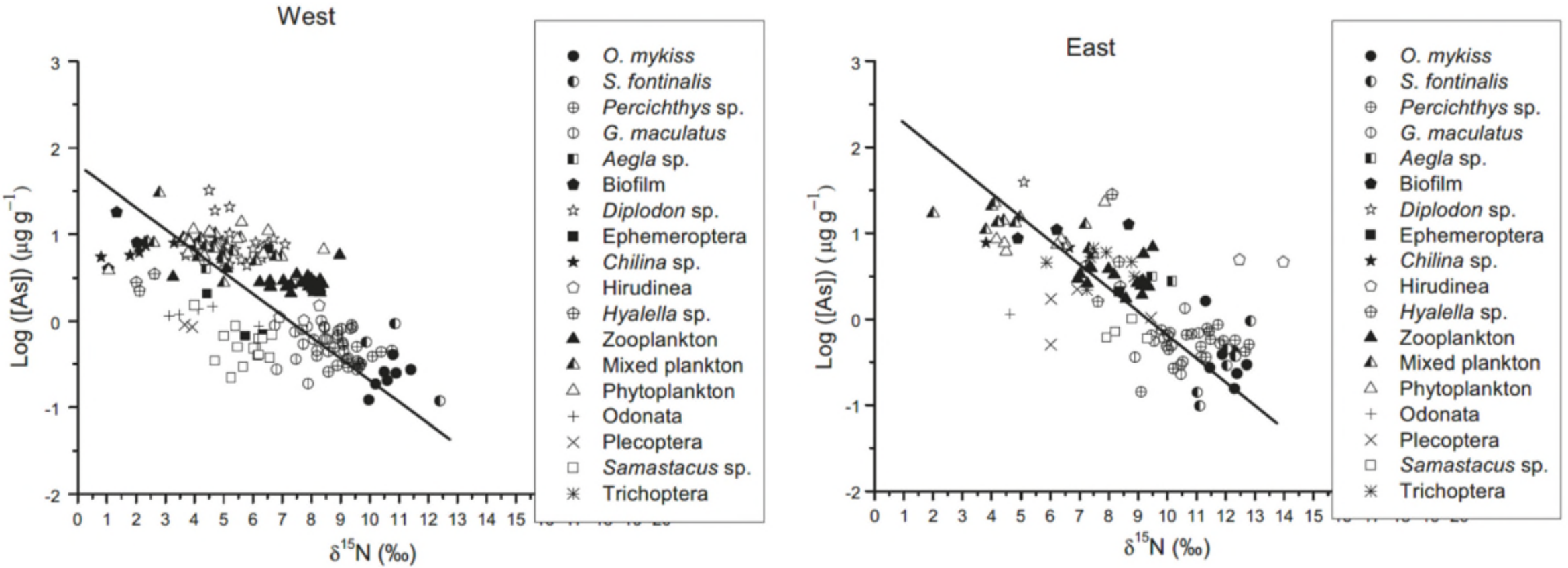
Figure 1. Arsenic bioaccumulation measured in field studies.

Literature Review - Biomagnification

- iAs undergoes biodilution/biodiminution
- iAs bioaccumulates at lower trophic levels, including aquatic plants (e.g., periphyton, phytoplankton, and zooplankton)
- iAs concentrations decrease with increasing trophic level in the foodweb
  - Chen and Folt 2000; Chen et al., 2008; Cheng et al., 2013; Chetalat et al., 2019; Dovick et al., 2015, Lopez et al., 2016; Maeda et al., 1990; Rahman et al., 2012

Literature Review – Biomagnification (cont.)

- Studies using stable isotope analysis to quantify organism trophic level position demonstrate biodiminution (Revenga et al., 2012)



Revenga et al. 2012

Literature Review – Bioaccumulation/Conversion

- Fish exposed in laboratory settings absent a food web accumulate As in tissue
- Majority of total Arsenic (tAs) is in organic forms (e.g. methylated forms of As and arsenobetaine)
  - tAs in fish tissue was primarily arsenobeteine (56% in carp; 89% in eel, 95% in mullet, rainbow trout, and chub; Ciardullo et al 2008 and 2010)
  - 90% of tAs in muscle, liver, gill tissues of tilapia exposed to iAs in laboratory was organic As; 30-80% of tAs in gastrointestinal tract was organic As (Pei et al 2019)
  - 70-80% of tAs in tissues of carp exposed to iAs in laboratory was organic (Cui et al 2021)
- Internal bioregulation converts inorganic As to organic As

Literature Review Summary

- Arsenic concentrations in tissue are not related to arsenic concentrations in the water column of natural systems
- Arsenic concentrations decrease with increasing trophic level
- This appears to be due to bioregulation of arsenic in aquatic organisms – conversion of inorganic forms to organic forms
- Bioaccumulation in the traditional sense does not appear to apply to arsenic

Additional Analyses of IDEQ Data

Additional Analysis of 2019 IDEQ Data

1. **Multivariate analysis -** identify which, if any, parameters have a statistically significant effect on iAs concentrations in fish tissue
2. Relationship between fish **body weight** and tissue iAs concentration
3. Effect of fish **feeding guild (diet)** on the relationship between iAs concentration in tissue and surface water
4. Relationship between fish weight and trophic level on **ratio of iAs to tAs**
5. Effect of Idaho **river basin** on the relationship between iAs concentrations in tissue and surface water.

Feeding Guild Assignments

- Assumed adult diet when assigning guild

Species	Guild/Diet
Bridgelip sucker	Herbivore
Cutthroat trout	Insectivore
Dace sp.	Insectivore
Mountain whitefish	Insectivore
Reside shiner	Insectivore
Sculpin sp.	Insectivore
Catfish sp.	Piscivore
Brook trout	Piscivore
Brown trout	Piscivore
Largemouth bass	Piscivore
Northern pikeminnow	Piscivore
Rainbow trout	Piscivore
Smallmouth bass	Piscivore

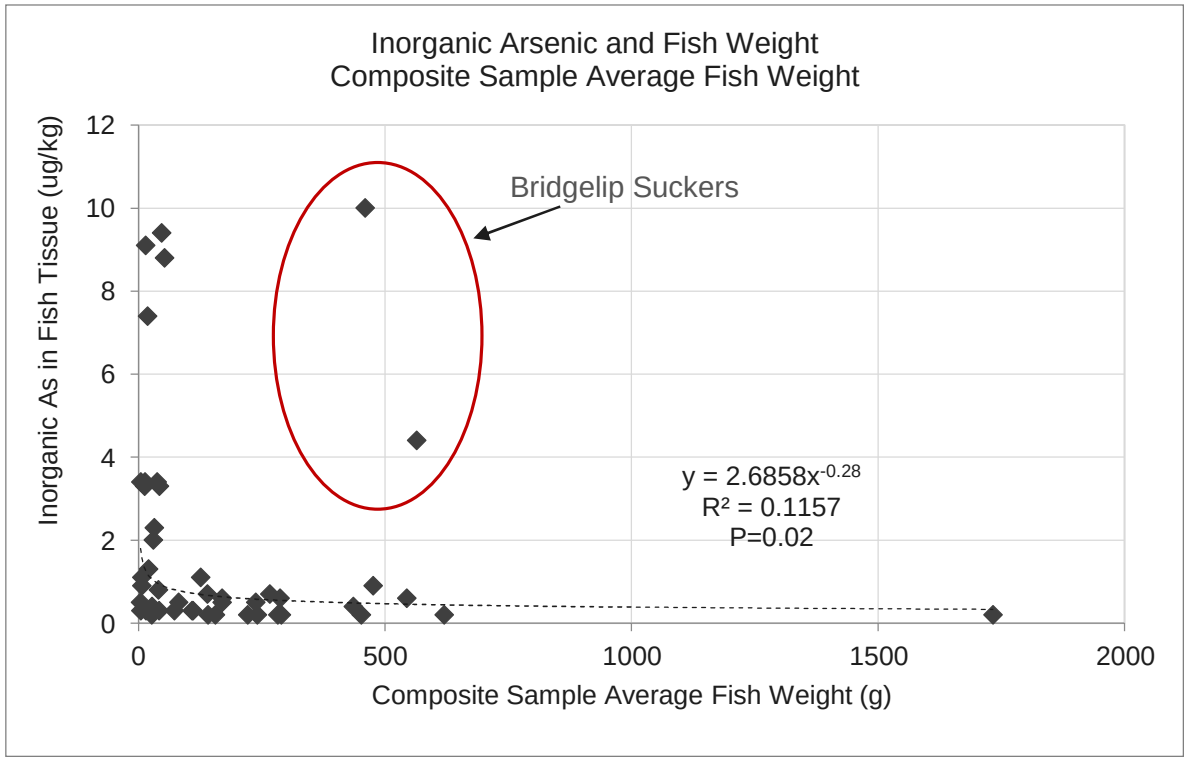
1. Multivariate Analysis

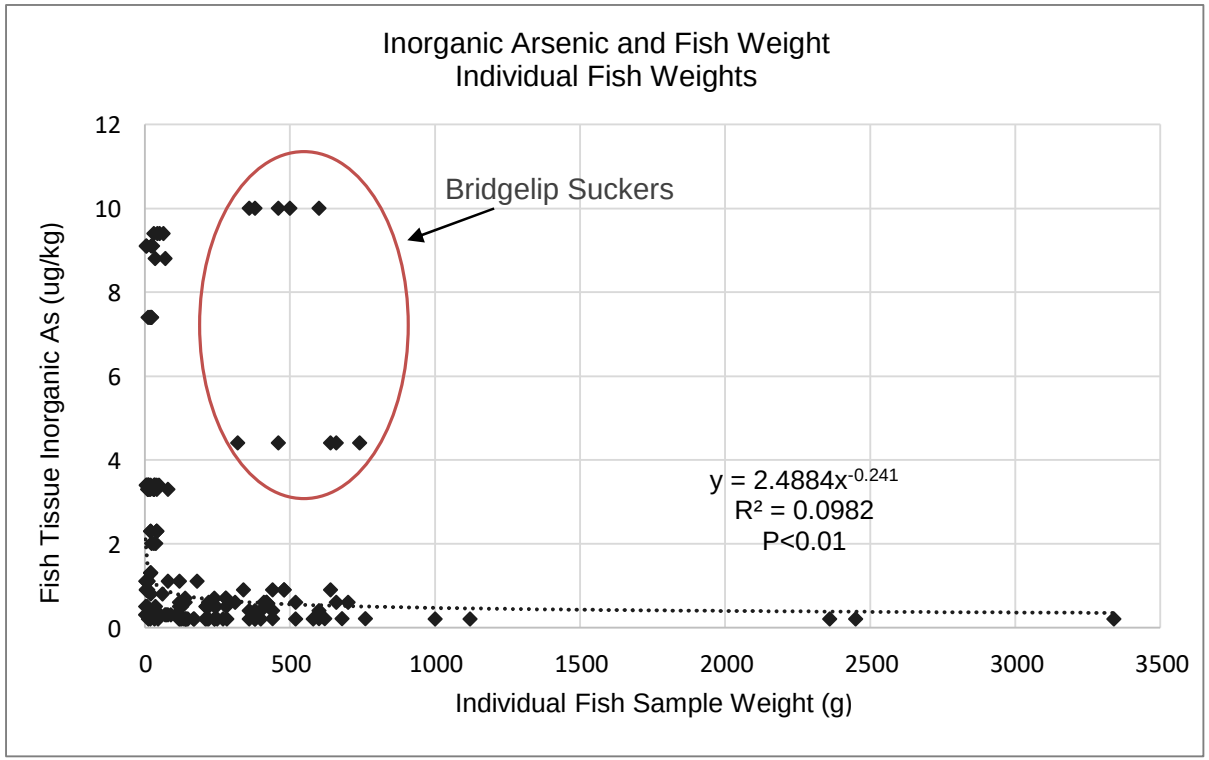
- Identify parameters with a statistically significant effect on iAs concentration in fish tissue
- Only fish weight has a statistically significant effect on iAs tissue concentration

Parameter	F-Ratio	P-value
Basin	0.88	0.51
Species	1.66	0.14
Feeding Guild	0.09	0.77
Average Fish Sample Weight*	12.4	**0.002**
Tissue Total As	0.78	0.39
Surface Water Total As	1.74	0.20
Surface Water Inorganic As	3.09	0.09
Error		

*Average weight of composite sample fish

2. Relationship Between Fish Weight and iAs in Tissue

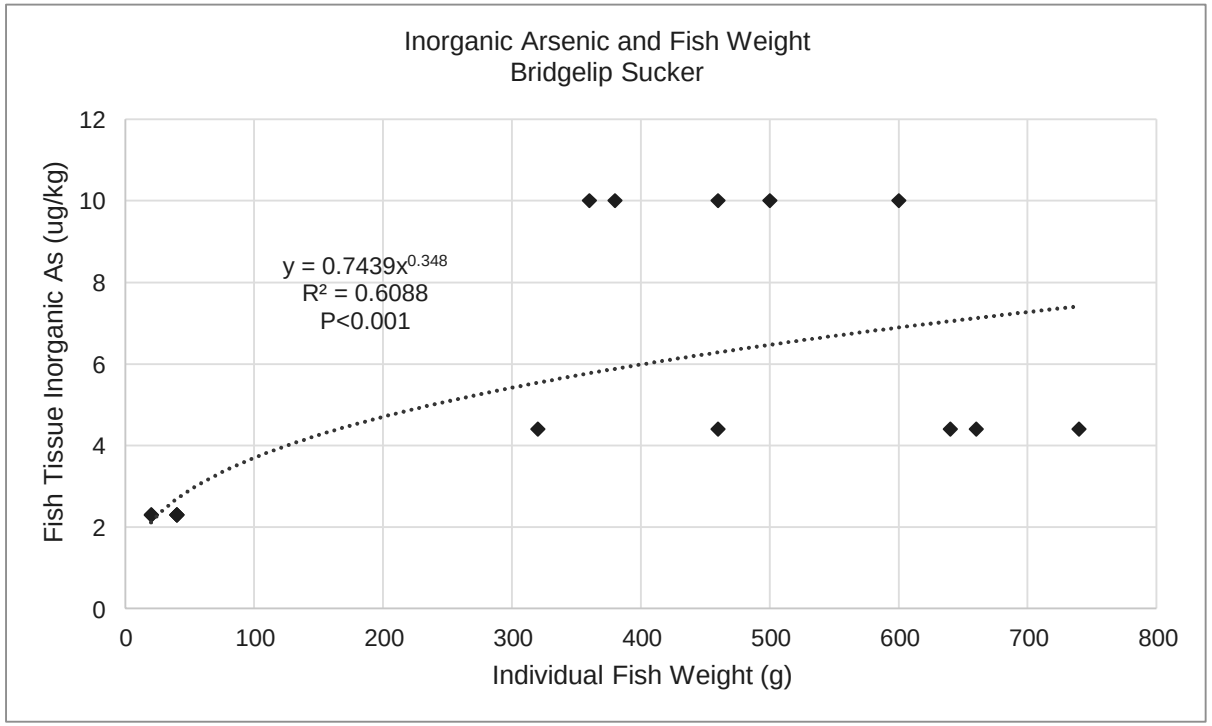




- Fish <100 g have a large range of iAs tissue concentrations
- Virtually all fish >100 g have iAs tissue concentration ≤1 µg/kg
  - Bridgelip sucker is the exception

2. Relationship Between Weight and iAs in Tissue - Bridgelip Sucker

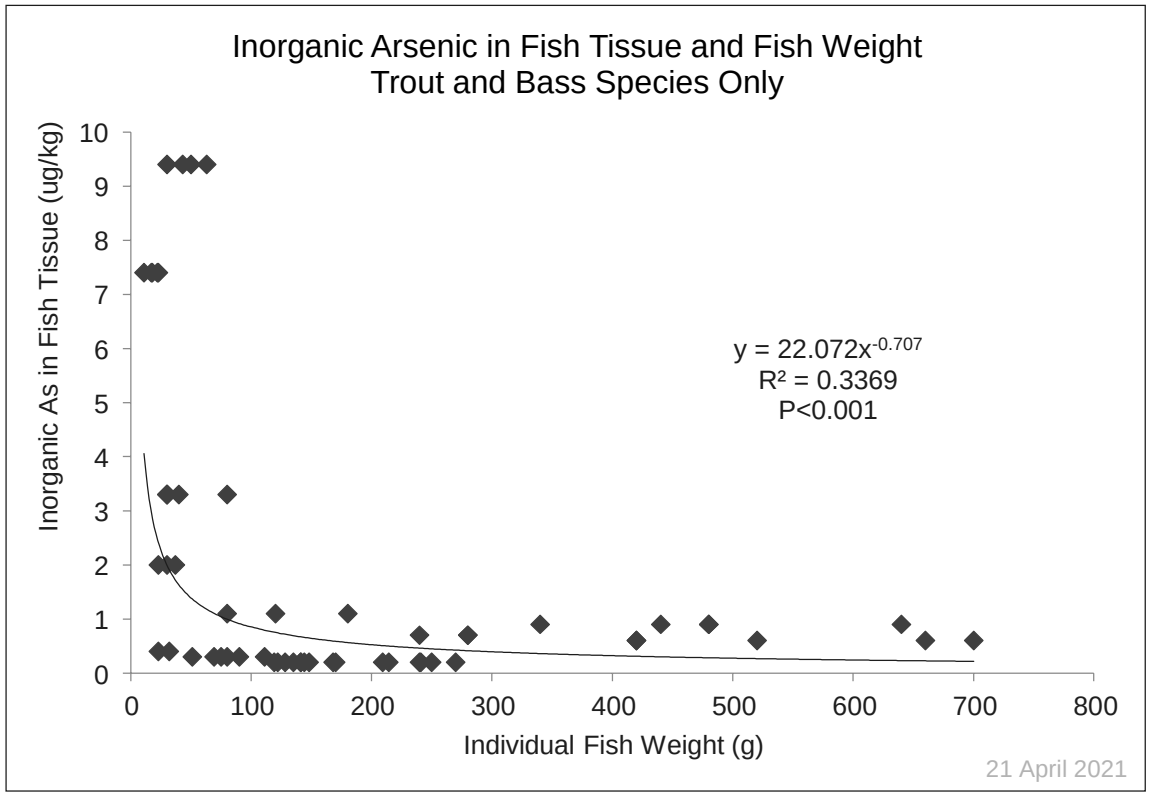
- iAs tissue concentrations increase with increasing weight
- Bridgelip sucker diet changes from primarily aquatic insect larvae for small suckers (<150 mm in length) to primarily herbivorous as suckers grow larger (Dauble 1980)



- As a result, suckers transition from a higher to a lower trophic level with increasing weight, likely explaining the increase in iAs tissue concentration with increasing weight

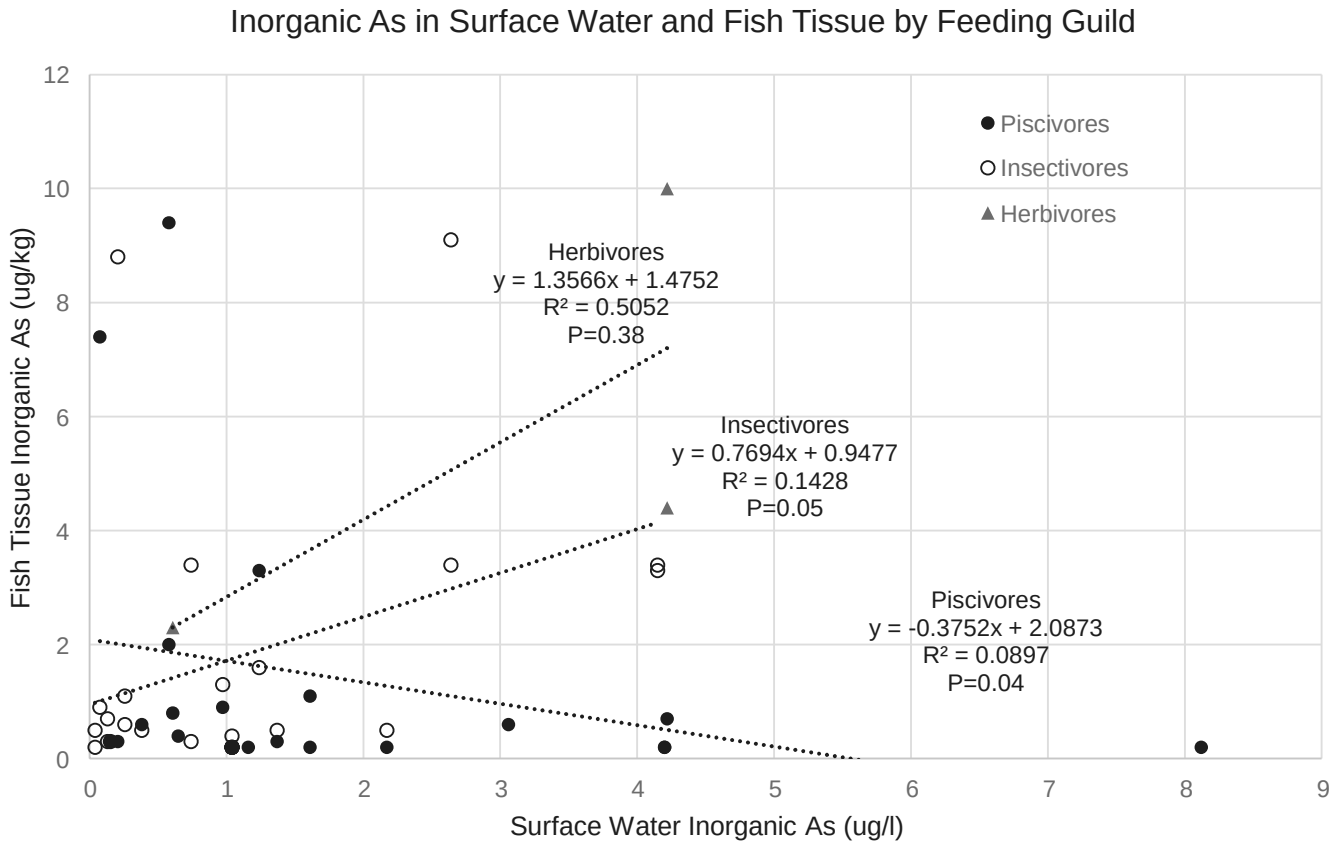
2. Relationship Between Weight and iAs in Tissue - Trout and Bass Species

- Brown trout, rainbow trout, brook trout, largemouth bass, and smallmouth bass are primarily piscivorous as adults
- Young may have more insectivorous diet (i.e. lower trophic level)
  - Change in iAs concentration as fish grow and transition from lower to higher trophic levels
- The decrease in iAs tissue concentration with increasing weight is statistically significant



3. Effect of Feeding Guild on the Relationship Between iAs in Tissue and Surface Water

- Herbivorous fish – not statistically significant, small sample size (n=3)
- Insectivorous and piscivorous fish – significant relationships between iAs in surface water and fish tissue
- However, little of the variation in tissue iAs concentrations is explained by iAs in surface water



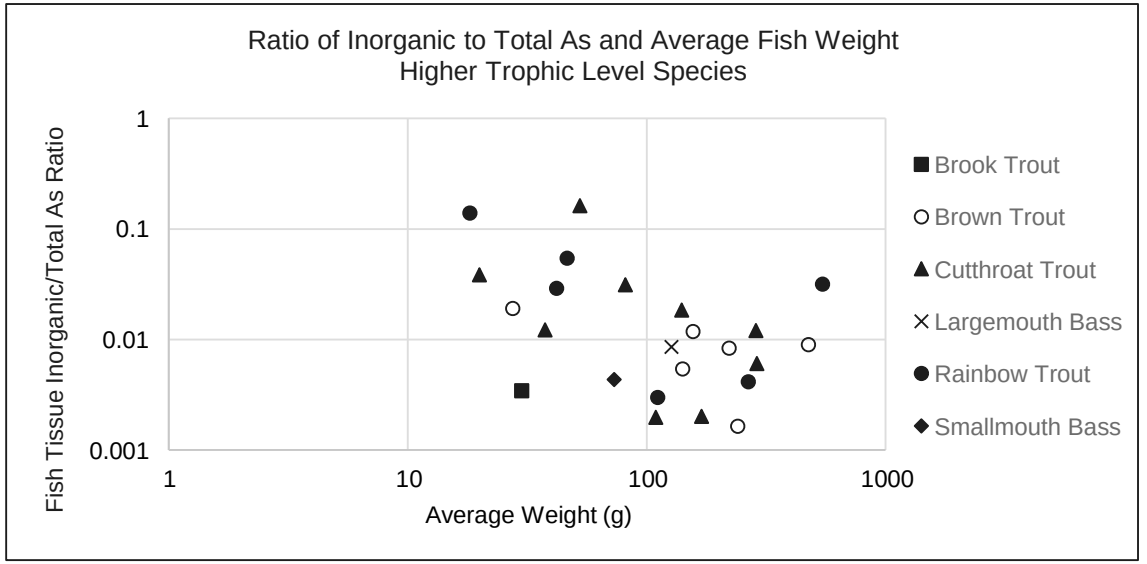
3. Effect of Feeding Guild on the Relationship Between iAs in Tissue and Surface Water

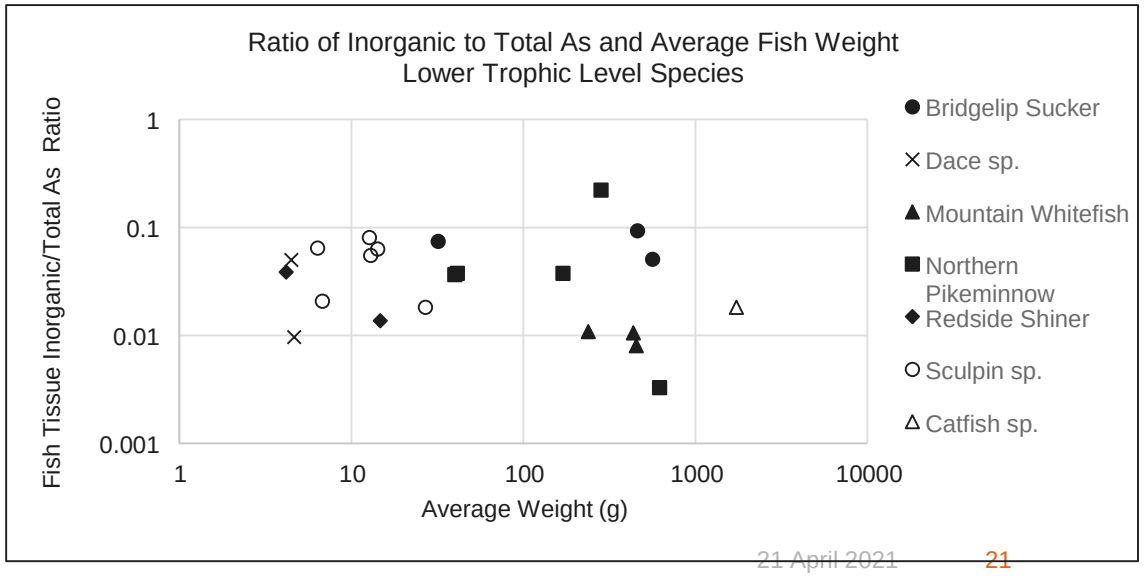
- tAs highest in herbivorous fish, followed by piscivorous fish, and lowest in insectivorous fish
- iAs highest in herbivorous fish, then insectivorous fish, and lowest in piscivorous fish
- Herbivorous fish (bridgelip sucker)
  - Longer and heavier than the insectivorous and piscivorous fish
  - But higher As concentrations because diet is primarily algae
- Consistent with literature

Guild	Median Sample Weight (grams) (Min – Max)	Median Sample Length (mm) (Min – Max)	Median Inorganic Arsenic (µg/kg) (Min – Max)	Median Total Arsenic (µg/kg) (Min – Max)
Herbivororous	380 (20 - 740)	340 (135 – 400)	4.4 (2.3 – 10)	87 (31 – 108)
Insectivorous	20 (2 – 600)	110 (60 – 400)	0.6 (0.2 – 9.1)	41 (11 – 278)
Piscivorous	240 (11 – 2,450)	240 (110 – 540)	0.4 (0.2 – 9.4)	53 (0.9 – 583)

4. Relationship Between Ratio of iAs to tAs and Fish Weight

- Literature suggests larger, higher trophic level fish are likely to have lower of iAs to tAs ratios than lower trophic level species
- The ratio of iAs to tAs in most higher trophic level species declined with increasing body weight as these species transitioned to a higher trophic level
- The ratio of iAs to tAs in lower trophic level fish did not change substantially with increasing weight
- 2019 IDEQ data consistent with literature





4. Ratio of iAs to tAs: Fish Weight and Trophic Level

- The iAs to tAs ratio tends to decrease with increasing weight and with increasing trophic level

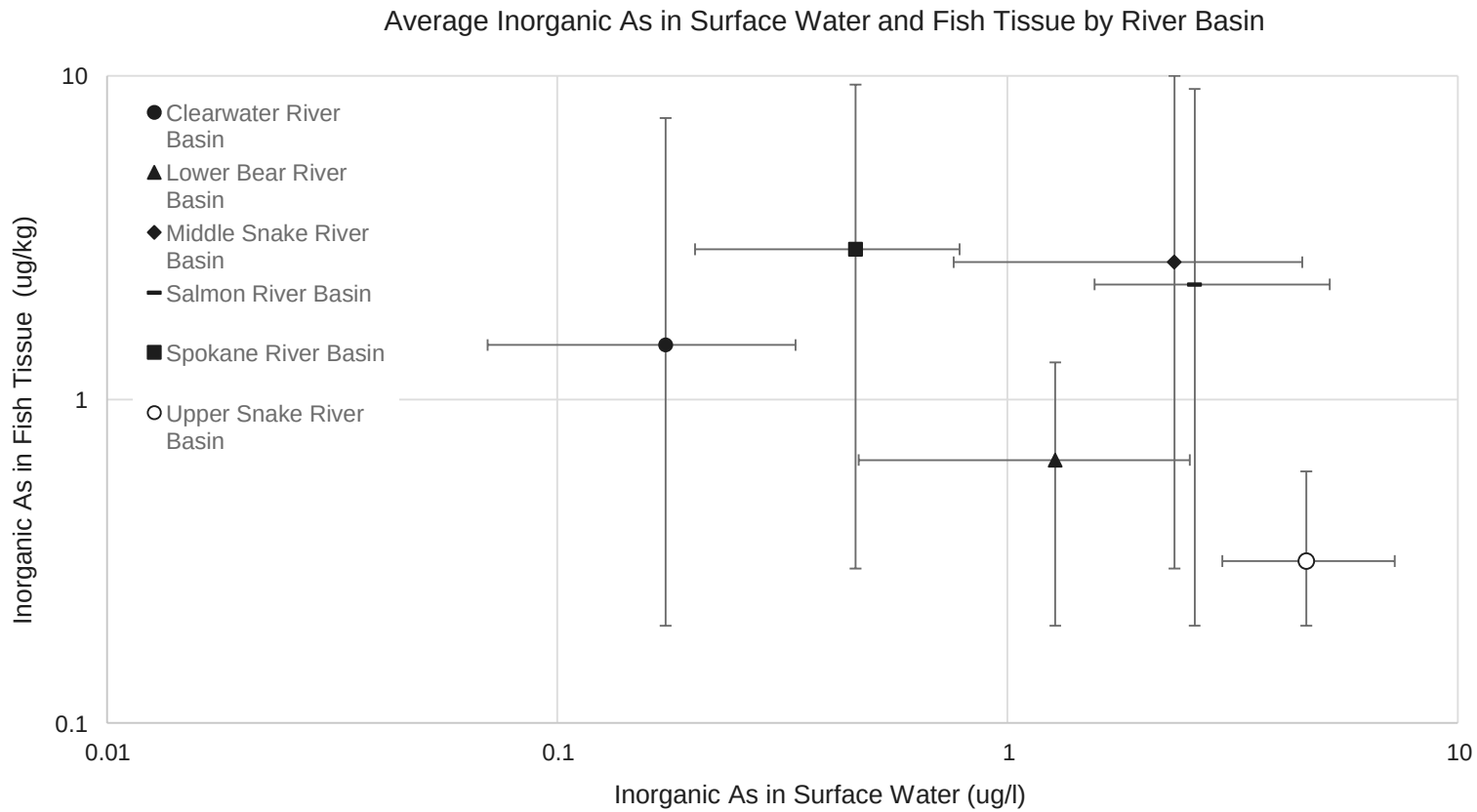
A = algae
I = insects
F = fish

Species	Primary Diet Components of Adult Fish	Weight Range (g)						Individual Species Average
		0-24	25-49	50-99	100-249	250-999	1000+	
Bridgelip Sucker	A		0.07			0.07		0.07
Common Carp	A, I						0.02	0.02
Dace sp.	A, F	0.03						0.03
Catfish	A, I, F						0.02	0.02
Mountain Whitefish	I				0.01	0.01		0.01
Sculpin sp.	I	0.05	0.02					0.05
Redside Shiner	I, F	-0.03						0.03
Brook Trout	I, F		0.003					0.003
Brown Trout	I, F		0.02		0.06	0.009		0.009
Cutthroat Trout	I, F	0.04	0.01	0.1	0.008	0.008		0.03
Rainbow Trout	I, F	0.14	0.04		0.003	0.02		0.04
Northern Pike Minnow	I, F		0.04		0.04	0.11		0.07
Smallmouth Bass	F			0.004				0.004
Largemouth Bass	F				0.009			0.003
Weight Class Average		0.05	0.03	0.07	0.01	0.02 (0.01)[a]	0.02	

[a] Weight class average if bridgelip sucker samples are excluded.

5. Effect of River Basin on the Relationship Between iAs in Tissue and Surface Water

- Overlap in fish tissue iAs concentrations across river basins
- Some river basins have no overlap in surface water iAs concentrations
- iAs concentrations in tissue and water are independent



Notes:
•Horizontal bars represent the min and max of the surface water iAs concentrations at each basin
•Vertical bars represent the min and max of the fish tissue iAs concentrations at each basin

Conclusions

Conclusions

- 2019 Idaho data are consistent with trends reported in the literature across a wide variety of study locations and freshwater aquatic foodwebs
- Further evaluation of the 2019 data indicates:
  - iAs undergoes biodilution/biodiminuition (decrease in concentration with increasing trophic level) in Idaho aquatic food webs
  - iAs tissue concentrations decrease with increasing fish size and trophic level, regardless of iAs concentration in surface water for most fish species
  - Organic As is the primary form of As in fish tissue, especially in larger and upper trophic level fish likely because of metabolic transformation of iAs to organic As
- As a result, iAs in surface water is not predictive of iAs in fish tissue

Thank you!

Questions/Discussion

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