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

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Presenters

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Introduction
Idaho 2019 Data - Summary of Previous Analyses

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

\[ y = 2.0932x + 75.185 \]
\[ R^2 = 0.0013 \]
\[ P = 0.81 \]

\[ y = 0.1802x + 1.5901 \]
\[ R^2 = 0.0116 \]
\[ P = 0.48 \]

\[ y = 0.0977x + 1.6812 \]
\[ R^2 = 0.0038 \]
\[ P = 0.69 \]
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)
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
• Studies using stable isotope analysis to quantify organism trophic level position demonstrate biodimination (Revenga et al., 2012)
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 arsenobetainee (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

<table>
<thead>
<tr>
<th>Species</th>
<th>Guild/Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridgelip sucker</td>
<td>Herbivore</td>
</tr>
<tr>
<td>Cutthroat trout</td>
<td>Insectivore</td>
</tr>
<tr>
<td>Dace sp.</td>
<td>Insectivore</td>
</tr>
<tr>
<td>Mountain whitefish</td>
<td>Insectivore</td>
</tr>
<tr>
<td>Reside shiner</td>
<td>Insectivore</td>
</tr>
<tr>
<td>Sculpin sp.</td>
<td>Insectivore</td>
</tr>
<tr>
<td>Catfish sp.</td>
<td>Piscivore</td>
</tr>
<tr>
<td>Brook trout</td>
<td>Piscivore</td>
</tr>
<tr>
<td>Brown trout</td>
<td>Piscivore</td>
</tr>
<tr>
<td>Largemouth bass</td>
<td>Piscivore</td>
</tr>
<tr>
<td>Northern pikeminnow</td>
<td>Piscivore</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>Piscivore</td>
</tr>
<tr>
<td>Smallmouth bass</td>
<td>Piscivore</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>F-Ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin</td>
<td>0.88</td>
<td>0.51</td>
</tr>
<tr>
<td>Species</td>
<td>1.66</td>
<td>0.14</td>
</tr>
<tr>
<td>Feeding Guild</td>
<td>0.09</td>
<td>0.77</td>
</tr>
<tr>
<td>Average Fish Sample Weight*</td>
<td>12.4</td>
<td><strong>0.002</strong></td>
</tr>
<tr>
<td>Tissue Total As</td>
<td>0.78</td>
<td>0.39</td>
</tr>
<tr>
<td>Surface Water Total As</td>
<td>1.74</td>
<td>0.20</td>
</tr>
<tr>
<td>Surface Water Inorganic As</td>
<td>3.09</td>
<td>0.09</td>
</tr>
</tbody>
</table>

*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

\[
y = 22.072x^{-0.707} \\
R^2 = 0.3369 \\
P < 0.001
\]
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

<table>
<thead>
<tr>
<th>Guild</th>
<th>Median Sample Weight (grams) (Min – Max)</th>
<th>Median Sample Length (mm) (Min – Max)</th>
<th>Median Inorganic Arsenic (µg/kg) (Min – Max)</th>
<th>Median Total Arsenic (µg/kg) (Min – Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbivorous</td>
<td>380 (20 - 740)</td>
<td>340 (135 – 400)</td>
<td>4.4 (2.3 – 10)</td>
<td>87 (31 – 108)</td>
</tr>
<tr>
<td>Insectivorous</td>
<td>20 (2 – 600)</td>
<td>110 (60 – 400)</td>
<td>0.6 (0.2 – 9.1)</td>
<td>41 (11 – 278)</td>
</tr>
<tr>
<td>Piscivorous</td>
<td>240 (11 – 2,450)</td>
<td>240 (110 – 540)</td>
<td>0.4 (0.2 – 9.4)</td>
<td>53 (0.9 – 583)</td>
</tr>
</tbody>
</table>
4. Relationship Between Ratio of iAs to tAs and Fish Weight

- Literature suggests larger, higher trophic level fish are likely to have lower ratios of iAs to tAs 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

<table>
<thead>
<tr>
<th>Species</th>
<th>Primary Diet Components of Adult Fish</th>
<th>Weight Range (g)</th>
<th>Individual Species Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0-24</td>
<td>25-49</td>
</tr>
<tr>
<td>Bridgelip Sucker</td>
<td>A</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Common Carp</td>
<td>A, I</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Dace sp.</td>
<td>A, F</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Catfish</td>
<td>A, I, F</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Mountain Whitefish</td>
<td>I</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Sculpin sp.</td>
<td>I</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Redside Shiner</td>
<td>I, F</td>
<td>-0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Brook Trout</td>
<td>I, F</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Brown Trout</td>
<td>I, F</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>Cutthroat Trout</td>
<td>I, F</td>
<td>0.04</td>
<td>0.1</td>
</tr>
<tr>
<td>Rainbow Trout</td>
<td>I, F</td>
<td>0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>Northern Pike Minnow</td>
<td>I, F</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Smallmouth Bass</td>
<td>F</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Largemouth Bass</td>
<td>F</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>Weight Class Average</td>
<td></td>
<td>0.05</td>
<td>0.03</td>
</tr>
</tbody>
</table>

A = algae  
I = insects  
F = fish  

*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
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