Mercury (Hg) and Selenium (Se) in Colorado Pikeminnow and in Razorback Sucker from the San Juan River

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Why are Hg and Se of concern?

- Widespread concerns about Hg contamination of fish: Fish consumption advisories in San Juan River Basin (CO, NM, UT, Navajo Nation)

- Se & Hg in endangered fish may indicate injury & suggest slowed recovery in the wild

- Public concern about coal-fired power plant emissions
Sources of Mercury to the SJRB

- **Natural Sources (31%)**:
  - Volcanoes
  - Forest fires volatize Hg (re-emission; Hg is a grasshopper pollutant)

- **N. Amer. Sources (30%)**:
  - Burning activities
    - Coal-fired power plants
    - Incinerators, crematoria
  - Hg devices, home wastes
  - Gold-mining activities

- **Sources in Asia (~21%)**
San Juan River Basin Mercury Deposition Annual Total (in 2001-05) was 712 kg (~1600 lbs) - USEPA 2005
San Juan River Basin Mercury Deposition Annual Total in 2020 is expected 957 kg (~35% increase) – based on UNEP 2008
Watershed Mercury Processes

Natural Emissions

Anthropogenic Emissions

Wet Deposition

Dry Deposition

Litterfall and Throughfall

Runoff and Erosion

Shallow Ground Water

Percolation

Weathering

Evasion

Settling Resuspension Diffusion

Rivers
Mercury in San Juan River food webs

- Predator Fish: Colorado Pikeminnow
- Prey Fish (example): flannelmouth sucker
- Aquatic invertebrates
- Periphyton & Vegetation

Boxplot of mercury (ug/g ww) in whole fish from the San Juan River (reported by Simpson and Lusk 1999)

- Detritivore: n=46
- Insectivore: n=86
- Omnivore: n=196
- Piscivore: n=7

HG_WET: F(3,331) = 7.1841, p = 0.0001; KW-H(3,335) = 19.9389, p = 0.0002

• Few fish Hg data relevant to piscivorous pikeminnow – more data needed...
2007-10: Osmundson Pikeminnow Study

- Determine Hg concentrations in Colorado pikeminnow throughout critical habitat using muscle plugs
- Assess health risks to Colorado pikeminnow from Hg exposure
  - Osmundson and Lusk expanded scope of study in San Juan River basin to include razorback sucker, selenium analyses and mercury analyses of museum pikeminnow.
San Juan River 2009 Hg & Se data for Pikeminnow & Razorback Muscle Tissues

Ln(Se) and Ln(Hg) in pikeminnow and razorback sucker muscle tissues collected from the San Juan River 2009

LnHG: F(1,44) = 0.0184, p = 0.8928; KW-H(1,46) = 0.0809, p = 0.7760
LnSe: F(1,43) = 1.0906, p = 0.3022; KW-H(1,45) = 1.0611, p = 0.3030

We expected ratio of Hg in Pikeminnow–to-sucker to be ~ 4 (as other basins)?
Total length (mm) and Weight (g) of Colorado pikeminnow collected in Upper Colorado River Basins in 2008-09
[Basin: CRB=Upper Colorado River; GRN=Green River; SJR=San Juan River; WRB=White River; and, YRB=Yampa River]

- Length_mm: \( F(4,91) = 45.1605, p = 0.0000; \)
- KW-H(4,96) = 60.7845, \( p = 0.0000 \)
- Weight_g: \( F(4,89) = 25.8306, p = 0.0000; \)
- KW-H(4,94) = 61.9863, \( p = 0.0000 \)

**Basin: CRB GRN SJR WRB YRB**

- **Total Length (mm)**
  - CRB: 0
  - GRN: 500
  - SJR: 1000
  - WRB: 1500
  - YRB: 2000

- **Total Weight (g)**
  - CRB: 2500
  - GRN: 3000
  - SJR: 3500
  - WRB: 4000
  - YRB: 4500

**Outliers**

**Extremes**
San Juan River Pikeminnow were Small

Histogram of Colorado Pikeminnow Total Length (mm)
Blue = Includes San Juan River pikeminnow
Red = Does not include San Juan River pikeminnow
BoxPlot of Mercury (ug/g ww) in Colorado Pikeminnow muscle by Watershed and the San Juan River by Size Class

[Watershed: SJR 200-San Juan River 200mm; SJR 300-San Juan River 300mm; SJR 400-San Juan River 400mm;
CRB-Upper Colorado River; GRN-Gren River; WRB-White River; YRB-Yampa River]
Scatterplot of the natural logarithm of mercury in muscle tissue (ug/g wet weight) and total length (mm)

Pikeminnow tissues collected from the Colorado (CRB), Green (GRB), San Juan (SJR), White (WRB), and Yampa (YRB) River Basins.

Linear Model: \( \text{LnHg (muscle)} = -3.2054 + 0.0046 \times \text{Total Length} \)
\[ r = 0.7447, \ p = 0.0000 \]

Polynomial model (red line with 0.9 conf. int.) \( \text{LnHg} = -5.8803 + 0.0171 \times x - 1.3182E-5 \times x^2 \)
BoxPlot of Mercury in Colorado Pikeminnow by Decade
[Watershed: GRN-Green River; SJR-San Juan River; YRB-Yampa River]

- **Median**
- **25%-75%**
- **Non-Outlier Range**
- **Outliers**
- **Extremes**

### Watershed: GRN-Green River
- **1960**: (n=29)
- **2010**: (n=29)

### Watershed: SJR-San Juan River
- **1960**: (n=13)
- **2010**: (n=8)

### Watershed: YRB-Yampa River
- **1960**: (n=2)
- **2010**: (n=9)
Mercury Emissions over Time

YEAR (AD)

- 2000
- 1950
- 1900
- 1850
- 1800
- 1750
- 1700

TOTAL MERCURY (ng/L)

- Mt St Helens (1980 AD)
- Industrialization (circa 1880-present)
- WWII manufacturing (circa 1940-45 AD)
- Krakatau (1883 AD)
- Gold Rush (circa 1850-64 AD)
- "Unknown"
- Tambora (1815 AD)
- Pre-industrial

Hg Flux (ng/cm²/yr)

Crater Lake

Clear Lake

White Dome

USGS Hg in Ice Cores

Nydick 2008 Sediment HG in Western CO
What are Mercury Effects to Fish?

- **Potent Neurotoxin**
  - Affects central nervous system (reacts with brain enzymes, then lesions)
  - Affects hypothalamus and pituitary, affects gonadotropin-secreting cells
  - Altered behaviors: Reduced predator avoidance, reproductive timing fail
  - Reduced ability to feed (emaciation/growth effects)

- **Endocrine disruptor**
  - Suppressed reproductive hormones in male and female fish
  - Reduce gonad size and function, reduced gamete production
  - Altered ovarian morphology, delayed oocyte development
  - Reduced reproductive success
  - Transfer of dietary Hg of the maternal adult during oogenesis and into developing embryo

- Fish have inability to grow new brain cells or significantly reduce brain Hg

- **Beckvar (2005)** - survival, growth, reproduction, behavior at 0.2ug/g in whole fish
- **Yeardley (1998)** - Hg > 0.1 mg/kg WW likely harmful to piscivorous mammals
- **USEPA (2000)** - Hg > 0.3 mg/kg WW likely harmful to certain people that eat fish
Current and expected future (35.5% increase by 2020) whole-body mercury concentrations in Colorado Pikeminnow along with reproductive, behavioral, and lethal effects concentrations for surrogate species described by Beckvar et al. (2005).
Potential effects to pikeminnow recovery

- Assume a recovered pop of pikeminnow in San Juan River of 700 adult (450 mm+) fish
- ~ 350 female pikeminnow, & each averages 77,400 eggs/F = 27 million eggs per year

No. of Viable Eggs and Surviving Larvae Under Each Scenario

- Recovered Pop San Juan
- 2010 Fecundity with Hg effects
- 2010 Fecundity with Se effects
- 2020 Fecundity with future Hg
- 2020 Fecundity with add'l stressors?
Sources of Selenium

Natural Sources:
- Geology (e.g., shales)
- Se Accumulator plants

Anthropogenic Se
- Irrigation of Se-rich soils
- Coal mining, leaching
- Power plant emissions & flyash
Selenium (Se) Cycling

- Soils of marine origin naturally Se-rich (Cretaceous Period shale, coals)
- Se enters surface waters thru erosion, leaching, & runoff of Se-rich soils
- Burning of coal with Se air emissions, deposition to land, surface runoff
- Contributions of Se in invertebrates, algae, and fish in the San Juan River have increased with expansion of agriculture & energy development
BoxPlot of selenium (ug/g dry weight) in plants and invertebrate samples (in green) and whole body fish (in red) collected from the San Juan River (upstream Reach 8 to downstream Reach 1) 1990-1996
Boxplot of selenium (ug/g dry weight) in whole body fish composites collected from the San Juan River and its tributaries (1990-1996)
(4 ug/g is Se level of concern in whole body fish)
Boxplot of Selenium in Colorado Pikeminnow muscle tissues over time in the San Juan River

Selenium (ug/g dry weight)

- Median
- 25%-75%
- Non-Outlier Range
- Outliers
- Extremes

(n=28)
(n=4)
(n=2)

1959 1993 2009

Se ppm DW: F(2,31) = 0.2624, p = 0.7709;
KW-H(2,34) = 0.9338, p = 0.6269
Boxplot of Selenium in Razorback sucker muscle tissues over time in the San Juan River

Se ppm DW: F(1,40) = 3.6995, p = 0.0616; KW-H(1,42) = 8.3955, p = 0.0038
Boxplot of selenium (ug/g dry weight) in razorback sucker muscle tissues in the San Juan River by river reach (rounded) and over time

- Selenium in RBS in 1995
  - Outliers
  - Extremes
- Selenium in RBS in 2009
  - Outliers
  - Extremes

Se ppm DW: $F(10,14) = 0.3773, p = 0.9367$; $KW-H(10,25) = 5.5907, p = 0.8484$
Se ppm DW: $F(6,10) = 2.4756, p = 0.0986$; $KW-H(6,17) = 9.2706, p = 0.1589$
Scatterplot of selenium in razorback sucker muscle tissue by mass (weight in grams)

Natural Logarithm of Selenium Concentrations (ug/g dry weight)

Weight_g: LnSe: y = 1.08 + 0.0002x; r = 0.1999, p = 0.2044; 
\( r^2 = 0.0399 \)
Effects to Fish from Excess Selenium

- **Se is a teratogen (larvae have defects)**
  - Adult fish appear healthy (but pop often declines over time)
  - Dietary Se is most important
  - Deformities of larvae are in response to maternal exposure
    - Subsequent deposit of excess Se into their eggs
    - Yolk absorption by embryo/larvae during development leads to oxidation of enzymes and tissues and deformities occur
      - Deformed larvae have reduced survival, reduced growth
  - Those larvae that remain may also have reduced survival if Se body burden plus Se in their diet exceeds safe dose
**Effects of Se in diet of larval Razorback Sucker (Hamilton & Beyer studies)**

- Used dose studies to describe a relationship between larval survival and dietary selenium specifically for 5 to 35 day razorback sucker larvae.
  - 1990-96 razorback surrogate diet range <0.1-18 μg/g; $\bar{X}=4.5$ μg/g
  - If Se increases (120%) proportional to diet 0.3–40 μg/g; $\bar{X}=10$ μg/g

![Graph showing survival rates against selenium concentration in diet](image-url)
Possible effects of Se (&Hg) on razorback sucker recovery

Recovered pop in San Juan River = ~ 2900 razorback sucker

No. of Viable Eggs and Larvae Under Each Scenario
Ideas on Actions to Answer Questions

- Monitor Hg and Se in fish, water, air, and sources
- Monitor biomarkers in endangered or surrogate fish, e.g., vitellogenin levels, sex hormones, histopathology
- Reduce Hg/Se globally, nationally, and locally
- TMDL for Hg/Se in San Juan River Basin
- Se/Hg isotope study to validate sources
- Conduct lab studies exposing endangered fish (adults and larvae) to mercury and selenium in diets
Acknowledgements

- USFWS Colorado River Recovery Program
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- Navajo Nation Department of Fish and Wildlife
- Navajo Nation Environmental Protection Agency
- Colorado Division of Wildlife
- USFWS New Mexico Ecological Services Field Office
- USFWS Environmental Contaminants Program
- USGS Biological Surveys Collection at UNM
- UNM Museum of Southwestern Biology
- Bureau of Indian Affairs –SWRO, NRO
- Region 9 US Environmental Protection Agency

Thanks
Following slides are not used in the presentation, but are for questions

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Should Take Action >

Take Action >

Take Action >
Hg and Se in San Juan River water

Selenium in the San Juan River (BIA/KB 1994-2006)

<table>
<thead>
<tr>
<th>BIA Monitoring Location</th>
<th>T-Se Avg (Range)</th>
<th>WQS: NM=5 TR; NN=2T</th>
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<tbody>
<tr>
<td>SJR at Archuleta, NM</td>
<td>&lt;1 ug/L</td>
<td>does not exceed</td>
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<tr>
<td>SJR at Farmington, NM</td>
<td>0.5 (0.02-2.0) ug/L</td>
<td>max exceeds NN</td>
</tr>
<tr>
<td>SJR at Shiprock, NM</td>
<td>0.6 (0.02-7.0) ug/L</td>
<td>max exceeds NN, NM</td>
</tr>
<tr>
<td>SJR at Mexican Hat, UT</td>
<td>1.1 (0.08-7.0) ug/L</td>
<td>max exceeds NN, NM</td>
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</tbody>
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Mercury in the San Juan River

- Data are not adequate for WQStds evaluation: (~>0.2 ug/L)
- Navajo Nation WQS=0.001ug/L Hg; 0.0001ug/L MeHg
- New Mexico WQS = 770ug/L Hg
- Both NM and NN = 0.3 ug/g wet weight Hg in fish fillets