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Mercury in the Pelagic and Benthic Food Webs of the Great Salt Lake

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Jodi Gardberg
Utah Division of Water Quality

Great Salt Lake Technical Team – July 20, 2011
Great Salt Lake Diet Analyses
Hypothesized, literature

Birds

Avocets
BN stilts
Goldeneye
Phalaropes
Eared grebe
Calif. gulls
Brine fly adults

Brine Shrimp

Misc. Invertebrates

Freshwater Periphyton & detritus

Phytoplankton

Biostrome Periphyton

Brine Fly Larvae

69%
11%
80%
48%
56%
11%
70%
52%
20%
Do Brine Shrimp Bioaccumulate Methylmercury From the Deep Brine Layer of the Great Salt Lake?

Erin Fleming and Wayne Wurtsbaugh
Department of Watershed Sciences
Utah State University

Project Funded by The Division of Forestry, Fire & State Lands
Formation of the Deep brine layer (Monimolimnion)

- 10-16% Salinity
- 6.3 m (20.7')
- 2 m (max)
- 6.6'
- Anoxic, sulfur rich water
Distinctive microbial community in anoxic, sulfide-rich waters

Photosynthetic purple-sulfur bacteria from 6.5 m (not present in recent years)

Photo, April 1987
• Background

• Although there is normally insufficient light for photosynthesis, the deep brine layer is extremely rich in sedimenting organic material.

• Total mercury, and especially methyl mercury, is extremely high in deep-brine layer (Naftz et al. 2008).

• Because of the high density water, the deep-brine layer has limited ability to mix into the upper mixed layer. However, some limited mixing is expected, but the amount is unknown.
• Objectives

• Determine if brine shrimp graze at the interface of the deep brine layer and take up mercury from that layer

• Determine whether mercury uptake by shrimp is enhanced if deep brine layer is mixed into the upper layer
Study Design

- Measure profiles of mercury and relevant limnological parameters in an area of Gilbert Bay underlain by the deep brine layer.
- Measure mercury uptake of brine shrimp in mesocosms that simulated a water column with, and without, a deep brine layer.
- Measure mercury uptake in brine shrimp when deep brine layer water is mixed with surface water.
- Preliminary measurements & experiments in 2009, more detailed ones in 2010.
Field study (2010)

Pumped water from specific depths for chemical analyses & brine shrimp counts.

Collected water for laboratory experiments.
Deep Brine Water Characteristics

- Mixed layer
  - 3 m
- Deep Brine
  - 7 m

- High organic matter
  - Particulate
  - Dissolved organic carbon (DOC)
    - 3 m – 42 mg C/L
    - 7 m – 53 mg C/L
  - DOC binds with and maintains mercury in solution

- Anoxic

- \( H_2S \) – rich (toxic)
  - Sulfide reduction linked to production of methyl mercury

- High mercury, especially methyl mercury
Field study (August 3, 2010)

- Particulate carbon
- Water for Laboratory Experiments

Particulate Carbon (mg L\(^{-1}\))

Mercury (ng L\(^{-1}\))

Mixed Layer Means:
- Total Hg 2.2 ng L\(^{-1}\)
- Methyl Hg 1.2 ng L\(^{-1}\)

Artemia (Number L\(^{-1}\))

Artemia Hg (ng/g dry wt.)

620 ± 0.08
Vertical stratification simulation

Experimental Design:

- Six, 46-L columns
- 3 columns with deep brine water, 3 without
- 18:16 light:dark regime to promote photosynthesis
- 27°C
- 10 *Artemia* nauplii/L
- 14 day-long experiment
  *Artemia* grew from 1-mm to maturity (~9 mm)
Mercury concentrations in columns

- **Mixed columns**
  - **Uniform Concentrations**
    - Methyl Hg – 0.7 ng/L
    - Total Hg – 7.3 ng/L
Mercury concentrations in columns

- **Mixed columns**
  - Uniform Concentrations

- **Deep-brine columns**: High Hg in deeper water
  - Methyl Hg
    - 1-22 ng/L
  - Total Hg
    - 6-56 ng/L
Brine shrimp feeding in the deep-brine interface
Artemia Distribution in columns

- Shrimp concentrated at top and bottom in mixed-layer treatments
- They concentrated at deep-brine interface in the stratified columns
At end of experiment, brine shrimp in deep brine treatment had significantly lower levels of mercury, despite exposure to higher mercury levels!
Mixing simulation experiment in 34-L aquaria

- Three treatments (2 replicates each)
  - 0% deep brine; 100% mixed-layer
  - 10% deep brine; 90% mixed
  - 25% deep brine; 75% mixed

- 18:16 light:dark

- 27°C

- 10 *Artemia* nauplii/L

- 14 day-long experiment (*Artemia* grew to maturity)

- Aerated initially for 1 day to remove H$_2$S; 1 hr/day subsequently
Mixing simulation

• Significantly higher mercury in treatments with more deep brine water

• Increasing mercury from beginning to end of experiment

• (due to contamination from aeration?)
Poor *Artemia* survival after 14 d in treatments with higher proportions of deep-brine water. Toxic factor unknown (Hg?, Other metals? Organic compounds?)

![Graph showing Artemia survival rates](image)

**ANOVA:** $p = 0.002$
But, lower mercury levels in *Artemia* in treatments with more deep-brine water (higher mercury concentrations)!

ANOVA; \( p < 0.000 \)
Conclusions for Deep Brine Layer Experiments

- *Artemia* enter upper layer of deep brine layer, but do not penetrate far.

- In Column Experiment, growth and survival unaffected by presence of deep brine layer.

- In Aquaria Mixing Experiment, survival much lower in treatments with deep brine layer water: toxic component unknown.
In both experiments, mercury concentrations in *Artemia* were significantly lower when exposed to deep brine layer water with high methyl and total mercury concentrations.

Likely explanation: High particulate carbon concentrations in deep brine layer dilutes the mercury shrimp are consuming.

* 0.2 and 5.5 m values estimated based on chlorophyll a and Chl a:POC ratios

Depth of water used in lab experiments.
Mercury and selenium bioaccumulation in the stromatolite community of the Great Salt Lake, Utah, USA

Wayne Wurtsbaugh¹, Jodi Gardberg², Caleb Izdebski¹
¹Utah State University;  Utah DWQ²

Funding from the Utah Division of Water Quality
Reference for this biostrome research:

Biostrome Distribution in Gilbert Bay

- **Biostrome Structures**
  - Photo: Dave Liddell
  - Mounds, ca. 1-m high

**Study Sites**

- **Biostromes 11% (23%)**
- **Beneath deep brine layer (47%)**
- **Oolitic sand 31%**
- **Fine alluvium 7%**
- **Seiche-influenced alluvium 4%**

**After Eardley (1938)**

**Gilbert Bay**

10 km

**Bahamas**

**Photo: Dave Liddell**

**Mounds, ca. 1-m high**
Stromatolites (Biostromes)
Dominant hard substrate for periphyton, brine fly larvae & pupae

Distribution in Gilbert Bay

Anoxic deep brine layer

Aphanothece sp. (cyanobacteria)

Food Web Importance: Principal Brine Fly Habitat

Ephydra cinerea
Simple Food Web

Cyanobacteria → Brine fly larvae → Goldeneye, grebes, avocets, gulls, etc.

(Aphanothece sp.) and adults
Consumption Advisories on Three Species of Ducks

Goldeneye (Diet: 70% brine fly larvae)

Northern shoveler

Cinnamon teal

Goldeneye (Diet: 70% brine fly larvae)
Goldeneye increase Hg levels ~8X after arriving at Great Salt Lake and feeding on brine fly larvae.

Could be due to feeding on contaminated food in GSL, or because later-arriving birds have more mercury.
Questions

- How important are the stromatolite communities for algal and invertebrate production in the Great Salt Lake?

- Do mercury and selenium bioaccumulate in the stromatolite communities and contribute to the high mercury loads in ducks that feed in the lake?
Stromatolite Sampling Methods

- Brine fly larvae & pupae:
  - Bucket Sampler & SCUBA
  - Scrub stromatolite surface with brush

Mercury – 2008 (3 stations, 5 times, June – Dec)
Cold vapor atomic fluorescence spectrometry (USGS Lab)

Selenium – 2006-07 (2 stations, June)
Hydride generation & atomic fluorescence spectrometry – Frontier Geosci.
Biostrome Sampling Methods

Stromatolite chunks broken off underwater

• Chl a extracted
• Periphyton removed
  - With & without acidification to remove carbonates
• Portions preserved for mercury analyses

Adult brine flies collected on shore with net

• All Hg analyses by cold vapor atomic fluorescence spectrometry at the U.S. Geological Survey Wisconsin Mercury Research Laboratory
Abundance of Periphyton on Stromatolites Compared to Phytoplankton

Periphyton on biostromes estimated to contribute 40% of the primary productivity in Gilbert Bay (60% phytoplankton)

*Based on May-October phytoplankton in Gilbert Bay (2002-2005), and summer periphyton values
Brine fly larvae very abundant on stromatolites

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X = 15,500 larvae per square meter

Biomass per square meter comparable to that of brine shrimp

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X = 15,500 larvae per square meter

Biomass per square meter comparable to that of brine shrimp
Moderate Total Dissolved Mercury Concentrations in Water Over Biostromes

12 ng L\(^{-1}\): EPA Freshwater Aquatic Life Standard

Uncontaminated Worldwide MeHg baseline (0.3 ng L\(^{-1}\))

Gray and Hines (2009)
Mercury concentrations in brine flies are below, or at levels that have been shown to harm birds.

MERCURY
Increases through stages & food web

< 4 ug/g  (Heinz et al. 2010)

Reproductive effects in mallards fed diets w/ MeHg

0.5 ug/g  (Heinz et al. 1976)

Mercury concentrations in brine flies are below, or at levels that have been shown to harm birds.

ANOVA  p <0.000
Biomagnification moderate, except for larvae to Goldeneye transfer

MERCURY
Increases through stages & food web

Mercury (µg/g dry wt) + S.E.

––––––– Brine Flies –––––––

ANOVA  p < 0.000

*  **  ***

MERCURY Increases through stages & food web

Log scale

 Mercury (µg/g dry wt) + S.E.

<– 1.2 X Biomag –>

Goldeneye Data from Vest et al. 2008

1 Goldeneye Data from Vest et al. 2008
Selenium Concentrations Relative to Mercury Concentrations

Low Hg:Se Molar ratios suggest that although Hg levels are high in the biota, toxicity may be minimized by sequestration

\[
\text{Hg} + \text{Se} \rightarrow \text{HgSe}_{\text{(insoluble)}}
\]

\(^1\text{Ganther et al. 1972; Ralston et al. 2007}\)
Conclusions

- Stromatolites/periphyton and brine flies are important in the economy of the lake, and important in the diets of many bird species, likely rivaling the importance of brine shrimp as a food source.

- Mercury concentrations are moderate in biostromes and in brine flies, but biomagnification not important in the periphyton → brine fly larvae transfer.

- Goldeneye ducks have very high mercury concentrations: either there is very high biomagnification in the brine fly → duck transfer, the ducks are obtaining mercury from elsewhere, or they are sequestering it in livers & detoxifying with selenium.

- Hg:Se ratios < 1 suggest that even the high mercury levels may not be toxic to the biota.
Source of High Mercury Unknown

- Natural sources in watershed?
  Mercury mine operated in Mercur, 25 miles (40 km) from the Great Salt Lake. Other abandoned mines even closer.

- Natural concentration in salt lake?
  Na and Cl concentrated 200-300 fold over river water. Mercury in the GSL (in mixed layer) is concentrated 2-3 fold (based on data from Naftz (in prep.).
Source of High Mercury Unknown

- Long-range atmospheric deposition?
- Legacy mining contributions & recycling?

- Current atmospheric Hg deposition to lake\(^1\) 36 kg/yr is not abnormally high

- Legacy gold/silver mining Hg use in Utah\(^2\) (1864-present) 19,900,000 kg (136,000 kg/yr)

\(^1\) Peterson & Gustin (2009)
\(^2\) C.L. Ege, Selected Mining Districts of Utah, UGS Misc. Pub. 05-5 2005
Questions?

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