The role of plants in the Hg biogeochemical cycle

Outline

Hg: Why do we care?
The Hg biogeochemical cycle
The influence of plants on the Hg biogeochemical cycle

Mercury – Element atomic number 80
Liquid at room temperature
Ubiquitous

Important Hg facts

• Mercury is ubiquitous in the environment
• The air you breathe contains Hg
• Our detection limits are low
  – a.k.a.-We can measure it in everything
• Mercury is a global pollutant
What are uses?

- Thermometer
- Fluorescent light bulb
- Dental filling

What are issues?

- Occupational exposure
- MeHg (mercury)
- MeHg is a subtle neurotoxin
Where does Hg come from in fish?
In order to understand how to mitigate issues associated with an environmental contaminant—we must

– understand its bio-geo-chemical cycle

– have a scientific understanding of the behavior in the environment

What is a biogeochemical cycle of an element

• The flow of chemical elements and compounds between living organisms and the physical environment including the atmosphere, hydrosphere, or lithosphere
Components of a bio-geochemical cycle

- Reservoirs
- Sources
- Sinks
- Flux

Overview of the Mercury Biogeochemical Cycle

Sources
Natural:
- Soils
- Geothermal Active Zones
- Volcanoes
- Areas enriched in Hg by geologic processes

Anthropogenic:
- Coal fired power plants
- Waste incineration and other combustion
- Ore processing
- Chlor-alkali plants and other chemical production facilities
Atmospheric Hg sources in Nevada

Anthropogenic
- Point sources
- Non point sources
  1) disturbed naturally enriched areas
  2) imported Hg

Factors that control Hg release from soils –
Light
Temperature
Precipitation
Atmospheric oxidants
Chemistry

Overview of the Mercury Biogeochemical Cycle
Measuring gaseous mercury (Hg) exchange

\[ Flux = Q \frac{C_{out} - C_{in}}{A} \]
Mineral trends high in gold are often naturally enriched in mercury

Natural sources of atmospheric Hg
Soil moisture is a predominant driver of Hg emissions from soil.
Mercury in the Atmosphere

- **Gaseous elemental mercury (Hg\(^0\))**:  
  - Ubiquitous in the atmosphere – 99%  
  - Complex behavior of emission/deposition/re-emission  
  - Long atmospheric residence time  
  - Large number of natural and anthropogenic sources

- **Reactive gaseous mercury (RGM)**:  
  - Oxidized mercury species (HgCl\(_2\), Hg(OH)\(_2\), etc.)  
  - Shorter atmospheric residence time  
  - Anthropogenic emission sources and secondary formation by oxidation of Hg\(^0\)

- **Particulate mercury (Hg\(_{\text{p}}\))**:  
  - More common in fine fraction (<2.5 microns)  
  - Anthropogenic emission sources and secondary formation by sorption of other Hg species onto existing particles

- **Organic Hg - methyl and dimethyl Hg**

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Overview of the Mercury Cycle

- Hg\(^0\)  
  - Converted to other forms  
  - Deposition  
  - Transported
Overview of the Mercury Cycle

Sink
Wet Deposition $\mu g/m^2 \cdot yr$
(deposition of mercury in precipitation)

Total Mercury Wet Deposition, 2009

Silts not pictured:
AK05 1.2 $\mu g/m^2$
ARRI 3.1 $\mu g/m^2$

National Atmospheric Deposition Program/Mercury Deposition Network
Overview of the Mercury Cycle

Sink
Dry Deposition – ng/m$^2$ hr
or μg/m$^2$ yr
- Not well understood
- Little data exists
- Site-specific
- Projected atmospheric lifetimes:
  RGM < Hg$_p$ < Hg$^0$

Mercury deposited from the atmosphere can be RE-EMITTED!!
(includes re-emission of both anthropogenic and naturally deposited mercury)
Mercury deposited from the air to soils

- Sequestered-bound to organic materials or sulfur containing compounds
- Re-emitted
- Little moved in soil solutions
- Runoff may be important carried as particles
Mercury Deposition is a Nationwide and Global Issue

Where does Hg come from in fish?
Fish consumption advisories NV

Runoff from anthropogenic sources
- Urban areas
- Industrial releases
- Disturbed areas
- Legacy mining

Carson River Superfund Site
Atmospheric Hg sources in Nevada

Anthropogenic
-Point sources
-Non point sources
1) disturbed naturally enriched areas
2) imported Hg

Lyman et al., 2008

What about the

• Bio in Biogeochemical cycle?
Mono methyl mercury (CH₃HgCl, CH₃HgOH)
- Produced primarily by sulfate reducing bacteria in the sediments
- Bioaccumulated in food webs
- Subtle neurotoxin
- Binds to proteins and lipophilic
- Primary route of exposure for humans is ingestion of fish

Global mercury budget

<table>
<thead>
<tr>
<th>Source Description</th>
<th>Metric Tonnes per Year</th>
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<tbody>
<tr>
<td>All natural sources</td>
<td>2200-3200</td>
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<tr>
<td>Wet and dry deposition</td>
<td>3500</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>2600</td>
</tr>
<tr>
<td>River flow</td>
<td>200</td>
</tr>
<tr>
<td>Extraction from deep reservoirs</td>
<td>2400</td>
</tr>
<tr>
<td>Land storage</td>
<td>200</td>
</tr>
<tr>
<td>Ocean</td>
<td>3100</td>
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Mason and Sheu 2002
GBC
Scientific method

• Question- What is the role of plants in the Hg biogeochemical cycle
• Hypothesis
• Develop experiment to test hypothesis
  – Control and treatment
  – Replication
• Collect data
• Interpret data
  – Statistical analysis (significance)
• Draw conclusions
EcoCELL

- Large gas exchange chambers
  - \( \text{Flux} = (C_o - C_i) \times \frac{Q}{A} \)
- Precisely controlled

- Continuously measuring (solar irradiance, air T and RH, soil T and % swc, ET, CO\(_2\) and H\(_2\)O exchange)
Total ECOCELL volume 183 m³
Dimensions 7.3 x 5.5 x 4.5 m³

Controlled flow of ambient air
Controlled temperature

Individual soil containers
2.8m (l) x 1.3m (w) x 1.8m (d)
5 tonnes gravel overlain by 4.5 tonnes of Hg amended substrate (12 ug/g)
Each is a weighing lysimeter
$6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy} = \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

August 2000 Whole cell fluxes
**ppm Hg in Oldest Leaves as a Function of Time**

**Cell 1**

<table>
<thead>
<tr>
<th>ppm Hg</th>
<th>time after planting wisps (months)</th>
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</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>0.05</td>
<td>1</td>
</tr>
<tr>
<td>0.10</td>
<td>2</td>
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<tr>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>0.20</td>
<td>4</td>
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<tr>
<td>0.25</td>
<td>5</td>
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</table>

**Cell 2**

<table>
<thead>
<tr>
<th>ppm Hg</th>
<th>time after planting wisps (months)</th>
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<tbody>
<tr>
<td>0.00</td>
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**Mercury Enriched Soil**

- Soil Hg conc. $12.3 \pm 1.3 \mu g/g$
- Foliar Hg conc. $0.18 \pm 0.02 \mu g/g$ (at 5 month) $n = 18$

**Plants in Pots of Low Mercury Soil**

- Soil Hg conc. $0.03 \pm 0.01 \mu g/g$
- Foliar Hg conc. $0.16 \pm 0.01 \mu g/g$ (at 5 month) $n = 9$
Ecopods

Experimental Design

1.5 ng Hg/m$^3$ air  
15 ng Hg/m$^3$ air  
70 ng Hg/m$^3$ air  

0.03 µg Hg/g soil  
6 µg Hg/g soil  
25 µg Hg/g soil
Hg concentration aspen foliage air

Frescholtz et al., 2003
Conclusion: plants are an important sink for atmospheric mercury.
How do plants take up mercury? Controversial - stomata uptake or passive cuticular uptake or both

How would you investigate?

Measuring mercury (Hg) exchange

\[
\text{Flux} = Q \frac{C_{\text{out}} - C_{\text{in}}}{A}
\]
What would you manipulate?

litterfall
shoot
air
vascular
location
root
soil

Four plant species:
Andropogon gerardii
Sorghastrum nutans
Rudbeckia hirta
Populus tremuloides

Soil [Hg]: 0.02 / 0.90 μg g⁻¹

Light / Dark
Ambient / Scrubbed air
[CO₂]: 360, 613, 846 ppm
[Hg]: 0, ambient, 2x, 5x
(0-12 ng m⁻³)
**A. gerardii**

**Hg exchange**

Air Hg

clean / ambient air

**Stomatal movement and gas exchange**

Light / Dark

Air CO₂

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**P. tremuloides**

**Hg exchange**

Air Hg

clean / ambient air

**Stomatal movement and gas exchange**

Light / Dark
<table>
<thead>
<tr>
<th></th>
<th>Stomatal conductance</th>
<th>Foliar Hg flux</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>species</td>
<td>light</td>
</tr>
<tr>
<td>Overall</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R. hirta</td>
<td>-</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>S. nutans</td>
<td>-</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>A. gerardii</td>
<td>-</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>P. tremuloides</td>
<td>-</td>
<td>0.087</td>
</tr>
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Foliar Hg flux (ng m⁻² h⁻¹)

JStamenkovic - Dissertation Defense

Dissertation Defense

Soilroot

Litterfall

Translocation

Air

Shoot

Vascular

Root

Soil
What happens to Hg taken up by plants?

Are there other things to consider?
SO WHAT ARE YOUR CONCLUSIONS REGARDING THE ROLE OF PLANTS IN THE BIOGEOCHEMICAL CYCLE OF HG?

• Science is an adventure of the human spirit. It is essentially an artistic enterprise, stimulated largely by curiosity, served largely by disciplined imagination & based largely on faith in the reasonableness, order, & beauty of the universe.
  –Warren Weaver