LAKE CHARACTERIZATION STUDY: 
Sediment Triad Analysis of Lakes Sammamish, Washington, and Union

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Deanna Matzen (KC-DNR)
Jim Simmonds (KC-DNR)
Dana Walker (KC-DNR)
INTRODUCTION: Study site

METHODS: Sediment Triad Analysis

RESULTS: Correlation Between 3 Lines-of-Evidence

CONCLUSIONS & RECOMMENDATIONS
Study Site: Lakes Sammamish, Washington, and Union
Research Questions

- What are the contaminants of concern (COC)?

- Is there a measurable response to this contamination? If so, are contaminants causing the observed response?

- Which lake or areas of the lakes are most impacted?

- What are the potential contaminant sources?
Methods-Sediment Quality Triad

Sediment Chemistry

**Advantages**
- Gauge the overall degree of contamination

**Disadvantages**
- Little indication of bioavailability
- Only measure discrete set of contaminants

Toxicity Tests

**Advantage**
- Evaluate the sediment’s toxicity to aquatic organisms

**Disadvantages**
- Difficult to link toxicity to particular contaminants
- No standard evaluation criteria

Benthic Evaluation

**Advantage**
- Direct evidence of *in situ* biotic alterations

**Disadvantage**
- Difficult to link impairment to particular contaminants
- No standard evaluation criteria
Lab Analyses

- Sediment Chemistry-KC Environmental Lab
  - Base/neutral/acid extractable organic compounds (BNAs)
  - Pesticides and herbicides
  - PCBs
  - Metals
  - Tributyltin and other butyltin isomers
  - PAHs

- Bioassays-KC Environmental Lab
  - Chironomus tentans and Hyalella azteca mortality
  - C. tentans growth

- Benthic Community Structure and Abundance
  - Taxa abundances
  - Benthic Metrics
Sampling Stations in Lakes Sammamish, Washington, and Union

Legend

Sampling Locations
Site
- Sampling Location
- Reference Location

CSO Station Type
- CSO/Former CSO/Pump Station
- Storm Drain
Chemical Analyses

**SEDIMENT SAMPLE**

1. Chemistry

   - **PCA/Bootstrap**
   - **SQGs**

   - Identify Chemicals that Correlate with Bioassay Endpoints and/or Benthic Metrics
   - Identify Problematic Chemicals
### Sediment Chemistry-Sediment Guidelines

#### Comparison to SQGs (PEL/TELS and Floating Percentile)

Percentage of stations in each lake with SQG-Qs >1

<table>
<thead>
<tr>
<th>Chemical Group</th>
<th>SQG</th>
<th>Sammamish</th>
<th>Washington</th>
<th>Union</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dibenzofuran</td>
<td>FP</td>
<td>0%</td>
<td>0%</td>
<td>13%</td>
</tr>
<tr>
<td>TBT</td>
<td>FP</td>
<td>0%</td>
<td>10%</td>
<td>73%</td>
</tr>
<tr>
<td>Organochlorine Pesticides</td>
<td>TEL</td>
<td>0%</td>
<td>0%</td>
<td>33%</td>
</tr>
<tr>
<td>DDT</td>
<td>TEL</td>
<td>0%</td>
<td>34%</td>
<td>53%</td>
</tr>
<tr>
<td>Phthalates</td>
<td>FP</td>
<td>31%</td>
<td>34%</td>
<td>73%</td>
</tr>
<tr>
<td>PAHs</td>
<td>FP</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>TEL</td>
<td>25%</td>
<td>17%</td>
<td>73%</td>
</tr>
<tr>
<td>Metals</td>
<td>FP</td>
<td>0%</td>
<td>28%</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>TEL</td>
<td>25%</td>
<td>76%</td>
<td>93%</td>
</tr>
<tr>
<td>PCBs</td>
<td>FP</td>
<td>94%</td>
<td>97%</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>TEL</td>
<td>100%</td>
<td>100%</td>
<td>93%</td>
</tr>
</tbody>
</table>
Sediment Chemistry – Principle Component Analysis

- Principle Component Analysis (PCA) - multivariate statistical technique
  - reduces variables in a data matrix

- Results:
  - ‘PAHs’ (PC1)- 12 PAHs
  - ‘Metals’ (PC2)- 6 Metals, Total PCBs, Bis(2-Ethylhexyl)Phthalate, and Aroclor 1254
  - ‘Pesticides’ (PC3)- Arsenic, Total DDT, 4, 4 DDT, and 4, 4 DDE
  - ‘Butyl Tins’ (PC4)- Butyl Tins; Mono-n-Butyltin, Tri-n-Butyltin, and Di-n-Butyltin.
Bioassay Analysis

- **Comparison to Control: Statistical Significance**
  - ANOVA w/ post hoc Dunnett’s test with at \( \alpha = 0.05 \)

- **Comparison to Reference: Reference Envelope**
  - Purpose: Determine if conditions at test site are different from the reference
  - Method: Tolerance limits are the lower confidence interval bound around some percentile of the underlying data distribution.
  - If \( \alpha = 0.05 \) & percentile =10%, there is a 95% certainty that a survival values less than the tolerance interval is as low or lower than the 10th percentile of the distribution of reference site toxicity results.
### Bioassay Comparison

<table>
<thead>
<tr>
<th>$r^2$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.57</td>
<td>$C.\ tentans$ Mortality $\rightarrow H.\ azteca$ Mortality</td>
</tr>
<tr>
<td>0.14</td>
<td>$H.\ azteca$ Mortality $\rightarrow C.\ tentans$ Growth</td>
</tr>
<tr>
<td>0.12</td>
<td>$C.\ tentans$ Mortality $\rightarrow C.\ tentans$ Growth</td>
</tr>
</tbody>
</table>

### Legend

- **Station Type**
  - △ $C.\ tentans$ Mortality
  - □ $C.\ tentans$ Growth
  - ℹ️ Less than Reference Envelope
  - ☢️ CSO/Former CSO/Pump Station
  - ▲ Storm Drain

- **C. tentans** Growth
- **C. tentans** Mortality
- **H. azteca** Mortality
Correlation Analysis: Chemistry-Toxicity

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Statistic</th>
<th>C. tentans Growth</th>
<th>C. tentans Survival</th>
<th>H. azteca Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1 (Metals)</td>
<td>Pearson Correlation</td>
<td>-0.434</td>
<td>-0.282</td>
<td>-0.25</td>
</tr>
<tr>
<td></td>
<td>Sig (2-tailed)</td>
<td>0.00**</td>
<td>0.027*</td>
<td>0.050*</td>
</tr>
<tr>
<td>PC2 (PAHs)</td>
<td>Pearson Correlation</td>
<td>-0.558</td>
<td>-0.118</td>
<td>-0.345</td>
</tr>
<tr>
<td></td>
<td>Sig (2-tailed)</td>
<td>0.00**</td>
<td>0.361</td>
<td>0.00**</td>
</tr>
<tr>
<td>PC3 (Pesticides)</td>
<td>Pearson Correlation</td>
<td>0.244</td>
<td>0.087</td>
<td>0.138</td>
</tr>
<tr>
<td></td>
<td>Sig (2-tailed)</td>
<td>0.056</td>
<td>0.502</td>
<td>0.197</td>
</tr>
<tr>
<td>PC4 (Butyl Tins)</td>
<td>Pearson Correlation</td>
<td>-0.28</td>
<td>-0.151</td>
<td>-0.333</td>
</tr>
<tr>
<td></td>
<td>Sig (2-tailed)</td>
<td>0.052</td>
<td>0.241</td>
<td>0.01**</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).**

*Correlation is marginally significant at the .05 level (2-tailed)*
Bootstrap Procedure: Type I Error?

<table>
<thead>
<tr>
<th>C. tentans Survival</th>
<th>Pyrene</th>
<th>Lead</th>
<th>BEHP</th>
<th>TBT</th>
<th>Anthracene</th>
<th>Chemical Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.03</td>
<td>-0.86</td>
<td>-0.19</td>
<td>-0.58</td>
<td>-0.17</td>
<td>-0.56</td>
</tr>
<tr>
<td></td>
<td>0.82</td>
<td>2.00</td>
<td>1.10</td>
<td>-0.11</td>
<td>0.48</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td>1.03</td>
<td>0.11</td>
<td>0.40</td>
<td>-0.30</td>
<td>0.56</td>
<td>-0.28</td>
</tr>
<tr>
<td></td>
<td>1.06</td>
<td>0.50</td>
<td>-0.69</td>
<td>-1.32</td>
<td>-0.48</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>0.86</td>
<td>-1.05</td>
<td>1.00</td>
<td>-1.32</td>
<td>-0.65</td>
<td>3.00</td>
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<tr>
<td></td>
<td>1.12</td>
<td>-0.49</td>
<td>0.26</td>
<td>-0.55</td>
<td>-0.22</td>
<td>-0.56</td>
</tr>
<tr>
<td></td>
<td>0.85</td>
<td>-0.06</td>
<td>0.45</td>
<td>0.91</td>
<td>0.59</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>0.80</td>
<td>-0.98</td>
<td>-1.19</td>
<td>-0.83</td>
<td>-0.28</td>
<td>-0.56</td>
</tr>
</tbody>
</table>

|                     | -0.12   | -0.16  | -0.25  | -0.19   | -0.22      |                  | **-0.35**        |

<table>
<thead>
<tr>
<th>C. tentans Survival</th>
<th>Pyrene</th>
<th>Lead</th>
<th>BEHP</th>
<th>TBT</th>
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<td>0.07</td>
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<td>-1.19</td>
<td>-0.30</td>
<td>0.56</td>
<td>0.15</td>
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<td></td>
<td>1.06</td>
<td>-1.05</td>
<td>0.26</td>
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<td>-0.55</td>
<td>0.59</td>
<td>-0.21</td>
</tr>
<tr>
<td></td>
<td>1.12</td>
<td>0.91</td>
<td>0.91</td>
<td>-0.37</td>
<td>0.07</td>
<td>-0.11</td>
</tr>
<tr>
<td></td>
<td>0.85</td>
<td>-0.98</td>
<td>0.94</td>
<td>-0.83</td>
<td>0.48</td>
<td>-0.56</td>
</tr>
<tr>
<td></td>
<td>0.80</td>
<td>-0.98</td>
<td>-0.99</td>
<td>-0.83</td>
<td>0.48</td>
<td>-0.56</td>
</tr>
</tbody>
</table>

|                     | -0.06   | -0.01  | -0.08  | 0.10    | 0.14       |                  | **0.04**         |

=Pearson Correlation Coefficient

Kari Moshenberg : SETAC : November, 2004
### Bootstrap: Chemistry-Toxicity

<table>
<thead>
<tr>
<th>Endpoint</th>
<th>$r^2$ (r) of top 5 Chemicals</th>
<th>Chemicals ($r^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. tentans Survival</td>
<td>0.16 (-0.47)</td>
<td>DBT (0.15), Pyrene(0.14), Phenanthrene(0.14), Chrysene(0.14), Benzo(a)Anthracene(0.14)</td>
</tr>
<tr>
<td>C. tentans Growth</td>
<td>0.47 (-0.68)</td>
<td>Aroclor 1254(0.35), Anthracene(0.35), Bis(2-Ethylhexyl)Phthalate(0.35), Benzo(k)fluoranthene (0.32), Total PCBs(0.32)</td>
</tr>
<tr>
<td>H. azteca Survival</td>
<td>0.30 (-0.56)</td>
<td>Bis(2-Ethylhexyl)Phthalate(0.32), Cu (0.23), Phenanthrene(0.22), Anthracene(0.19), Benzo(k)fluoranthene(0.18)</td>
</tr>
</tbody>
</table>
Benthic Community Structure & Abundance

- **Shannon-Weaver** - # of distinct taxa
- **Species Richness** - Evaluates both the # of species and the proportional representation of taxa within the benthic community
- **Hilsenhoff Biotic Index** - Pollution tolerances of taxa
Benthic Regression Models

- **Predictor Variables**
  - Chemical: 4 PCs
  - Physical: Depth, Grain Size, Extractable Phosphorus, Ammonia Nitrogen

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Shannon-Weaver</th>
<th>Species Richness</th>
<th>HBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia Nitrogen</td>
<td>-0.45</td>
<td>-0.49</td>
<td>0.35</td>
</tr>
<tr>
<td>Extractable Phosphorus</td>
<td>-0.45</td>
<td>-0.43</td>
<td>0.38</td>
</tr>
<tr>
<td>Depth</td>
<td>-0.32</td>
<td>-0.57</td>
<td>0.17</td>
</tr>
<tr>
<td>Percent Fines</td>
<td>-0.22</td>
<td>-0.45</td>
<td>0.12</td>
</tr>
<tr>
<td>PC1 (PAHs)</td>
<td>-0.17</td>
<td>-0.07</td>
<td>0.20</td>
</tr>
<tr>
<td>PC2 (Metals)</td>
<td>-0.23</td>
<td>-0.07</td>
<td>0.24</td>
</tr>
<tr>
<td>PC3 (Pesticides)</td>
<td>-0.25</td>
<td>-0.48</td>
<td>0.18</td>
</tr>
<tr>
<td>PC4 (Butyl Tins)</td>
<td>-0.16</td>
<td>-0.17</td>
<td>0.28</td>
</tr>
</tbody>
</table>

**Model Adjusted $r^2$**

- 0.26
- 0.47
- 0.20

= Significant Term in Regression Model

Kari Moshenberg : SETAC : November, 2004
Decision Matrix

- Chemistry data
  » Floating Percentile SQG

- Bioassay Data
  » Weighted statistical significance based on bootstrap $r^2$
  » Weighted reference envelope based on bootstrap $r^2$

- Benthic Community Structure and Abundance
  » Weighted statistical significance based on benthic models.

- Graded Stations
  » A (0-10 Points): Minimally Impacted
  » B (10-20 Points): Moderately Impacted
  » C (20-30 Points): Severely Impacted
Research Questions

- What are the contaminants of concern (COC)?
  - SQGs: PCBs, metals, PAHs, and phthalates
  - Aroclor 1254, Zn, Cu, and Pb, Pyrene, and BEHP
  - **Lake Union**-TBT, metals, PAHs, and phthalate, PCB

- Is there a measurable response to this contamination? If so, are the contaminants causing the response?
  - Bioassay
    - Week-Moderate correlation with contamination
    - *C. tentans* growth most responsive
  - Benthic
    - Nutrient concentrations, grain size, depth explained most variation
    - Species richness most responsive to sediment characteristics
Research Questions

- Which lakes or areas of the lakes are most impacted?
  - Lake Union more impacted than Lakes Washington & Sammamish.
  - Nearshore areas

- What are the potential contaminant sources?
  - Point Sources of Contamination
    - Industrial Facilities
      - Lake Washington: Quendall/Baxter, ASARCO heavy metals, military facilities
      - Lake Union: Gasworks Park (PAHs), Seattle City Light Steam Plant (PCBs), shipyards (Cu, Zn, TBT)
  - Non-Point Sources of Contamination
    - Urban Runoff
    - Atmospheric deposition
Recommendations

- Chemistry
  - More information about chemicals related to toxicity

- Bioassays
  - Bioassays with chronic and sub-lethal endpoints

- Benthic
  - Continue investigating relationships between physical & chemical parameters & benthic community

- Bioaccumulation
  - PCBs and Hg present in Lake Washington fish

- Station groupings: opportunities for future study
  - A (78%): Minimally Impacted
  - B (17%): Moderately Impacted
  - C (5%): Severely Impacted
Chemistry-Toxicity

- Acid Volatile Sulfide/Simultaneously Extractable Metals (AVS/SEM)
  - Hypothesis: If sufficient SEM<AVS, metals bind to sediment phase sulfides and are not bioavailable, thus not toxic (Di Toro et al. 1990).
  - Results
    - 40% of Samples had SEM/AVS ratios of >1
    - 5% of samples had SEM/AVS ratios of >20 (All in Lake Union)
    - Little predictive power, but could be due to low occurrence of SEM/AVS ratios>20

- Correlation analysis
  - Evaluate relationship between chemical PCs and bioassay test results.

- Bootstrap
  - Investigate correlations between contaminants and bioassay tests results.
Uncertainty

- **Chemical Contaminants**
  - Not all chemicals analyzed
  - Detection limits & laboratory procedures
  - Chemicals without SQGs
  - Uncertainties in SQGs (only growth & survival)

- **Bioassay**
  - Acute rather than chronic tests (chronic tests are more sensitive)
  - No information about bioaccumulation
  - Statistical methods

- **Benthos**
  - Is response associated with organic enrichment or contamination?
  - Statistical methods