Bioaccumulation of Toxic Contaminants in Lamprey
Current levels and Methods to Simulate Organic Contaminant Uptake in Lamprey

• Dianne Barton, Water Quality Coordinator, bard@critfc.org
Outline of Today’s Talk

• Problem – Lamprey vulnerability
• Fish Tissue Contaminant Levels
  – Results from 96-98, 2009, and 2012
• Aquatox – Simulating Contaminant Fate and Ecological Effects
• Aquatox Short Course
• Future Work
  – Linking computer simulation to restoration
Lamprey as “bioindicator” species

- Relatively high lipid content, 4-6 years in freshwater provides time to bioaccumulate, filter feeders

Trinity River, CA
Au and Hg mining district
J.B. Bettaso and D.H. Goodman

Ammocoetes contained levels of Hg 12 to 25 times those of mussels and an order of magnitude higher than salmonids from nearby

Level of Hg considered detrimental to early life stages of fish – **0.2 ppm**, average bottom feeder - **.1 ppm** (Beckvar et al., 2005)
Lamprey vulnerability

• Particularly prone to bioaccumulation of lipophilic contaminants
• Feeding strategy makes the juvenile life stage susceptible to contaminants that bind to sediment and organic matter
• Diverse habitats subject lamprey to multiple routes of exposure
• European eel – direct mortality and sublethal effects
  – contaminants cause disturbance of the immune, reproductive, nervous, endocrine system,
• Limited data on exposure and toxicity thresholds for many chemicals
### Lamprey Ammocoete Sensitivity – Portland Harbor Study

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Model of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pentachlorophenol – used as a pesticide and disinfectant</td>
<td>• Oxidative phosphorylation uncoupler – depresses formation of energy (ATP)</td>
</tr>
<tr>
<td>• Copper</td>
<td>• Gill dysfunction</td>
</tr>
<tr>
<td>• Diazinon – phosphate insecticide</td>
<td>• Acetylcholinesterase inhibitor - nervous system function</td>
</tr>
<tr>
<td>• Aniline - precursor to polyurethane, dyes, herbicides</td>
<td>• Polar narcosis - water soluble narcotics</td>
</tr>
<tr>
<td>• Napthalene - mothballs, fumigant</td>
<td>• Narcosis - progressive lethargy</td>
</tr>
<tr>
<td>• Lindane - organochlorine insecticide, lice treatment</td>
<td>• Central nervous system interference</td>
</tr>
</tbody>
</table>
## Lamprey Ammocoete Sensitivity – Portland Harbor Study

<table>
<thead>
<tr>
<th>Relative Sensitivity</th>
<th>Model of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pentachlorophenol – sensitive (15&lt;sup&gt;th&lt;/sup&gt; percentile, similar to trout, salmon)</td>
<td>• Oxidative phosphorylation uncoupler – depresses formation of energy (ATP)</td>
</tr>
<tr>
<td>• Copper – average (46&lt;sup&gt;th&lt;/sup&gt; percentile)</td>
<td>• Gill dysfunction</td>
</tr>
<tr>
<td>• Diazinon – insensitive (72&lt;sup&gt;nd&lt;/sup&gt; percentile)</td>
<td>• Acetylcholinesterase inhibitor - nervous system function</td>
</tr>
<tr>
<td>• Aniline – insensitive (90&lt;sup&gt;th&lt;/sup&gt; percentile)</td>
<td>• Polar narcosis - water soluble narcotics</td>
</tr>
<tr>
<td>• Napthalene – insensitive (compared to four other species)</td>
<td>• Narcosis - progressive lethargy</td>
</tr>
<tr>
<td>• Lindane – insensitive (compared to numerous other fish species)</td>
<td>• Central nervous system interference</td>
</tr>
</tbody>
</table>
Drugs and Toxins that Inhibit Oxidative Phosphorylation

- TFM – Lampricide
- Cyanide
- Azide – anion N₃-
- Oligomycin – antibiotic
- Rotenone – pesticide
- CCCP – carbonyl cyanide m-chlorophenyl hydrazone
- DNP – (2,4 – dinitrophenol), 30’s diet pill, bodybuilder and athletes, environmental contaminant from auto exhaust, burning
Pacific Lamprey Tissue Studies

- 96/98 EPA report – adult composites
- 2009 CRITFC – adult composites
- 2012 Lamprey study with USGS – sediment and juvenile
Contaminants Found in Lamprey

• Measured Bioaccumulative Contaminants
  – Legacy – Dioxins (2,3,7,8 – TCDD), Furans (PCDFs)
  – Pesticides
  – PCBs (77, 81, 126, 169) dioxin-like

• Emerging - lipophilic
  – Brominated flame retardants

• Metals
  – Hg, As, Cu, Zn, Se, Al
1996-98 Adult Fish Tissue Survey

- Lamprey Composite from two locations – Willamette Falls, Fifteen mile Creek RM .2-.5
- 3 fillet composites with skin (20/composite, 3 replicates)
- 9 whole body composites (10-20/composite, 6 replicates)
  - Concentration of organics were among the highest (w/ sturgeon, mtn. whitefish, sucker)
  - Generally lower than levels reported from the early 1970s and 80’s
Figure 2-2. Basin-wide average concentrations of total pesticides in composite fish tissue collected from Columbia River Basin. Study sites are described in Table 1-1. Sample numbers are given in Table 1-2a,b.
## 2009 Pacific Lamprey Toxics Study

- Adult Composites, 3 locations, whole body (5) composites

<table>
<thead>
<tr>
<th>Site</th>
<th>Number of Adults</th>
<th>Date</th>
<th>Percent Fat % wet wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Day</td>
<td>5</td>
<td>8/25/2009</td>
<td>19.4</td>
</tr>
<tr>
<td>John Day</td>
<td>5</td>
<td>8/25/2009</td>
<td>14</td>
</tr>
<tr>
<td>John Day</td>
<td>5</td>
<td>8/25/2009</td>
<td>14.6</td>
</tr>
<tr>
<td>Willamette Falls</td>
<td>2</td>
<td>8/17/2009</td>
<td>20.8</td>
</tr>
<tr>
<td>Willamette Falls</td>
<td>5</td>
<td>8/19/2009</td>
<td>9.6</td>
</tr>
<tr>
<td>Willamette Falls</td>
<td>5</td>
<td>8/26/2009</td>
<td>16.7</td>
</tr>
<tr>
<td>Deschutes River /Shears Falls Ladder</td>
<td>5</td>
<td>8/12-17/2009</td>
<td>12.6</td>
</tr>
</tbody>
</table>

Equal weight aliquots – whole fish
## Preliminary Comparison of 96/98 to 2009 sampling

<table>
<thead>
<tr>
<th></th>
<th>%Lipid</th>
<th>ng/kg</th>
<th>mg/kg</th>
<th>ng/kg</th>
<th>ng/kg</th>
<th>ng/kg</th>
<th>ng/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average 2009</strong></td>
<td>lower</td>
<td>lower</td>
<td>higher</td>
<td>lower</td>
<td>lower</td>
<td>lower</td>
<td></td>
</tr>
<tr>
<td><strong>Average 1996-1998</strong></td>
<td>18.4</td>
<td>5500</td>
<td>0.1</td>
<td>90000</td>
<td>33000</td>
<td></td>
<td>lower</td>
</tr>
<tr>
<td>Whole Body Only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*2009 includes congener PCB 81, 96-98 does not*

- Chlordane – organochlorine pesticide, legacy 1983
- * 2,3,4,8 TCDF – chlorinated dioxin, highest concentration in 96-98 study
A Food Web Approach

From Macneale, et. al, 2010, Front Ecol. Environ 8(9) 475-482

Figure 3. Representative Pacific Northwest salmon stream community.
AQUATOX – Environmental Fate and Ecological Effects in Aquatic Ecosystems

Ecosystem components

- Phytoplankton (trophic level 1)
- Zooplankton (trophic level 2)
- Forage fish (t. level 3)
- Piscivore
- Piscivore
- Detritivore
- Periphyton
- Zoobenthos
- Detritus
- Inflow

Inorganic nutrients:
- P (phosphorus)
- N (nitrogen)
- Si (silicon)
- CO₂
AQUATOX

• It can simulate the combined effects of nutrients and pesticides in agricultural runoff
• Simulates eutrophication and impacts of Best Management Practices
• Complex food web modeling: user can specify
  – Multiple level feeding preferences
• Metals capabilities are limited
Bioaccumulation in AQUATOX

Toxicant in water:
- ionization
- volatilization
- hydrolysis
- photolysis
- microbial degradation

Uptake through gill:
- respiration rate
- assimilation efficiency

Partitioning

Toxicant in food sources
- Organic sediments
- Algae

Uptake from diet
- consumption rates
- assimilation efficiency
- growth rates
- toxicity
- lipid content

Losses of toxicant:
- predation
- mortality
- depuration
- biotransformation
- spawning
- promotion
- emergence

- nutrient cycling
- loss of predation
Farm Pond, Esfenvalerate
Chemical Uptake in animals

Juvenile bass
Adult bass
### Animal Data:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half Saturation Feeding</td>
<td>1.0</td>
<td>mg/L</td>
<td>Leidy &amp; Ploskey '80, p. 42 max.=4.2</td>
</tr>
<tr>
<td>Maximum Consumption</td>
<td>1.8</td>
<td>g/g/d</td>
<td>Kiorboe et al. 1985</td>
</tr>
<tr>
<td>Min Prey for Feeding</td>
<td>0.3</td>
<td>g/sq.m</td>
<td>&quot; (0.03)</td>
</tr>
<tr>
<td>Sorting: degree to which there is selective feeding</td>
<td>1</td>
<td>unitless</td>
<td>Default -- no sediment effect</td>
</tr>
<tr>
<td>Suspended Sediments Affect Feeding</td>
<td></td>
<td></td>
<td>Default -- no sediment effect</td>
</tr>
<tr>
<td>Slope for Sed. Response</td>
<td>0.0</td>
<td>unitless</td>
<td>Default -- no sediment effect</td>
</tr>
<tr>
<td>Intercept for Sed. Resp.</td>
<td>0.0</td>
<td>unitless</td>
<td>Default -- no sediment effect</td>
</tr>
<tr>
<td>Temp. Response Slope</td>
<td>2.4</td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>Optimum Temperature</td>
<td>26.0</td>
<td>°C</td>
<td>L &amp; P '80</td>
</tr>
<tr>
<td>Maximum Temperature</td>
<td>40.0</td>
<td>°C</td>
<td>&quot;</td>
</tr>
<tr>
<td>Min Adaptation Temp.</td>
<td>5.0</td>
<td>°C</td>
<td>&quot;</td>
</tr>
<tr>
<td>Mean wet weight</td>
<td>0.0006</td>
<td>g wet</td>
<td>Thomann '89</td>
</tr>
<tr>
<td>Endogenous Respiration</td>
<td>0.01</td>
<td>1/d</td>
<td>Leidy &amp; Ploskey, 198, p. D16 = 0.18</td>
</tr>
<tr>
<td>Specific Dynamic Action</td>
<td>0.07</td>
<td>(unitless)</td>
<td>Kiorboe et al. 1985</td>
</tr>
<tr>
<td>Excretion : Respiration</td>
<td>0.17</td>
<td>ratio</td>
<td>Scavia and Park, 1976</td>
</tr>
</tbody>
</table>
CRITFC
AQUATOX 3-Day Training Work Shop

• November 29\textsuperscript{th} – December 1\textsuperscript{st}, 2011
• CRITFC – Portland, OR
• Free
• Lamprey/salmon and pesticides
• Classroom or via GoToMeeting
Short Course will focus on some lamprey specific issues

• **Lab 7: Effect of lipid content on lamprey bioaccumulation**—Willamette River tributary
  – Zollner Creek site in Willamette River Valley (new study)
    • [setup of study is probably too tedious for lab, but can provide as background—uses Lab 3 resulting study]
  – USGS NAWQA site with nearby row crops, vineyards, grain and grass fields, and large poultry houses
  – Large data set includes pesticides and bioaccumulation in fish
  – Lamprey larval growth will be simulated for multiple years with accumulation of lipids
  – Returning adults will have persistent pesticide(s) and PCBs and high lipid content
  – Participants can vary water and sediment exposure to see uptake in lamprey, and lipid content to see the effect on depuration and bioaccumulation
  – Simulated tissue concentrations can be compared with human consumption standards

• **Lab 8: Toxicity of contaminants to lamprey**
  – Will build on Lab 7
  – Effects of simulated toxicants (chlorpyrifos, legacy dieldrin and PCBs) on lampreys
  – Participants can investigate chronic effects with various levels of contaminants
Future Work

• Understand better the role of contaminants as a threat to the survival of the species
  – Mitigate the impact on restoration activities
  – Evaluate sites for sediment health

• Linking computer simulation to restoration
  – Restoration site evaluation
  – Determine spatial and temporal distribution of target pollutants under various management scenarios
  – Evaluate likely pollutant attenuation scenarios under various management or remediation approaches