Legacy of Mining: Mercury Distribution and Effects on Aquatic Biota in the Guadalupe River, Santa Clara County, California.

James Haas
U.S. Fish and Wildlife Service
California-Nevada Operations Office
Outline

• Introduction/Background
• Study design
• Methods
• Results/Discussion
  – Distribution of Hg
  – Aquatic macroinvertebrates
  – Fish
• Conclusions
Co-investigators

• Sediment and biological tissue collection and analyses
  – Gary Ichikawa, California Dept. of Fish and Game

• Invertebrates
  – Dr. Pete Ode and Tom King, California Dept. of Fish and Game
  – Dr. Michael Morrison, Great Basin Research Institute

• Fish
  – Dr. Swee Teh, School of Veterinary Medicine, UC Davis
  – Dr. Michael Morrison, Great Basin Research Institute
Introduction

• Objectives
  – Evaluate distribution of mercury from historic mining operations
  – Correlation Hg in sediment and tissue with indicators of biological health at different levels of biological organization
  – Graduate
The Mines

• Historic Mercury Mining District in Santa Clara County
• Complex of mines – most productive in North America
• Over 1,000,000 flasks of mercury produced during 122 years of operation
• Open pit operations beginning early 20th century
The Mercury Problem

from Watras and Huckabee (1994)
Regulatory History

• Remediated by Dept. of Toxic Substances Control under CERCLA 1987-1999

• 1994 Remedial Action Plan inadequate to protect aquatic and aquatic-dependent species

• Main remedial projects
  – Hacienda Furnace Yard completed 1998
  – Mine Hill completed 1999
Natural Resource Damage Assessment

- NRDA Investigation initiated by USFWS and Calif. Dept. of Fish and Game (CDFG) in 1995
- Preliminary field collections completed 1998
- Pre-assessment Screen Determination completed 2000
- Cooperative assessment with 7 PRPs initiated in 2000
- Consent decree finalized November 2005
- Restoration project implementation
Damage Assessment Problem

- Show the mines as the predominant source of Hg in the watershed
- Show exposure of biota to Hg
- Separate effects of Hg on populations and communities from
  - natural differences in habitat quality
  - effects of dams on hydrology, substrate, water quality
  - urbanization, and other land uses
Habitat Gradient

High elevation, lower order

Mid-elevation, dams and Hg input

Lower elevation, higher order, urbanization
Example

Truckee River - Effect of Distance from Lake Tahoe on Fish IBI

\[ y = 56.676e^{-0.0446x} \]

\[ R^2 = 0.9752 \]

Truckee River - Effect of Urbanization on Fish IBI

\[ y = -1.9765x + 10.482 \]

\[ R^2 = 0.9478 \]
# Study Outline

## 1. Field – Repeated over 2-3 seasons

### Collections/Chemistry

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Invertebrates</th>
<th>Fish/Amphibians</th>
<th>Birds’ Eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crayfish, Mollusks, Insects</td>
<td>Trout, Roach, Sucker, Sculpin, Lamprey, Non-Native</td>
<td>Black-crowned Night Heron, Mallard, Kingfisher</td>
</tr>
</tbody>
</table>

- Total and MeHg Metals Scan
- Total and MeHg
- Total Hg

### Studies

- IBI, Caged *Corbicula* and crayfish
- Habitat Evaluation
- Quantitative electrofishing
- Caged Roach
- Amphibian surveys
- Larval success

## 2. Laboratory

<table>
<thead>
<tr>
<th>Fish</th>
<th>Chronic Exposure</th>
<th>Endpoints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet/Water</td>
<td>=&gt; Chronic Exposure</td>
<td>Survival, Histopathology, Reproduction, Genetic alteration, biochemical induction</td>
</tr>
</tbody>
</table>

=> **Dose Response** => 1. Population/Community Effect

2. Restoration
Limitations

- **Financial**
- **Legal**
  - NRDA Regulations
    - Defined injury acceptance criteria
    - Rebuttable presumption
  - Cooperative agreement with PRPs
- **Economic valuation of injury**
  - Habitat Equivalency Analysis
    - Area
    - Percent service loss
    - Natural recovery
Study Outline

1. Field – 1-2 seasons

Collections/Chemistry

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Invertebrates</th>
<th>Fish/Amphibians</th>
<th>Birds’ Eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crayfish, Mollusks, Insects</td>
<td>Trout, Roach, Sucker, Sculpin, Lamprey, Non-Native</td>
<td>Black-crowned Night Heron, Mallard, Kingfisher</td>
</tr>
<tr>
<td>Total and MeHg</td>
<td>Total and MeHg</td>
<td>Total Hg</td>
<td>Total Hg</td>
</tr>
</tbody>
</table>

Studies

<table>
<thead>
<tr>
<th>IBI, Caged Corbicula and crayfish</th>
<th>Habitat Evaluation</th>
<th>Reproductive Success</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantitative electrofishing/Health assessment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caged Roach</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amphibian surveys</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Larval success</td>
<td></td>
</tr>
</tbody>
</table>

2. Laboratory

Fish => Chronic Exposure

Endpoints

Survival, Histopathology, Reproduction, Genetic alteration, biochemical induction

=> Dose Response => 1. Population/Community Effect

2. Restoration

=> Histology – Field-collected fish
• Stratified sampling with reference creek
• High elevation background sites
• Mid-elevation sites below dams & Hg sources
• Low elevation sites for Hg attenuation
Methods

• Sites were sampled for total mercury in sediments, benthic macroinvertebrates (BMI), and fish

• Sub-samples of sediment and BMI were analyzed for methyl mercury
Methods

• Sediments
  – 3 composite samples per site

• Invertebrates
  – 1 composite sample of insects
  – 3 composite samples of wild crayfish
  – 3 composite samples of caged crayfish and Corbicula (28 day deployment)

• Fish
  – 3 composite samples per species
BMI and Fish Collections

• Late summer
• Benthic Macroinvertebrate (BMI) sampled following Harrington (1996)
  – 3 riffles per site/1 composite sample per riffle
  – Enumerated and keyed in lab
  – Lab personnel did not know site codes
• Fish sampled following Armour et al. (1983)
  – Quantitative electrofishing
    • 3 passes in four 25 m segments/site
  – Identified, weighted & measured
Fish Health Assessment Index

• Field health assessments were conducted on California Roach and age 0 rainbow trout (Adams et al. 1993)
• Visual examination of skin, eyes, gills, fins, liver, gall bladder, hindgut, gonads
• Preserved in formalin
Histopathology

- Same wild roach and trout evaluated in the field for Health Assessment Indices
- Livers and gonads were evaluated for histopathological lesions (Teh *et al.* 1997)
- Histopathologist did not know site codes
Aquatic Health

• Benthic Macroinvertebrate (BMI) Indices were calculated invertebrate communities based on diversity, distribution, and abundance metrics (Harrington 1996).

• IBI scores were calculated for fish assemblages based on abundance, diversity, and productivity metrics (Moyle and Marchetti 1999).
## Metrics

<table>
<thead>
<tr>
<th>Invertebrates</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number of species</td>
<td>1. Percent native species</td>
</tr>
<tr>
<td>2. EPT Taxa</td>
<td>2. Number of native species*</td>
</tr>
<tr>
<td>3. Shannon Diversity Index</td>
<td>3. Native trout age classes</td>
</tr>
<tr>
<td>4. Percent Intolerant Taxa</td>
<td>4. Native cyprinid age classes</td>
</tr>
<tr>
<td>5. Percent Tolerant Taxa</td>
<td>5. Native sucker age classes</td>
</tr>
<tr>
<td>6. Percent contribution of dominant taxa</td>
<td>6. Total number of species*</td>
</tr>
<tr>
<td>7. Percent Functional Feeding Groups</td>
<td>7. Total abundance*</td>
</tr>
<tr>
<td>8. Abundance Estimate</td>
<td>8. Percent top carnivores</td>
</tr>
<tr>
<td></td>
<td>9. Percent tolerant species</td>
</tr>
<tr>
<td></td>
<td>10. Percent introduced pond species</td>
</tr>
</tbody>
</table>

*Adjusted for stream order
Habitat evaluations were performed to separate potentially confounding effects of habitat quality from Hg effects on BMI and fish health indicators (Armour et al. 1983; Welsh and Lind 1996).
## Habitat Assessment

<table>
<thead>
<tr>
<th>Landscape (once/reach)</th>
<th>UTM, Length of reach, Aspect, Elevation, Slope, Stream order, Distance to upstream dams, &amp; Number of upstream road crossings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrohabitat</strong> (625 m lengths)</td>
<td>Number of pools, glides, and riffles; % upland habitat (grass, wood, shrub, residential); % riparian cover, % riprap</td>
</tr>
<tr>
<td><strong>Microhabitat</strong> (5-125 m segments, 5 transects/segment)</td>
<td>Stream &amp; bank width; % overhang; bank cover &amp; stability; pool quality &amp; width; canopy height &amp; % cover; water depth &amp; velocity; embeddedness; substrate; in-stream cover; Water – pH, DO, Temperature, Conductivity</td>
</tr>
</tbody>
</table>
Chemical Analyses

• Analyses for T-Hg by California DFG Moss Landing Marine Laboratory using a Perkin-Elmer FIMS-100.

• Sub-samples for M-Hg sent to Frontier Geosciences
Statistics

- ANOVA
- Linear regression
- Multiple regression
  - Semi-partial correlation coefficients
## Field Activities

<table>
<thead>
<tr>
<th>Medium</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invertebrates</td>
<td>1996, 1998</td>
</tr>
<tr>
<td>Fish</td>
<td>1996, 1998</td>
</tr>
<tr>
<td>Caged organisms</td>
<td>1996, 1998</td>
</tr>
<tr>
<td>Amphibian Surveys</td>
<td>1997, 1998</td>
</tr>
<tr>
<td>Habitat Surveys</td>
<td>1997, 1998</td>
</tr>
</tbody>
</table>
• Sediment T-Hg showed a negative exponential relationship with distance from historic mining areas
Sediment T-Hg concentrations exceeded hazardous waste criteria of 20 ug/g (ww) as far as the confluence of Guadalupe and Alamitos Creeks.
Crayfish

T-Hg in Crayfish - Guadalupe River Watershed

Site

- Pre-Plant
- HC
- ALB
- ALM
- GCA
- GCB
- GCC
- LGA
- LGB
- LGC

T-Hg (ug/g ww)

- Wild
- Planted

Lost
Wild Fish

T-Hg in Fish - Guadalupe River Watershed 1998

T-Hg (μg/g ww)
**Biota [T-Hg]**

<table>
<thead>
<tr>
<th>Fish Species</th>
<th>N</th>
<th>Intercept</th>
<th>B</th>
<th>( P )</th>
<th>Adjusted ( r^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>YOY Rainbow Trout</td>
<td>7</td>
<td>0.033</td>
<td>0.122</td>
<td>0.014</td>
<td>0.679</td>
</tr>
<tr>
<td>Mixed-Age Roach</td>
<td>8</td>
<td>0.094</td>
<td>0.143</td>
<td>0.034</td>
<td>0.481</td>
</tr>
<tr>
<td>Adult Suckers</td>
<td>7</td>
<td>0.079</td>
<td>0.174</td>
<td>0.075</td>
<td>0.402</td>
</tr>
<tr>
<td>Crayfish</td>
<td>10</td>
<td>0.045</td>
<td>0.152</td>
<td>0.005</td>
<td>0.610</td>
</tr>
</tbody>
</table>

• T-Hg concentrations in biota could be described in log-log linear regressions with sediment T-Hg
Methylmercury

• Sediment MeHg was correlated to T-Hg on a log-log basis:

\[ r = 0.54; \, p = 0.03; \, n=16 \]

• Crayfish T-Hg was about 100% MeHg
Fish HAI scores showed variable responses.
• Gonadal macrophage aggregates (GMA) and germ cell necrosis (GCN) in male roach correlated with whole body T-Hg
Invertebrate BMI Scores

BMI Scores - Guadalupe River Watershed 1998

Score

CHA  ALB  ALM  GCA  GCB  GCC  LGA  LGB  LGC

Site
Then…

• A miracle occurred…
• …or statistics to the rescue
Creek Substrate

Substrate Percent Composition

- % Other
- % Fine Gravel
- % Coarse Gravel
- % Cobble
- % Boulder

Site:
- CHA
- AC
- HC
- ALB
- ALM
- GCA
- GCB
- GCC
- LGA
- LGB
- LGC
Water Quality

Water Quality Parameters

- Temp (Deg. C)
- pH
- DO (mg/L)

Value

Site

CHA, AC, HC, ALB, ALM, GCA, GCB, GCC, LGA, LGB, LGC
Discharge

Discharge - Guadalupe River Watershed - 1998

Cubic M/Sec

Site

CHA | AC | HC | ALB | ALM | GCA | GCB | GCC | LGA | LGB | LGC

0.0 0.2 0.4 0.6 0.8 1.0 1.2

Discharge - Guadalupe River Watershed - 1998
Benthic Macroinvertebrates

- **BMI Scores**
  - % Cobble (+)
  - Embeddedness (-)

- **EPT Taxa**
  - Sediment T-Hg (-)
  - % Cobble (+)

- **Intolerant BMI**
  - Water temperature (-)
  - % Boulder (+)
Sediment T-Hg was an important negative correlate with BMI metrics.
Fish

• IBI Score
  – Water temperature (-)
  – % Fallen Woody Debris (+)

• Total Number of Species
  – Water temperature (-)
  – % Algal mat cover (+)

• Sucker Age Class Score
  – % Boulder substrate (-)
Fish assemblage abundance, diversity, and productivity metrics correlated negatively with whole body T-Hg (age classes) or sediment T-Hg (number of species and integrated IBI score).
Conclusions

• The pattern of T-Hg concentrations in sediment established the predominant role of the historic mines as a source of Hg loading to the Guadalupe River and San Francisco Bay.

• Germ cell necrosis in male roach occurred at tissue concentrations below those typically associated with adverse effects in fish.

• Habitat data allowed separation of Hg effects on biota from other habitat effects such as stream substrate and riparian cover.
  – Effects of dams on habitat were not consistent between sites

• Sediment and tissue T-Hg showed small but consistently negative correlations with biotic health indicators.
  – Correlation doesn’t equal cause and effect
Ned’s Advice

“90% of finishing your dissertation is convincing your committee that you’re done.”
Things I’d Like to Do

• Coring in creeks
  – Hg profile and pre-mining background Hg

• Kingfisher exposure and productivity
  – Fledging success vs. Hg concentrations in prey

• Survival and development of larval rainbow trout
  – Sets with a known number of fertilized eggs
  – Water quality and Hg in sediment and water
References

• Harrington. 1996. Calif. Dept. Fish & Game, Rancho Cordova, CA
• Moyle and Marchetti. 1999. In: Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, Boca Raton, FL.
Acknowledgements

• Field Work: John Henderson, Larry Thompson, Laura Valoppi, Bill Beckon, Carmen Thomas, Dan Welsh
• Study design: Jim Harrington, CDFG
• Advisors: Dr. Tom Suchanek, Dr. Dave Hinton
• Committees: Dr. Keith Miles, Dr. Peter Moyle, Dr. Joe Cech, Dr. Steve Schwarzbach
• Funding was provided by the Department of the Interior NRDAR Fund, the California Department of Fish and Game Pollution Abatement Fund, and the U.C. Toxic Substances Research and Teaching Program.