Human exposure to methylmercury from marine and estuarine fish: A Gulf-wide approach

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Desired Outcomes

- Reduced human exposure to mercury
- Information for consumers and fishers on safe consumption of Gulf of Mexico seafood products

REQUIRES UNDERSTANDING:

- Contributions of Gulf fisheries to human exposure on a regional and national scale
- How mercury inputs to the Gulf of Mexico affect human and ecological exposures

Harvard School of Engineering and Applied Sciences
Outline

1. MeHg and your health - what is “safe” exposure?

2. Fish consumption patterns in the U.S. and Gulf Region

3. How are changes in mercury levels in Gulf of Mexico fish likely to affect human exposure?
1. MeHg and your health - what is “safe” exposure??
Minamata Disease

• Industrial contamination of fish
• Maternal hair 1.82 – 191 ppm
  – (EPA RfD = 1 ppm)
• Symptoms
  – 12 died within 100 days
  – peripheral neuropathy (glove-stocking, perioral dysthesia),
    dysarthria, tremor, ataxia, gait disturbance, visual disturbance
    (visual field constriction), audiological impairment,
    equilibrium problems (vertigo, dizziness, fainting), increased
    pain threshold, subjective symptoms (headache, muscle/joint pain,
    forgetfulness, fatigue)
  – Some signs and symptoms still apparent at 20 years
  – Some symptoms did not appear until later in life
  – “Disease”, liver, renal, diabetes not more prevalent
Iraqi poisoning

- Consumption of fumigated seed grain
  - 90,000 Mg of seed grain delivered in fall;
  - 1\textsuperscript{st} cases in December (latency avg 16 –38 days).
  - 6,530 hospital admissions, 459 hospital deaths

- Symptoms
  - Ataxia, blurred vision, slurred speech, hearing difficulties
  - Most common observations were of paresthesia (perioral)

- Exposure not clear; most published measurements were done on maternal hair (1- 674 ppm, n= 81).
# Adult Neurotoxicity Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Site</th>
<th>Exposure</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kosatsky &amp; Foran ’96</td>
<td>Several, fish eaters</td>
<td>200 ppb blood or 50 ppm hair</td>
<td>11- 31% of study populations had neuro effects at 200 ppb; conclude WHO was incorrect on LOAEL</td>
</tr>
<tr>
<td>Lebel et al ’96</td>
<td>Amazon</td>
<td>Median = 14 ppm hair ( 5.6 – 38.4)</td>
<td>Reduced chromatic discrimination, contrast sensitivity, restriction visual field; highest had decreased grip strength and manual dexterity</td>
</tr>
<tr>
<td>Lebel et al ’98</td>
<td>Amazon</td>
<td>Mean = 13 ppm</td>
<td>Excluded those with hair&gt; 50 ppm; hair Hg assoc. with visual field , Branches test.</td>
</tr>
<tr>
<td>Beuter and Edwards, ‘98</td>
<td>Northern Quebec (Cree)</td>
<td>Mean (over 25 yrs) = 2.2 – 31.1 ppm hair</td>
<td>Static and kinetic tremor related to Cree vs Parkinson’s pts.; tremor Fitt’s constant and irregularity assoc with Cree vs control</td>
</tr>
<tr>
<td>Yokoo et al ’03</td>
<td>Amazon</td>
<td>Mean = 4.2 ppm (0.56- 13.6)</td>
<td>Hg assoc with fine motor speed , dexterity , concentration</td>
</tr>
</tbody>
</table>
Adult Neurotoxicity Thresholds

<table>
<thead>
<tr>
<th>Agency</th>
<th>Exposure Level</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDA</td>
<td>5 μg kg(^{-1}) day(^{-1}) HgT; 3.3 μg kg(^{-1}) day(^{-1}) MeHg</td>
<td>Based on Swedish studies of Niigata disease ca. 1984</td>
</tr>
<tr>
<td>WHO (1990)</td>
<td>3-7 μg Hg kg(^{-1}) day(^{-1})</td>
<td>= 5% increase in paresthesia</td>
</tr>
<tr>
<td>EPA (1985)</td>
<td>3 μg kg(^{-1}) day(^{-1}) (~200 ug/L blood MeHg); LOAEL for multiple central nervous system effects (incl. ataxia and paresthesia) in Iraqi adults. Uncertainty Factor (10) = 0.3 μg kg(^{-1}) day(^{-1}).</td>
<td></td>
</tr>
</tbody>
</table>

EPA RfD (2000) fetal neurodevelopmental effects = 0.1 μg kg\(^{-1}\) body weight day\(^{-1}\) = 5.8 ug/L blood
Health effects at lower exposure levels

EPA’s RfD

Children IQ Deficits
- From fetal exposures above MeHg RfD

Adult Cardiovascular Effects
- From any fetal MeHg exposures
- Male consumers of non-fatty freshwater fish with high MeHg
- Male fish consumers
- All fish consumers

Decreasing Credibility

Source: G. Rice and J. Hammitt (2005), Harvard Center for Risk Analysis
EPA’s Reference Dose (RfD) for MeHg

- **0.1 μg per kg body weight per day** ≈ 1.1 ppm hair ≈ 5.8 μg/L blood (based on National Research Council findings in 2000)

- Protective compared to other regulatory or risk values (0.1 EU, 0.2 Health Canada, **0.3 ATSDR, 0.4 FDA, 0.23 WHO-FAO**)

- Committee considered neuropsychological effects in children exposed in utero through maternal seafood consumption in Faroes, Seychelles, New Zealand

<table>
<thead>
<tr>
<th>Faroes (N. Atlantic)</th>
<th>Seychelles (Indian)</th>
<th>New Zealand (S. Pacific)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Caucasian</td>
<td>African</td>
<td>Multi-ethnic</td>
</tr>
<tr>
<td>900 mother child pairs</td>
<td>700 mother child pairs</td>
<td>200 mother child pairs</td>
</tr>
<tr>
<td>Cord blood, maternal hair</td>
<td>Maternal Hair</td>
<td>Maternal hair</td>
</tr>
<tr>
<td>Pilot whale</td>
<td>Variety of fish (mostly small reef fish)</td>
<td>Shark (fish and chips)</td>
</tr>
<tr>
<td>Effects in 8 to 10 measures</td>
<td>Authors report no effects associated with mercury in kids up to 9 years of age</td>
<td>Effects in “IQ” tests</td>
</tr>
<tr>
<td></td>
<td>Boston Naming Test, Continuous Performance Test, Finger Tapping, California Verbal Learning</td>
<td>DDST, McCarthy Scales, Bailey Scales, WISC III</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DDST, McCarthy Scales, WISC R</td>
</tr>
</tbody>
</table>
EPA RfD = 0.1mg MeHg per kg body weight per day

At maternal blood concentrations of 58 μg/L blood mercury one would expect a doubling of the number of poor performers on neuro-developmental tests (from 5% to 10% of the population).
Cardiovascular disease is the Leading causes of deaths in the US
Possible mechanisms of action of MeHg on Cardiovascular Disease

• Increase oxidative stress
  – Production of free radicals, hydrogen and lipid peroxides
  – Binds to and inactivates selenium
  – High affinity for thiol groups, and may inactivate glutathion, catalase, and SOD
  – Correlated with oxidized-LDL levels

• Effects on blood pressure and heart rate variability

• Effects on endothelial cells, inflammatory response, platelet aggregability

Slide Courtesy of E. Guallar, Johns Hopkins
Mercury Cardiovascular Toxicity

### Ω–3 fatty content of selected fish

<table>
<thead>
<tr>
<th>Fish</th>
<th>ALA</th>
<th>EPA</th>
<th>DHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mackerel</td>
<td>0.1</td>
<td>0.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Atlantic herring</td>
<td>0.1</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Albacore tuna</td>
<td>0.2</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0.1</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Anchovy</td>
<td>Trace</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Greenland halibut</td>
<td>Trace</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Atlantic cod</td>
<td>Trace</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Atlantic white shrimp</td>
<td>Trace</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Catfish</td>
<td>Trace</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Northern lobster</td>
<td>0</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Flounder</td>
<td>Trace</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*Given as grams of fatty acid per 100 g of raw material. ALA indicates α-linolenic acid; EPA, eicosapentaenoic acid; and DHA, docosahexaenoic acid.*
Good Fish?  Bad Fish?

Source: Mahaffey et al., Env. Res., 2008
What Causes Exposures of Concern?

Blood MeHg (µg/L) in U.S. Women (16-49)

Source: Mahaffey et al., 2008, EHP, in press
## Fish meals resulting in exposure $>\text{RfD}$

**U.S. Women of Childbearing Age (16-49)**

EPA RfD = 0.1 ug/kg body weight per day

### Geographic Variability in Fish Hg

<table>
<thead>
<tr>
<th>Meals per month</th>
<th>Meal size</th>
<th>Mean FDA</th>
<th>90th</th>
<th>95th</th>
<th>99th</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4 (46%)</td>
<td>10$^\text{th}$ (5%)</td>
<td>$&lt;0.01$</td>
<td>$&lt;0.01$</td>
<td>$&lt;0.01$</td>
<td>0.01-0.03</td>
</tr>
<tr>
<td></td>
<td>50$^\text{th}$ (23%)</td>
<td>0.01-0.02</td>
<td>0.01-0.04</td>
<td>0.01-0.04</td>
<td>0.03-0.11</td>
</tr>
<tr>
<td></td>
<td>90$^\text{th}$ (5%)</td>
<td>0.02-0.07</td>
<td>0.02-0.09</td>
<td>$0.03-0.10$</td>
<td>0.07-0.29</td>
</tr>
<tr>
<td>5-8 (13.5%)</td>
<td>10$^\text{th}$ (1%)</td>
<td>0.01-0.02</td>
<td>0.01-0.02</td>
<td>0.01-0.02</td>
<td>0.04-0.06</td>
</tr>
<tr>
<td></td>
<td>50$^\text{th}$ (7%)</td>
<td>0.03-0.05</td>
<td>0.04-0.07</td>
<td>0.05-0.08</td>
<td>$0.13-0.21$</td>
</tr>
<tr>
<td></td>
<td>90$^\text{th}$ (1%)</td>
<td>0.09-0.14</td>
<td>0.12-0.19</td>
<td>0.13-0.21</td>
<td>0.36-0.58</td>
</tr>
<tr>
<td>&gt;8 (9%)</td>
<td>10$^\text{th}$ (&lt;1%)</td>
<td>$&gt;0.02$</td>
<td>$&gt;0.02$</td>
<td>$&gt;0.03$</td>
<td>$&gt;0.07$</td>
</tr>
<tr>
<td></td>
<td>50$^\text{th}$ (4.5%)</td>
<td>$&gt;0.06$</td>
<td>$&gt;0.08$</td>
<td>$&gt;0.09$</td>
<td>$&gt;0.24$</td>
</tr>
<tr>
<td></td>
<td>90$^\text{th}$ (&lt;1%)</td>
<td>$&gt;0.15$</td>
<td>$&gt;0.21$</td>
<td>$&gt;0.23$</td>
<td>$&gt;0.66$</td>
</tr>
</tbody>
</table>

Sunderland, EHP, 2007
National Health and Nutrition Examination Survey (NHANES) 2004 data on Blood Hg in US women 16-49


Source: Mahaffey et al., 2008, in press
Temporal Trends in Blood Hg 1999-2004 from NHANES survey

U.S. women ages 16-49

Source: Mahaffey et al., 2008, EHP, in press
2. Fish Consumption Patterns in the U.S. and Gulf Region
Per-Capita (g/day) Consumption of Marine Fish

Source: Degner et al., 1994; Sunderland, 2007; U.S. EPA, 2002
What Kind of Fish Do Anglers Eat?

- 80% of anglers consume their catch
- On average anglers share catch with 1.5 others

Source: 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (FWS 2001); respondents could select more than one species.

Source: Mercury Study Report to Congress, 1997
Survey of 402 Recreational Anglers in Gulf Region

Total Reported Meals – all participants
88 different species reported!

- shellfish: 43%
- salmon: 3%
- canned tuna: 7%
- saltwater finfish: 36%
- freshwater finfish: 10%
- fresh tuna: 12%
- salmon canned tuna: 15%
- speckled trout: 57%
- red drum: 14%
- fresh water finfish: 15%
- canned tuna: 14%
- saltwater finfish: 57%

Lincoln et al., in prep, HSPH; Slide courtesy of D. Senn
Top 24 Species Consumed in Florida

Per-capita consumption (g/d)

Marine Species:
~ 93% edible supply in commercial market (NMFS 2001-2003)
~ 90% consumption Florida residents surveyed in 1993-1994

Source: Degner et al., 1995
Species consumed and frequency of consumption

Source: Mahaffey et al., 2008, in press

Gulf residents consume more fish than national avg. but lg. amts of shellfish low in Hg
30 day mercury intake (μg Hg per kg body weight)

Source: Mahaffey et al., 2008, in press
3. How are changes in mercury levels in Gulf of Mexico fish likely human exposure?
Individual Mercury Exposure

\[ \Sigma (\text{Meal Frequency} \times \text{Meal Size} \times \text{Hg in Fish}) \]

- **Dietary Surveys** => Meal Frequency, Meal Size, Species Selection
- **behavioral patterns**
- **environmental quality**
  - By Species
  - Within Species
  - Geographic Variability
Mercury Levels in Commercial Fish and Shellfish

“error bars” show range of mercury concentrations for a given species.

Number of Samples
- 300 - 700
- 100 - 300
- 50 - 100
- 10 - 50
- 1 - 10
## Gulf of Mexico Landings

### Florida – Top 10 Species (2006)

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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shrimp (all species)</td>
<td>21,378,017</td>
<td>Low</td>
<td>King mackerel</td>
<td>6,270,059</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Blue Crab</td>
<td>11,886,781</td>
<td>Low</td>
<td>Dolphins (common)</td>
<td>5,233,068</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>Grouper (all species)</td>
<td>9,085,916</td>
<td>Med</td>
<td>Mullets (striped + white)</td>
<td>3,513,650</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>Mullet (all spp. + roe)</td>
<td>8,463,379</td>
<td>Low</td>
<td>Spanish mackerel</td>
<td>8,463,379</td>
<td>Med</td>
</tr>
<tr>
<td>5</td>
<td>Spiny Lobster</td>
<td>4,772,926</td>
<td>Low</td>
<td>Spotted seatrout</td>
<td>2,919,578</td>
<td>Med</td>
</tr>
<tr>
<td>6</td>
<td>King mackerel</td>
<td>3,965,306</td>
<td>High</td>
<td>Blue runner (mostly bait)</td>
<td>2,883,615</td>
<td>Low</td>
</tr>
<tr>
<td>7</td>
<td>Spanish mackerel</td>
<td>3,949,248</td>
<td>Med</td>
<td>Sheepshead</td>
<td>2,620,533</td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>Shark (including fins)</td>
<td>3,771,478</td>
<td>High</td>
<td>Gag groupers</td>
<td>2,281,170</td>
<td>Med</td>
</tr>
<tr>
<td>9</td>
<td>Snapper (all species)</td>
<td>3,757,218</td>
<td>Med</td>
<td>Red drum</td>
<td>2,172,673</td>
<td>Med</td>
</tr>
<tr>
<td>10</td>
<td>Oysters</td>
<td>2,444,888</td>
<td>Low</td>
<td>Red snapper</td>
<td>1,950,299</td>
<td>Low</td>
</tr>
</tbody>
</table>

NMFS 2007 data
~90% fish and shellfish consumed are marine and estuarine species

U.S. population-wide exposure to Hg

Source: Sunderland, EHP, 2007
% Contribution of Atlantic Ocean and Gulf of Mexico Harvests to U.S. Commercial Market

Source: Rice and Hammitt, 2005
Mean Hg concentrations in Gulf/Atl. fish compared to fraction of total consumption

Source: Degner et al., 1994; Sunderland, 2007; Carrington and Bolger, 2004
Based on results from 1993-1994 survey by Degner et al. in Florida.
Over 50% Hg Exposure from marine fish and shellfish that potentially reflect GoM Hg levels

For a 70 kg individual, per-capita exposure in FL = 0.12 μg Hg per kg bw per day > EPA’s RfD

Dietary data from Degner et al., 1995; Hg data from Sunderland, 2007 & Carrington & Bolger, 2004
• Gulf residents consume >> fish than national average (46 g/day vs <20 g/day)
• ~90% fish consumed are marine species
• ~24% total Hg exposure in Gulf (FL) residents from recreational fish
• >50% Hg exposure from marine fish and shellfish potentially from GoM fisheries
• Large portion of exposure is from migratory pelagic species (~44%)