Patterns of Global Seafood Mercury Concentrations and their Relationship with Human Health and the Environment

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Mercury, the Marine Environment, and Risk of Human Exposure

Mercury (Hg) is a pollutant of global importance that adversely affects human health and the environment. Environmental concentrations of mercury have increased three-fold due to anthropogenic activities, and the world’s oceans are one of the primary reservoirs where mercury is deposited (Mason et al. 2012).

People are commonly exposed to mercury through the consumption of shellfish, fish, and some marine mammals. However, there is a gap in our understanding of the relationship between anthropogenic releases of mercury and its subsequent biomagnification and bioaccumulation in seafood such as lobster, tuna, and swordfish. Determining how that translates to human exposure and risk on local, regional, and global scales is essential.

Report Overview

BRI’s report on Mercury in the Global Environment examines seafood mercury concentrations from existing reputable sources and presents collated data on different types of seafood with the goal of explaining the significance of these findings as they relate to human health and the environment.

The report highlights marine organisms that have the greatest concentrations of mercury. These data are then related to global seafood capture data to provide insight into the potential risks associated with consumption of marine species with high mercury concentrations. The data also identify marine species that have low average mercury concentrations. Results outlined in this report can contribute toward the development of national fish consumption advisories for mercury.

The Minamata Convention on Mercury is a global, legally binding treaty designed to protect human health and the environment from the adverse effects of mercury. The language of the treaty was agreed upon at the fifth meeting of the Intergovernmental Negotiating Committee and has been signed by 128 countries (as of this printing).

This report is designed to assist parties to the Convention and other interested organizations to understand spatial and temporal patterns of mercury concentrations in fish and to identify species that represent a potential risk to human health.

New scientific evidence demonstrates the need to review consumption guidelines for mercury. The toxicity of mercury is greater than previously thought, while emissions and releases of mercury are increasing globally.

While mercury in fish from open oceans originates from atmospheric deposition, nearshore areas where much subsistence fishing occurs are most influenced by mercury input through rivers and their watersheds.

Major Findings

- Mercury contamination is ubiquitous in global marine ecosystems.
- Mercury concentrations in fish vary by species and by ocean basin.
- Some of the most highly sought after marine fish species for seafood contain mercury concentrations that exceed safe levels for human consumption.
- When considering healthy versus risky fish choices, consumers should also be aware of the benefits of consuming certain fish with high omega-3 fatty acids (see matrix on page 9).
- BRI’s Global Biotic Mercury Synthesis (GBMS) database provides a standardized and comprehensive platform for understanding mercury concentrations that can aid parties to the Minamata Convention on Mercury during their ratification and implementation process.
Biodiversity Research Institute is a member of both the Mercury Air Transport and Fate Research and the Artisanal and Small-scale Gold Mining (ASGM) Partnership Groups of the United Nations Environment Programme (UNEP). BRI is contributing toward the first international treaty of a globally binding agreement to monitor and regulate mercury emissions by creating a mercury database clearinghouse and helping facilitate countries’ efforts to meet the requirements of the treaty.

In response to concerns brought forward by UNEP, BRI has developed a Global Biotic Mercury Synthesis (GBMS) database that provides information on the global distribution of biotic mercury concentrations that affect human health and the environment. The database includes data on a wide range of species including freshwater fishes, marine fishes, birds, and marine mammals. The data included in GBMS represents a valuable mechanism for integrating mercury science into important policy decisions related to the Minamata Convention on Mercury and the protection of human health and the environment from the risks of mercury exposure.

The GBMS database can assist with long-term monitoring of mercury in the environment. In addition, this database identifies species that are at risk of high mercury exposure and that also might represent a risk to humans due to fish consumption. Overall, GBMS has applications to several articles within the Minamata Convention (Table 1).
How GBMS Can Help Countries Meet the Treaty Requirements

BRI has compiled a Global Biotic Mercury Synthesis (GBMS) Database in association with UNEP’s Mercury Air Transport and Fate Research Partnership Group. The database contains biotic mercury concentrations from peer-reviewed publications and governmental sources. GBMS objectives and how they relate to the various Articles of the Minamata Convention are outlined in the table below:

<table>
<thead>
<tr>
<th>Objectives of Mercury in the Global Environment Project</th>
<th>Minamata Convention Article</th>
<th>Linkages between GBMS and Minamata Convention Articles</th>
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</thead>
</table>
| Identify global biological mercury hotspots and link those hotspots to potential mercury source types. | **Article 12**: Contaminated Sites  
**Article 19**: Research, Development, and Monitoring | • Biotic mercury concentrations can help identify sites contaminated by mercury.  
• Biotic mercury concentrations can be used to inform human and environmental risk assessments. |
| Compile and present mercury data in an easy-to-access and understand format. | **Article 14**: Capacity-building, Technical Assistance, and Technology Transfer  
**Article 17**: Information Exchange  
**Article 18**: Public Information, Awareness, and Education | • GBMS provides a model for database development used to compile and interpret biotic mercury concentrations.  
• GBMS facilitates the exchange of scientific information between the scientific community, the policy sector, and the general public. |
| Identify indicator species (fish, marine mammals, sea turtles, and birds) for long-term monitoring to reflect relevant spatial and temporal trends. | **Article 16**: Health aspects  
**Article 19**: Research, Development, and Monitoring | GBMS represents a comprehensive database on mercury concentrations that:  
• can be used to inform models on mercury concentrations in environmental media;  
• is a tool for assessing potential risk of human exposure to mercury via fish consumption;  
• documents the fate of mercury in freshwater and marine ecosystems;  
• can provide important information to countries about fish mercury concentrations within their national waters. |
| Establish a baseline of mercury concentrations including spatial and temporal trends. | **Article 22**: Effectiveness Evaluation | • Mercury concentrations in GBMS provide a baseline of monitoring data for assessing the effectiveness of the treaty. |

**Table 1.** Connection between BRI’s Global Biotic Mercury Synthesis Database and the Minamata Convention requirements.

GBMS represents a comprehensive, standardized, and cost effective approach for documenting and tracking changes in environmental loads of mercury as reflected in fish and wildlife. The use of key indicator organisms, such as apex marine predators, that are sensitive to environmental change is an integral part of a long-term monitoring program (see Evers et al. 2008; Chen et al. 2012). The data included in GBMS represents an important opportunity to better integrate mercury science into important policy decisions related to the long-term management of marine resources (Lambert et al. 2012).
Mercury concentrations within GBMS are not converted for display. Mercury data were compiled on a global scale from published literature and governmental sources. From each reference, mercury concentrations were averaged (using arithmetic means) at each location for each species sampled. The database holds information about the organism sampled as well as associated ecological data. For display and comparison of the data, mercury concentrations represent muscle tissue on a parts per million (ppm) wet weight (ww) basis. Mercury data on a dry weight basis were converted to ww using a percent moisture content of 80 percent at this time. Samples analyzed in tissues other than muscle were converted to muscle tissue. Because greater than 95 percent of the mercury in fish is in the form of methylmercury (Bloom 1992), total mercury concentrations within GBMS are not converted to methylmercury.

**Figure 1.** The global distribution of fish, including shark, and marine mammal mercury concentrations. The mercury concentration is presented in parts per million (ppm) on a wet weight (ww) basis.

**Behind the Data**

Mercury data were compiled on a global scale from published literature and governmental sources. From each reference, mercury concentrations were averaged (using arithmetic means) at each location for each species sampled. The database holds information about the organism sampled as well as associated ecological data. For display and comparison of the data, mercury concentrations represent muscle tissue on a parts per million (ppm) wet weight (ww) basis. Mercury data on a dry weight basis were converted to ww using a percent moisture content of 80 percent at this time. Samples analyzed in tissues other than muscle were converted to muscle tissue. Because greater than 95 percent of the mercury in fish is in the form of methylmercury (Bloom 1992), total mercury concentrations within GBMS are not converted to methylmercury.

**Geographic Distribution**

GBMS allows for spatial representation and comparison among studies, geographic locations, time, and ecosystem types. Data for this report have been compiled from 203 different references, representing 72 countries, 457 unique locations, and 1,959 averaged mercury samples from 33,895 total individual organisms (Figure 1).

Mercury research into freshwater fish in tropical wetlands is needed to better characterize potential hotspots.
Global Fish Mercury Concentrations

Seafood mercury concentrations are best known in fin fish. They are most studied in North America and Europe and least studied in Asia and South America (Karimi et al. 2012).

However, even in the United States, monitoring of seafood mercury concentrations needs improvement to ensure accurate exposure estimates over time (Sunderland 2007).

Healthier Fish Choices

Globally, mercury concentrations are lowest in smaller, short-lived fish. There are many regularly harvested fish, such as anchovies, sardines, flounder, cod, salmon, and haddock, that can be safely consumed on either a daily or weekly basis (Figure 2). These species, and many others, are often harvested commercially and shipped through global markets. Note that some species in some regions can exceed safe weekly consumption levels (e.g., anchovies from the Mediterranean Sea have average mercury concentrations greater than 0.11 ppm, ww; Figure 10).

Interpreting Mercury Concentrations and Risks of Exposure

For this report, fin fish and marine mammal mercury concentrations can be compared with consumption guidelines in Table 2 below. To provide context, the mercury concentrations presented can be compared with the number of seafood meals that could be eaten at various mercury concentrations in order to stay within the U.S. EPA’s health-based reference dose for methylmercury (see Table 2 for the fish meal limits by methylmercury concentration, and see U.S. EPA [2001] for details on how the fish meal limits were calculated). For further reference, the World Health Organization (WHO) and the European Commission (EC) criteria for fish mercury concentrations is 0.5 ppm with an “exemption” for larger, predatory fish species (e.g., swordfish, shark, some tuna species) of up to 1.0 ppm. This guidance level is very similar to the 0.95 ppm “no consumption” limit based on the U.S. EPA reference dose.

Table 2. Seafood mercury concentrations and associated meal frequency guidelines. The guidance is based on the U.S. EPA reference dose of 1x10^-3 mg of Hg/kg of body weight/day, a body weight of 132 pounds (60 kg) for an adult female person, and a fish meal size of about 6 ounces (170 grams). These guidelines could also be used for muscle tissues in marine mammals because >95% of Hg in marine mammals is in the methyl form. However, shellfish Hg concentrations greatly vary in percent methyl and therefore the consumption guidance provided here cannot be directly used with shellfish Hg data provided herein.
**Riskier Fish Choices**

Methylmercury is known to affect neurological development in children and is also linked to cardiovascular disease in adults (Clarkson et al. 2003; Valera et al. 2011; Grandjean et al. 2012).

Mercury concentrations are highest in large, long-lived species, many of which are pelagic. Marlin (representing multiple species within the Istiophoridae family), Pacific bluefin tuna (which can approach 1,000 pounds), and the wide-ranging swordfish and king mackerel have the highest mercury concentrations of any fish in the GBMS database (Figure 3). These and other commonly consumed fish species have average mercury body burdens that meet the no consumption guidance (Figure 3; Table 2).

While less than one percent of the world seafood harvest includes sharks (Figure 5), shark meat is sought after in several European and Central American countries and the demand for certain shark products (e.g., fins) in Asia drives a rapidly expanding shark fishery globally (Vannuccini 1999; Musick and Musick 2011).

Generally, mercury concentrations in sharks exceed safe consumption guidelines (Figure 4; n=6,414). For shark species commonly encountered such as bull, lemon, and nurse sharks, average mercury concentrations compared globally indicate highest levels in the Mediterranean Sea and the Gulf of Mexico.

**Figure 3.** The average muscle Hg concentration in fish with standard deviation compared against consumption guidance levels (Table 1). These fish represent species regularly consumed and having average muscle Hg concentrations >0.22 ppm (ww).

**Figure 4.** The average muscle Hg concentration in six shark orders with standard deviation and sample size (n).
Global fish harvest (including both live caught and aquaculture) totaled 148.5 million tonnes in 2010, with live caught fishes accounting for approximately 90 million tonnes (61 percent) of the total production (FAO 2012).

Sardine-like fishes (i.e., herrings, anchovies, and sardines), dominate global fish capture, with the Peruvian anchovy being the most caught species. Other highly sought after fishes include benthic and demersal fishes, coastal fishes, and pelagic fishes (Figure 5).

Benthic and demersal fishes include species such as cod, haddock, and flounder. The world’s coastal fishery represents an important resource for many of the world’s coastal communities. Pelagic fishes include billfish, a variety of mackerel fishes, and all of the tuna species (Figure 6).

Many of the pelagic fishes are long-lived apex predators in the marine environment, migrating across much of the world’s oceans. When considering fishes with the highest mercury concentrations (Figure 3), seven of the top ten species are considered pelagic.

Figure 5. The Food and Agriculture Organization of the United Nations (FAO) maintain the only standardized repository for global fisheries data. Data from FAO’s FISHSTATJ fisheries database totals global harvest of fishes in 2010 at more than 148 million tonnes.

Figure 6. Harvest of pelagic fishes accounts for 25% of the global fish harvest and is dominated by tuna species.

Pelagic fishes including bluefin tuna (shown above) are among the most highly sought after fishes, and are shown to contain some of the highest mercury levels (see fish matrix page 9).
Global Health Trade-Off for Mercury and Omega-3 in Fish

The matrix below illustrates the trade-offs and interactions of fish mercury concentrations and the associated omega-3 fatty acids. Those species or groups with low mercury levels and high omega-3 fatty acids are the healthiest options, while those with elevated mercury body burdens and low omega-3 fatty acids are riskier and less nutritious choices.

<table>
<thead>
<tr>
<th>Meal Frequency Recommendations</th>
<th>&lt;500 mg</th>
<th>500-1,000 mg</th>
<th>1,000-2,000 mg</th>
<th>&gt;2,000 mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted meals (&lt;0.05 µg/g)</td>
<td>Catfish, Clams, Crab* (most species), Croaker, Haddock, Scallops, Shrimp, Tilapia*</td>
<td>Blue Mussels,* Pink Salmon, Sockeye Salmon</td>
<td>Chinook Salmon,* Coho Salmon, Oysters</td>
<td>Atlantic Salmon, Sardines, Shad</td>
</tr>
<tr>
<td>1-2 meals per week (0.05-0.22 µg/g)</td>
<td>Atlantic and Pacific Cod, Flounder, Grenadier, Hake, Lobster,* Sole</td>
<td>Atlantic Pollock, Mahi Mahi, Mullet, Scad, Squid, Skipjack Tuna, any canned tuna</td>
<td>Atlantic and Pacific Mackerel, Atlantic Horse Mackerel, European Sea Bass, Rays, Skates</td>
<td>Anchovies,* Herring</td>
</tr>
<tr>
<td>1 meal per month (0.22-0.95 µg/g)</td>
<td>Grouper, Orange Roughy, Snapper</td>
<td>Bigeye Tuna, Bluefish, Halibut, Yellowfin Tuna</td>
<td>Albacore Tuna,* Atlantic Bluefin Tuna, Chilean Sea Bass</td>
<td>---</td>
</tr>
<tr>
<td>No consumption (&gt;0.95 µg/g)</td>
<td>King Mackerel</td>
<td>Marlin, Tilefish</td>
<td>Dogfish, Ground, and Mackerel Sharks, Pacific Bluefin Tuna, Swordfish*</td>
<td>---</td>
</tr>
</tbody>
</table>

Data Sources: BRI’s Global Biotic Mercury Synthesis (GBMS) Database; U.S. Environmental Protection Agency; U.S. Food and Drug Administration

*Pictured

Omega-3 Fatty Acids

While most fish contain omega-3 fatty acids, there is a trade-off in health benefits from those fish that also contain high mercury levels.

Omega-3 fatty acids are necessary for human health but the body cannot produce them, so people must eat foods that contain these essential fatty acids. Research shows that omega-3 fatty acids reduce inflammation and may help lower risk of chronic diseases such as heart disease, cancer, and arthritis.

Omega-3 fatty acids are highly concentrated in the brain and appear to be important for cognitive (brain memory and performance) and behavioral function.

Source: University of Maryland Medical Center/ www.umm.edu

Mercury concentrations vary widely across shark species (see Figure 4).
Data from the United Nations Food and Agriculture Organization (FAO) state that nearly 40 percent of global fish products enter international markets for either direct consumption or food processing (FAO 2012).

Tuna is consistently among the top five commodities in the global fish market. Skipjack, albacore, and yellowfin are the most common species utilized by the tuna canning industry, while bluefin tuna species are highly sought after for direct consumption, for example, for steaks (FAO 2004).

Based on models by Sunderland et al. (2009), present atmospheric mercury deposition rates will result in mercury concentrations doubling in the North Pacific Ocean by 2050. Such deposition rates are suspected to result in significant increases of mercury levels in pelagic marine fish, such as the Pacific bluefin tuna, if methylmercury production and bioaccumulation mimic projected mercury additions. Total muscle mercury of tuna is displayed alongside FAO fish capture from 2010 in Figure 7 below.

Figure 7. The Pacific Ocean tuna harvest by species in 2010 (FAO 2012) compared to the average muscle Hg concentration in each species with standard deviation.
Marine shellfish accounted for approximately 23 percent of the global fishery and aquaculture harvest in 2010; shellfish, particularly shrimp, are considered the most highly valued commodity on the global fish market (FAO 2012).

The composition of the global shellfish harvest is dominated by three main taxonomic groups including shrimps and prawns (28 percent); cephalopods such as squids, octopuses, and cuttlefish (15 percent); and molluscs (14.5 percent) including clams, mussels, scallops, and other bivalves.

The Food and Agriculture Organization (FAO), in collaboration with the World Health Organization (WHO), recently reviewed the risks and benefits of fish and shellfish consumption and provides mean mercury concentrations for a wide range of shellfish that are commonly consumed (FAO/WHO 2010). Mean mercury concentrations in shellfish vary by almost an order of magnitude (Figure 8).

Molluscs such as clams and scallops have a mean total mercury concentration of approximately 0.02 ppm, ww, while the American lobster has a mean mercury concentration of 0.22 ppm, ww.

Squids account for the largest percentage of cephalopods captured from the world’s oceans (~77 percent) and have a mean mercury concentration of 0.10 ppm, ww.

Figure 8. Total Hg concentrations in shellfish. Data are derived from a dataset without standard deviations or the spatial distribution of samples (FAO/WHO 2011).
While tracking seafood mercury concentrations commonly emphasizes shellfish and fish, marine mammals should also be considered for human health assessment purposes. Marine mammals are a traditional component of the diet of many subsistence communities around the world, particularly in the Arctic. Long-range transport of mercury at lower latitudes regularly moves to higher latitudes of the Arctic, and there is now added concern that warmer temperatures may be rapidly remobilizing formerly bound mercury stores from thawing glaciers, sediment, and permafrost (AMAP 2011).

Increased levels of mercury in fish and wildlife within the Arctic may be resulting from increasing mercury inputs and changes in the Arctic ecosystems. Based on data from our GBMS database, average marine mammal muscle tissue mercury concentrations are generally above safe consumption levels in all ocean basins, except the Antarctic Ocean (Figure 9; n = 4,362). Because human communities within the Arctic Ocean can have great dependency on marine mammals, their mercury concentrations in dietary items are of special concern.

Beluga and narwhals are commonly harvested and often have muscle mercury concentrations that exceed human health consumption guidelines of one meal per month (i.e., based on mercury concentrations between 0.22 and 0.95 ppm, ww). The effect thresholds for marine mammals are poorly understood, but based on mercury effect thresholds for terrestrial mammals, there could be significant adverse impacts on the reproductive success of marine mammals.
Clupeiform fishes (e.g., herring, sardines, and anchovies) are generally small, pelagic fishes often found in abundant schools. They dominated the overall global fisheries harvest during 2010 (Figure 5), led by the Peruvian anchovy, whose harvest totaled more than 4.2 million tonnes (FAO 2012).

Clupeiforms are low on the marine food web, feeding primarily on plankton, but they play a very important role as prey items for other, larger marine fishes. In part because of their lower trophic level, average mercury concentrations in clupeiforms are generally low (Figure 10).

The global harvest is generally dominated by catches from the Atlantic and Pacific Oceans, with relatively lower harvests from the Indian Ocean (Figure 10).

There is some variability in mercury concentrations within clupeiforms and across oceans. Generally, average mercury concentrations are lowest in herring species (Figure 11).

Figure 10. Mercury concentrations in clupeiforms and associated harvest data by oceanic region.

Figure 11. The average mercury concentrations of three taxa of clupeiforms with standard deviation of sample size (n), in the Northern Hemisphere.
References


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