

MERCURY IN THE GLOBAL ENVIRONMENT



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



Mercury, the Marine Environment, and Risk of Human Exposure

Mercury (Hg) is a pollutant of global importance that adversely impacts ecological and human health. Concentrations of mercury in the global environment have increased approximately three-fold as a result of anthropogenic activities, and the world's oceans are one of the primary reservoirs where mercury is deposited (Mason et al. 2012).

The consumption of shellfish, fish, and some marine mammals represents one of the primary pathways through which people are exposed to mercury. However, there is a gap in our understanding about the relationship between anthropogenic releases of mercury into the environment and the subsequent biomagnification and bioaccumulation of mercury in seafood such as lobster, tuna, and swordfish. Determining how this translates to exposure and risks for humans, on local, regional, and global scales is a critical need.



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



Report Overview

This report, produced by Biodiversity Research Institute (BRI), 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 ecological and human health.

The report provides insight into the species of marine organisms with 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. These data also identify marine species within the global seafood market that have low average mercury concentrations. Results outlined in this report can contribute toward the development of national fish consumption advisories for mercury.

The Governing Council of the United Nations Environment Programme (UNEP) is taking action to develop a global, legally binding treaty designed to monitor and regulate mercury emissions.

BRI's study highlights the global scale of mercury pollution and reinforces UNEP's efforts towards ratifying a global mercury treaty.



New scientific evidence demonstrates the need for a review of consumption guidelines for mercury. There are currently two trends occurring: 1) the toxicity of mercury is increasingly shown to be greater than previously thought; 2) environmental mercury loading from anthropogenic sources is increasing globally.

Major Findings

- The extent of mercury contamination is ubiquitous in global marine ecosystems and likely varies because of associated contaminant sources and the sensitivity of ecosystems from the input of mercury through atmospheric deposition and watershed sources.
- Various marine organisms regularly harvested and consumed by people have mercury concentrations that commonly exceed safe levels and include commercial seafood such as lobster, tuna, and swordfish; for subsistence-dependent communities that includes marine mammals such as small whales. Conversely, there are many commonly harvested species including shrimp, cod, haddock, herring, and sardines that have low body burdens of mercury.
- BRI's Global Biotic Mercury Synthesis (GMBS) database (see page 4) provides a standardized and comprehensive platform that can be used to describe ocean basins and marine species that are sensitive to mercury inputs and subsequent bioaccumulation, identify specific areas where further research is needed to better understand the biogeochemical mechanisms causing elevated mercury concentrations in biota, and examine spatial and temporal trends of key biotic indicators that can be linked to evaluating the effectiveness of the global legally binding mercury treaty.

Global Biotic Mercury Synthesis (GBMS) Database

Biodiversity Research Institute (BRI) has compiled a **Global Biotic Mercury Synthesis (GBMS) Database** in association with the United Nations Environment Programme's Mercury Air Transport and Fate Research Partnership Group.

The database contains biotic mercury concentrations from peer-reviewed publications and governmental sources. As a project of the Transport and Fate Partnership Group, the objectives are to:

1. Determine global spatial and temporal patterns of biotic mercury concentrations;
2. Identify species or groups of organisms that are of greatest concern for ecological and human health;
3. Locate global biological mercury hotspots, link with major mercury source types and determine if concern is related to contaminated sites or ecosystems sensitive to even small amounts of mercury input;
4. Distribute information in easy-to-access and understandable approaches for interested parties at local, regional, and global levels;
5. Use GBMS as a baseline to evaluate the effectiveness of the future global legally binding treaty on mercury.

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).

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.

Seafood mercury concentrations in the GBMS database are recorded as total mercury. Consumption guidelines generally refer to methylmercury concentrations in fish because that is the more toxic form of mercury. Methylmercury is known to impact 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). 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.

The database holds information about the organism sampled as well as associated ecological data. For displaying and comparing the data, mercury concentrations represent muscle tissue on a parts per million (ppm) wet weight (ww) basis. Mercury data on a dry weight basis was 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.

United Nations Environment Programme Global Treaty on Mercury

As a member of the Mercury Air Transport and Fate Research Partnership Group 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.

The goal is for the intergovernmental negotiating committee (INC) to complete a document for the Governing Council by the end of 2013.

In response to concerns brought forward by UNEP, BRI is developing a Global Biotic Mercury Synthesis database, which will determine the global distribution of biotic mercury concentrations that affect human and ecological health.

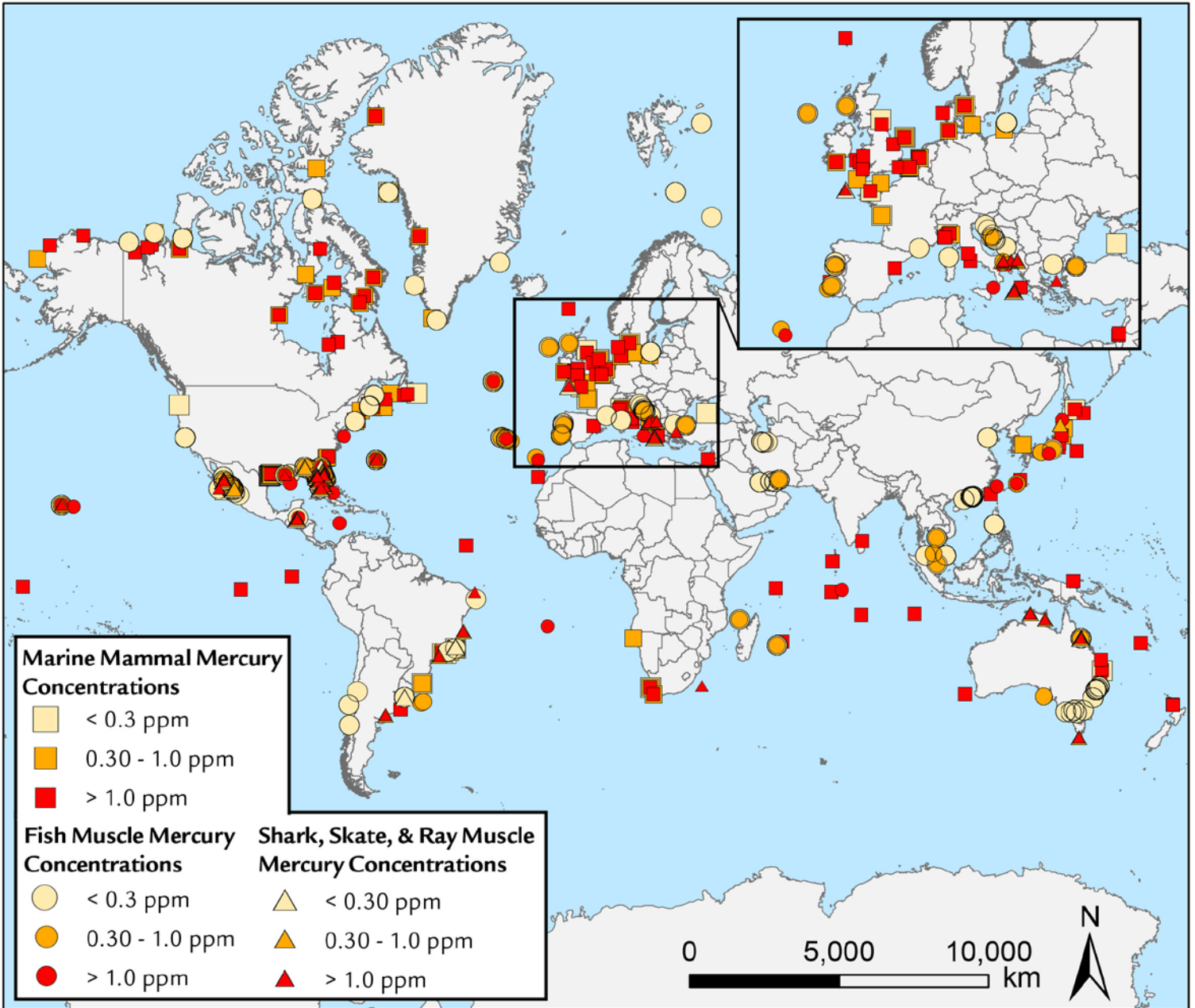


Figure 1. The global distribution of fish, including shark, and marine mammal mercury concentrations. The mercury concentration is presented in parts per million (ppm) on a wet weight (ww) basis.

Geographic Distribution

GBMS allows for spatial representation and comparison among studies, geographic locations, time, and ecosystem types. Data for this report only represent marine organisms and are from 200 different references from 324 unique locations around the world, totaling 1,379 averaged mercury samples from 25,826 total individuals sampled (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 U.S., 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 anchovy, sardines, flounder, cod, salmon, and haddock, which can be safely consumed on a weekly basis (Figure 2). These species, and many others are often harvested commercially and shipped through global markets. Note, some species in some regions can exceed safe weekly consumption levels.

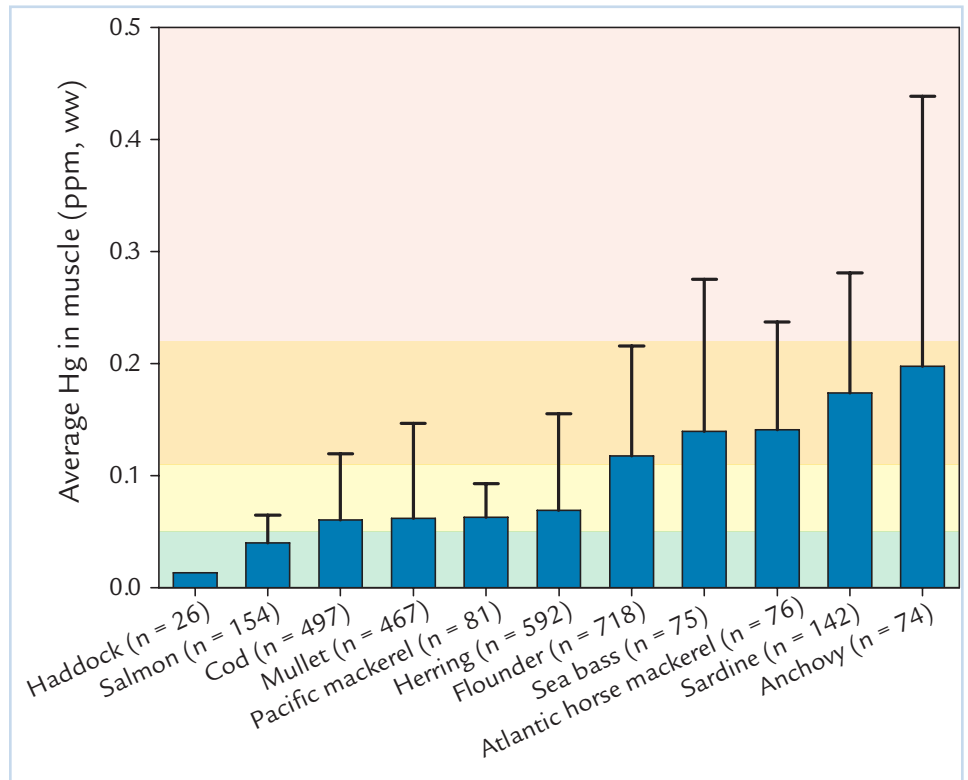


Figure 2. The average muscle Hg concentration in fish with standard deviation compared against consumption guidance levels (Table 1). These fish represent species regularly consumed and having average muscle Hg concentrations <0.22 ppm (ww).

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 1.

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 1 for the fish meal limits by methylmercury

concentration, and see U.S. EPA [2001] for details on how the fish meal limits were calculated).

Also for further reference, the World Health Organization (WHO) and the European Commission’s (EC) fish mercury concentration guidance level is 1.0 ppm (ww), above which fish may not be sold commercially. This guidance level is very similar to the 0.95 ppm “no consumption” limit based on the USEPA-based guidelines.

Methylmercury in seafood (ppm, ww)	Consumption Guidance
≤0.05	unrestricted
0.05-0.11	2 meals per week
0.11-0.22	1 meal per week
0.22-0.95	1 meal per month
>0.95	no consumption

Table 1. Seafood methylmercury concentrations and associated meal frequency guidelines. The guidance is based on the U.S. EPA reference dose of 1×10^{-4} mg/kg-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 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

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 exceed the consumption guidance of one meal per month (Figure 3; Table 1).

While less than one percent of the world seafood harvest includes sharks (Figure 5), shark meat is sought after in several European 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=5,929). 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 4).

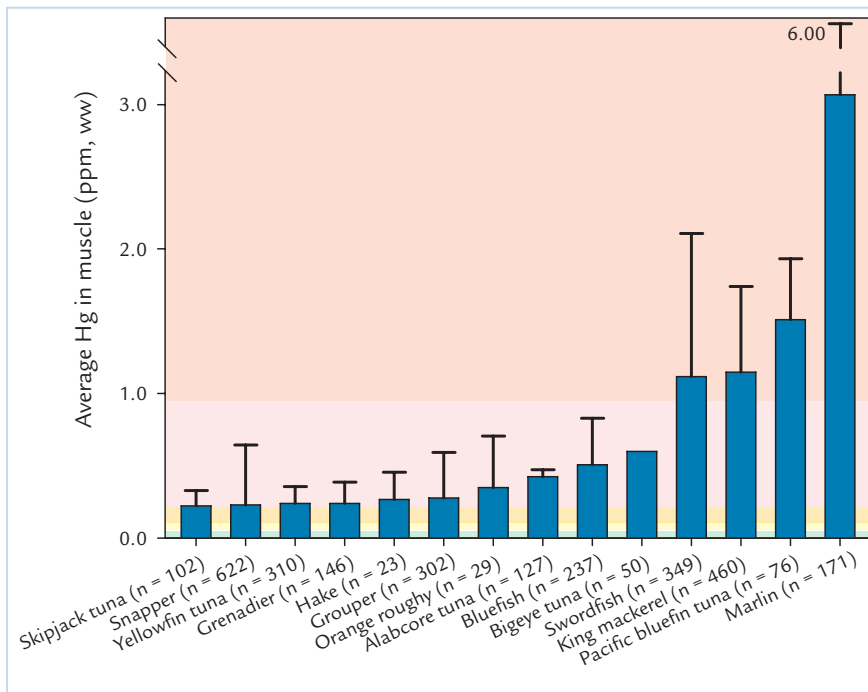


Figure 3. The average muscle Hg concentration in fish with standard deviation compared against consumption guidance levels (Table 1). These fish represent species regularly consumed and having average muscle Hg concentrations >0.22 ppm (ww).

(White marlin pictured above.)

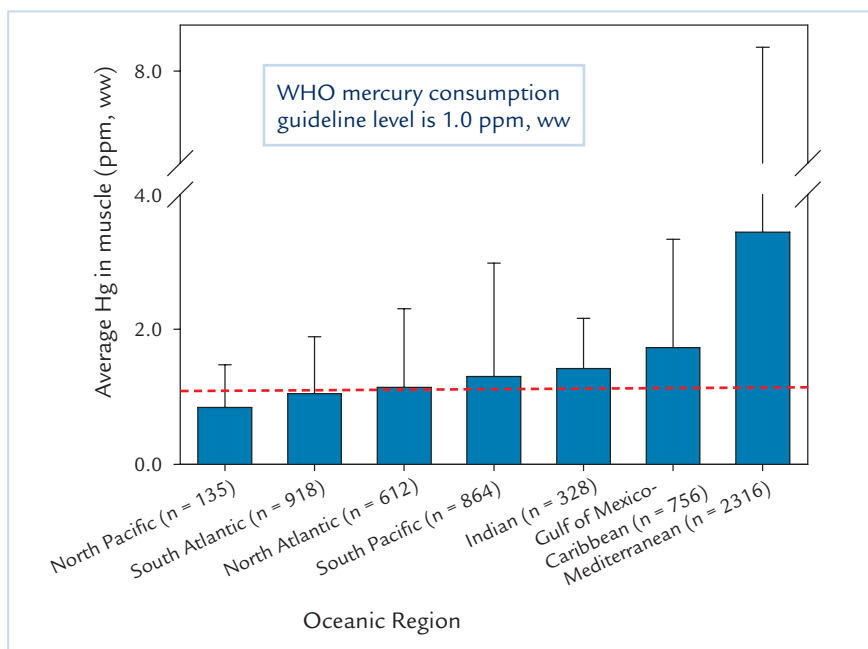


Figure 4. The average muscle Hg concentration in three shark orders (Carcharhiniformes - Ground sharks, Lamniformes - Mackerel sharks, and Squaliformes - Dogfish) with standard deviation and sample size (n) by oceanic region. (Lemon shark pictured above.)

Global Marine Fish Harvest Data

The United Nations Food and Agriculture Organization (FAO) maintains the only standardized repository for global fisheries data. The most up-to-date statistics on global fisheries are for the year 2010 (FAO 2012). The global production of fish and shellfish in 2010, including both live caught and aquaculture farmed, totaled 148.5 million tonnes with live caught fishes totaling approximately 90 million tonnes (61 percent) of the total production (FAO 2012). The Peruvian anchovy is the most caught species followed by the Alaska polluck, skipjack tuna, Atlantic herring and chub mackerel (FAO 2012).

Overall, the clupeiform fishes (herrings, sardines, and anchovies) dominated the global fish capture in 2010, accounting for 27 percent of the global capture and totaling more than 17 million tonnes (Figure 5). Pelagic fishes (including tunas, mackerels, billfish as well as jacks, barracudas, pompanos and other pelagics) account for approximately 25 percent of the global, live-caught harvest (Figure 5). Benthic and demersal fishes (e.g., flounder and halibut as well as cod, hake, and haddock) account for 17 percent of the global harvest, while coastal fishes (e.g., snappers, groupers, croakers, and seabass) account for approximately 11 percent of the total harvest (Figure 5).

When considering fishes with the highest mercury concentrations within the GBMS database, seven of the top ten species are considered pelagic (Figure 3).



Many of these species of pelagic fishes are long-lived, apex predators in the marine environment and migrate across much of the world's ocean basins. Tunas (including skipjacks, albacores, frigates, bluefins, yellowfins, and slender tunas) account for 32 percent of the global capture of large pelagic fishes, totaling more than 5 million tonnes in 2010 (Figure 5 inset). Large mackerels (including Atlantic, Spanish, king mackerels, and wahoos) are closely related to tunas and account for approximately 6 percent of the global harvest of large pelagic fishes. Other mackerel-like species (e.g., jack, horse, and chub mackerels) account for 30 percent of the global pelagic fish harvest (Figure 5 inset). Capture of billfish (e.g., swordfish and marlins) and bonitos together account for approximately one percent of the overall catch of pelagic species (Figure 5 inset).

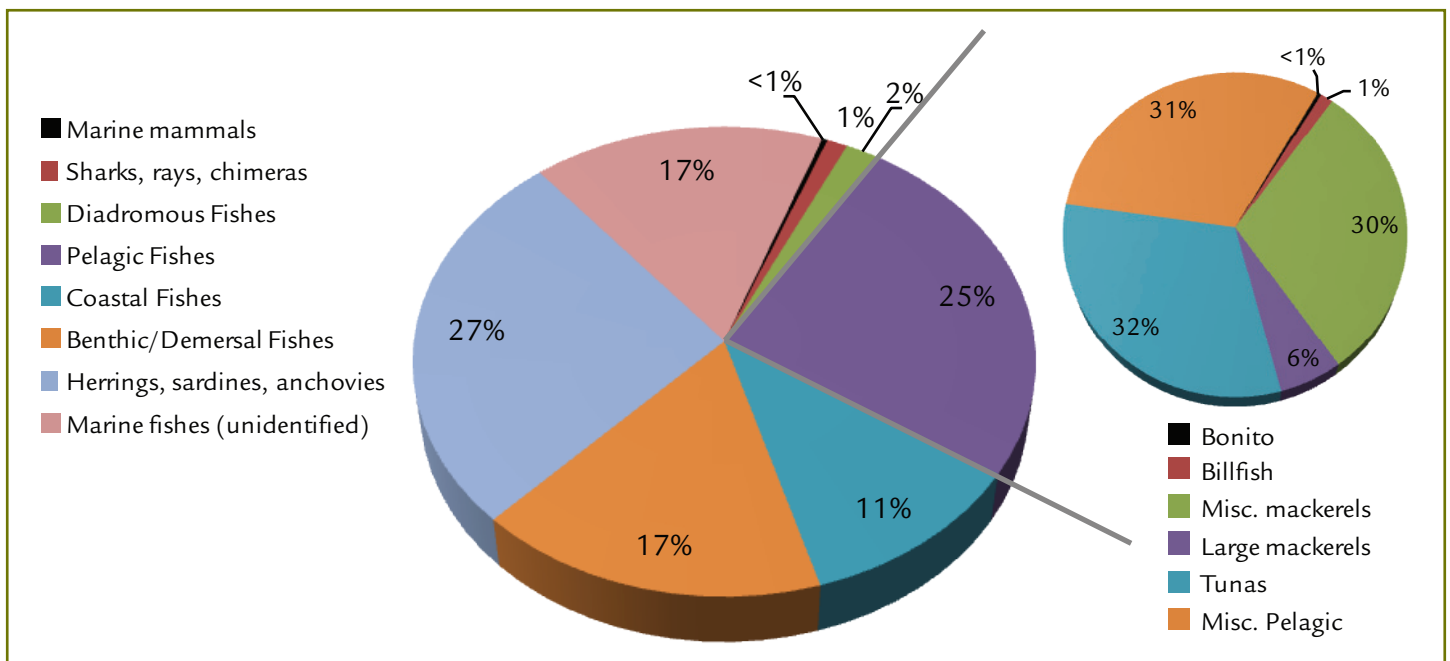










Figure 5. The global harvest of marine fishes (excludes aquaculture harvests and marine invertebrates). Data were obtained from the United Nations Food and Agriculture Organization and its standalone software FISHSTATJ (version 2.0).

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 in 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.

While selenium plays a role in demethylating mercury, and thus reducing methylmercury loads in the body, the extent of the protective abilities of selenium are not fully understood (Ralston et al. 2007; Whitfield et al. 2010).

Increasing Levels of Omega-3 Fatty Acids →

	 3 mgs/gram	 8 mgs/gram	 15 mgs/gram	
unrestricted meals 	Haddock Scallops Clams	Cuttlefish	Salmon	<i>Healthier Choices</i>
2 meals per week 	Cod	Mullet Squid	Shrimp/Prawn	Pacific mackerel Herring
1 meal per week 	Snapper Yellowfin tuna Grenadier	Flounder Spiny lobster Ground shark	Sea bass Skipjack tuna Atlantic horse mackerel Crab (claws)	Sardine Anchovy
1 meal per month 	Hake Grouper Orange roughy American lobster Bigeye tuna	Albacore tuna	Shark species	Shark species
no consumption 	Marlin	King mackerel Swordfish	Shark species	Pacific bluefin tuna Shark species
↑ Increasing Levels of Mercury in Seafood ↓				<i>Riskier Choices</i>

Matrix Legend

- Fish represented in photos in left column for mercury levels
- Fish represented in photos in top row for omega-3 levels

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.

Case Study: Tuna Mercury and Global Harvest



Data from the United Nations Food and Agriculture Organization (FAO) state that nearly 40 percent of the global fish production enters international markets for either direct consumption or food processing (FAO 2012).

Tuna is consistently among the top five commodities in the global fish market. Yellowfin, skipjack, and albacore are the most common species utilized by the tuna canning industry, while bluefin tuna is highly sought after for direct consumption (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 in pelagic marine fish, such as the Pacific bluefin tuna, if methylmercury production and bioaccumulation mimics projected mercury additions.

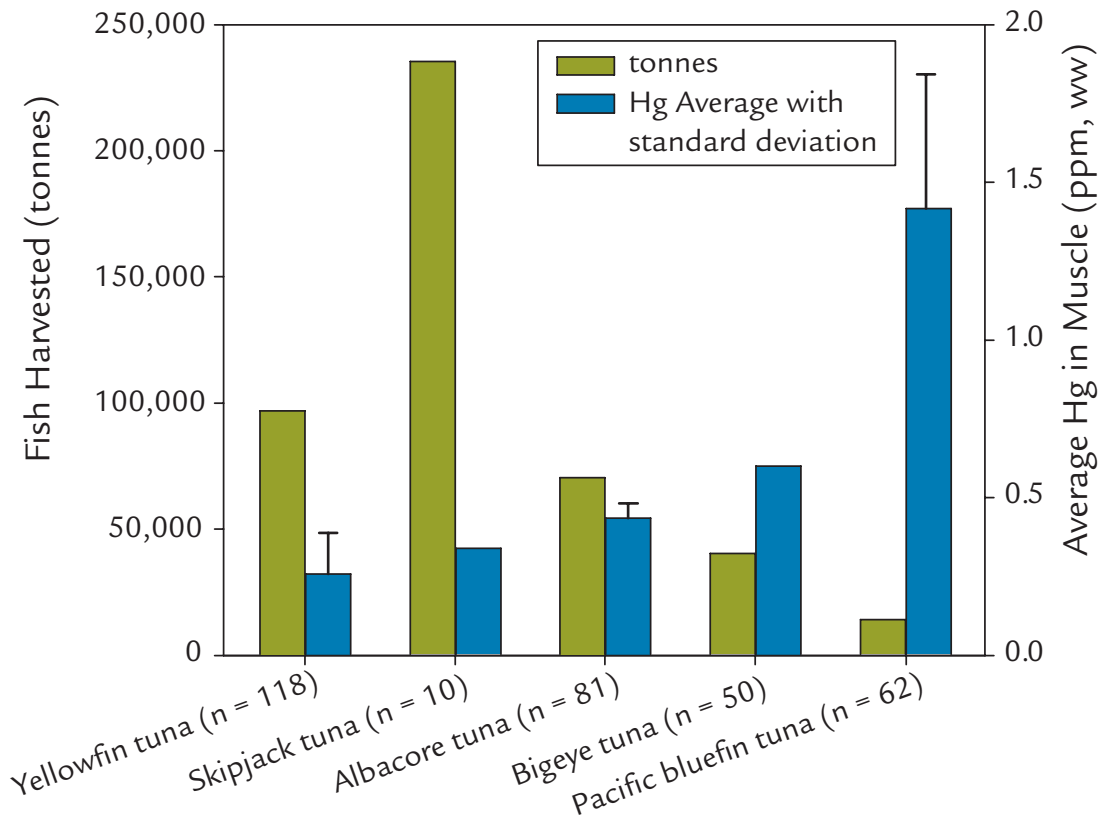


Figure 6. The Pacific Ocean tuna harvest by species in 2010 (FAO 2012) compared to the average muscle Hg concentration in each species with standard deviation harvested from the Pacific Ocean.

Case Study: Shellfish Mercury and Global Harvest

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 7).

Mussels such as clams and scallops have a mean total mercury concentration of approximately 0.02 ppm, wet weight (ww) while the American lobster has a mean mercury 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 of 0.10 ppm, ww.

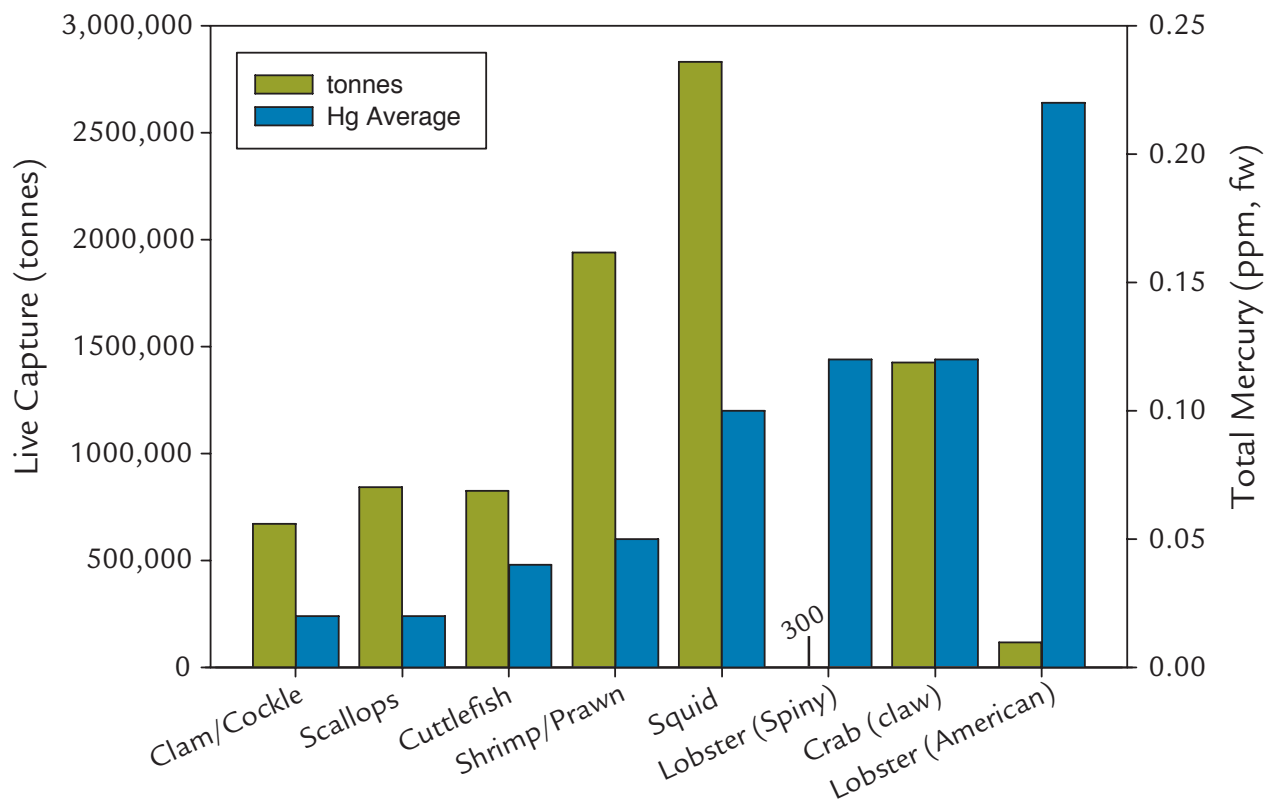


Figure 7. Total Hg concentrations in shellfish. Data are derived from a dataset without standard deviations or the spatial distribution of samples (FAO/WHO 2011).

Case Study: Mercury in Marine Mammals and Global Harvest

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 collected from our GBMS, average marine mammal muscle tissue mercury concentrations are generally above safe consumption levels in all ocean basins, except the Antarctic Ocean (Figure 8; n=3,109). 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.

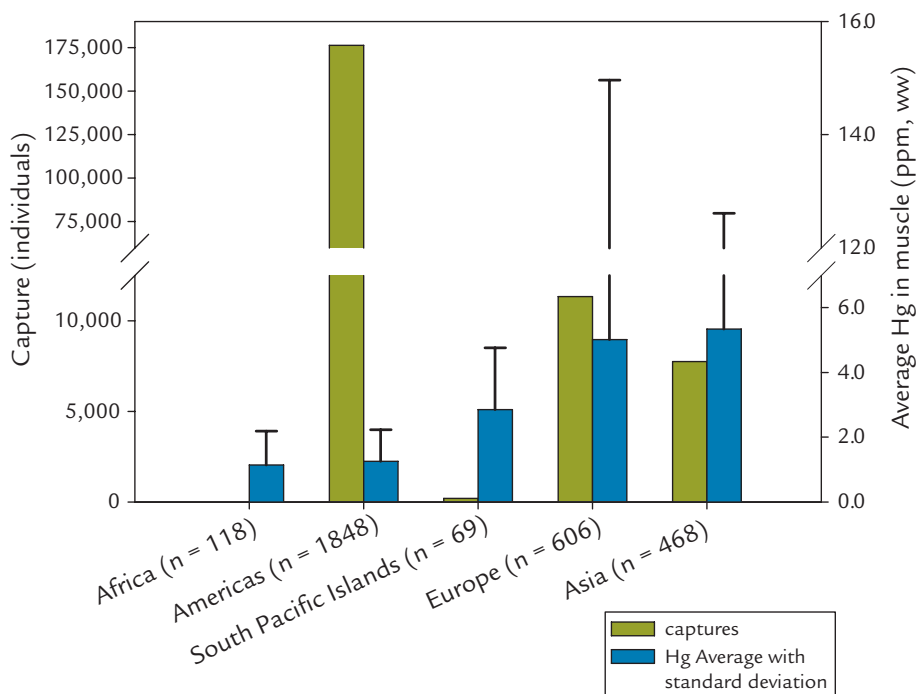


Figure 8. The average muscle Hg concentration in toothed marine mammals (*Odontoceti*) with standard deviation and sample size (n) by continent and South Pacific Islands and capture data from 2010 (FAO 2012).

Arctic Monitoring and Assessment Programme

The Arctic Monitoring and Assessment Programme (AMAP), part of the Arctic Council, provides information on the status of, and threats to, the Arctic environment, and scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants, such as mercury.

The GBMS database has and will continue to incorporate marine mammal and other Arctic biota mercury datasets and will serve as a resource for AMAP goals.

Case Study: Mercury in Clupeiforms and Global Harvest

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 (Fig. 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 marine plankton but play a very important role at the base of the food web as prey items for other larger marine fishes. In part because of their lower position within the marine food web, average mercury concentrations in clupeiforms are generally low (Figure 9). The



global harvest is generally dominated by catches from the Atlantic and Pacific Oceans, with relatively lower harvests from the Indian Ocean (Figure 9).

There is some variability in mercury concentrations within clupeiforms and across oceans however (Fig. 10). Generally, average mercury concentrations are lowest in herring species (Figure 10).

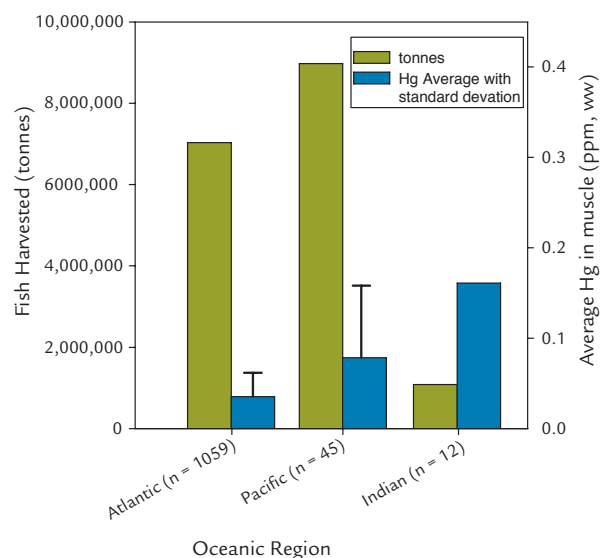


Figure 9. Mercury concentrations in Clupeiforms and associated harvest data for three oceanic basins.

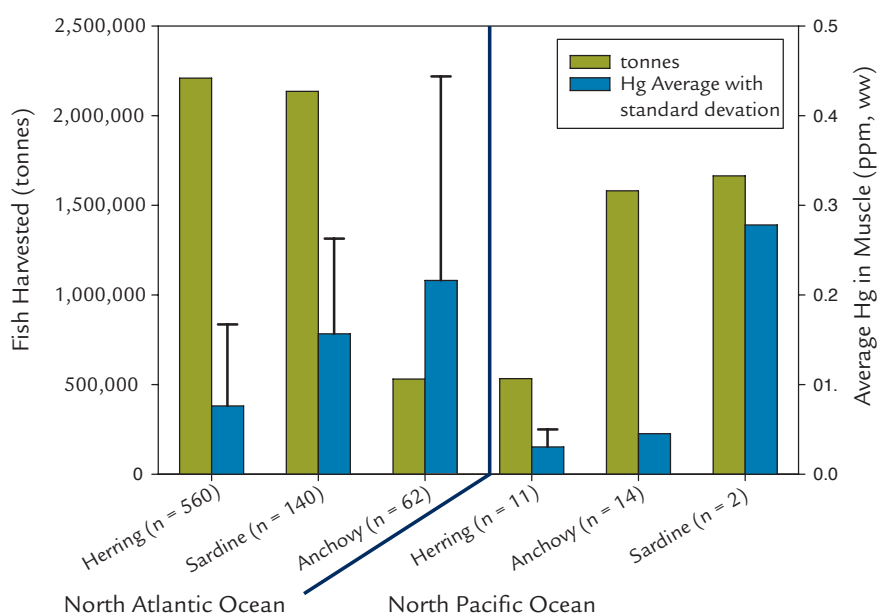


Figure 10. The average mercury concentrations of three taxa of clupeiforms with standard deviation of sample size (n), in the Northern Hemisphere.

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Suggested Citation for this Report

Evers, D.C., Turnquist, M.A., and Buck, D.G. 2012. Patterns of global seafood mercury concentrations and their relationship with human health. Biodiversity Research Institute. Gorham, Maine. BRI Science Communications Series 2012-48. 16 pages.

Credits

Editing and Production: Deborah McKew

Maps: p. 4: Madeline Turnquist; back cover: Ian Johnson. Source/citation: ESRI, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP and the GIS User Community.

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