Global Mercury Hotspots

New Evidence Reveals Mercury Contamination Regularly Exceeds Health Advisory Levels in Humans and Fish Worldwide

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The Global Fish and Community Mercury Monitoring Project

Mercury is a well-known neurotoxin that damages the kidneys and many body systems including the nervous, cardiovascular, respiratory, gastrointestinal, hematologic, immune, and reproductive systems (UNEP/WHO 2008).

IPEN and Biodiversity Research Institute (BRI) have collaborated to conduct a global mercury study in response to strong public and governmental interest in the negotiation and signing of a mercury treaty—the first global treaty on the environment in well over a decade by the United Nations Environment Programme (UNEP). The IPEN-BRI collaboration provides a rare opportunity to compile new and standardized mercury concentrations on a global basis.

The *Global Fish and Community Mercury Monitoring Project* is the first of its kind to identify, in one collaborative effort, global biological mercury hotspots. These hotspots are of particular concern to human populations and the ecosystems on which they depend.

Mercury is present in different forms, but the organic form of mercury, methylmercury, is especially toxic to humans and wildlife because it is readily absorbed by the body and can accumulate in places such as the brain.

People become exposed to methylmercury primarily through the consumption of fish. Many national and international health organizations recognize mercury in fish as a threat to human health, livelihoods, and the environment. However, these same organizations, particularly in developing and transitioning countries, have limited or no information about the mercury levels in fish and other food items of risk. The IPEN-BRI collaboration begins to bridge these data gaps.

Results from the study provide new data on mercury concentrations in samples from fish and people to accomplish the following goals:

1. Raise awareness about global mercury pollution among the general public, policymakers, and the human health assessment community;
2. Identify and characterize biological mercury hotspots around the world;
3. Explore how the treaty might affect mercury pollution at these hotspots.

Major Findings

- **The extent of significant mercury contamination is ubiquitous in marine and freshwater ecosystems around the world.**
- **Biological mercury hotspots are globally common and can be related to human-generated mercury releases to air, land, and water from multiple point and nonpoint source types.**
- **A high percentage (84%) of the fish sampled from around the world contained mercury concentrations that exceed fish consumption guidelines based on the U.S. Environmental Protection Agency's (U.S. EPA) reference dose for mercury exposure in humans.**
- **Human hair samples collected from around the world regularly exceed concentrations equivalent to the U.S. EPA reference dose. A total of 82% of the hair samples collected exceeded this concentration (1.0 parts per million).**

For an explanation of the graphs used throughout this report, turn to the Appendix on page 18.

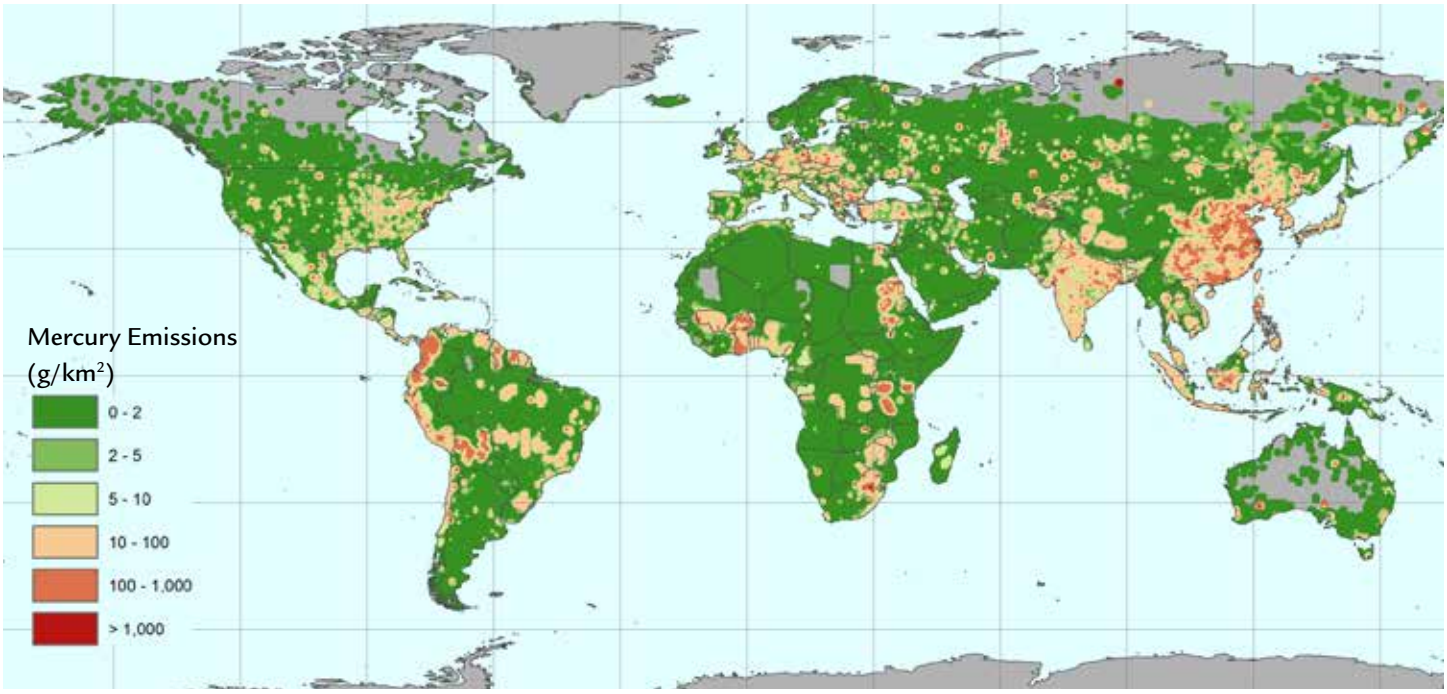


Figure 1. Global distribution of anthropogenic mercury emissions for 2010 (reproduced using data from AMAP/UNEP 2013).

Global Sources and Trends of Mercury

Concentrations of mercury in the global environment have increased approximately three-fold as a result of human activities. While industrial emissions have declined in North America and Europe during the past two decades, emissions have more than doubled in East Asia and India over a similar time period (Figure 1; AMAP/UNEP 2013).

The United Nations Environment Programme (UNEP) and the Arctic Monitoring and Assessment Program (AMAP) estimate global mercury emissions to air from human-generated sources for 2010 total approximately 2063 metric tons (Figure 2; AMAP/UNEP 2013).

Fossil fuel combustion and small-scale gold mining account for more than two-thirds of the 2010 mercury emissions to air (Figure 2; AMAP/UNEP 2013). Note that since there appear to be no available data on mercury air emissions from vinyl chloride monomer (VCM) production, emissions from this source are counted as zero. However, more mercury is used in VCM production than in most other intentional sources (UNEP/AMAP 2008).

Finally, some mercury sources release large quantities of mercury to soils, water, and wastes. Mercury that is released to media other than air will frequently contaminate aquatic ecosystems and contribute to the total global mercury pollution (Figure 3). In addition, much of this mercury will volatilize and enter the air at a later time.

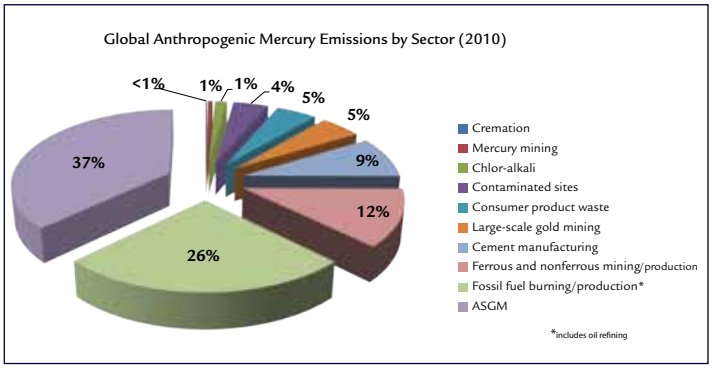
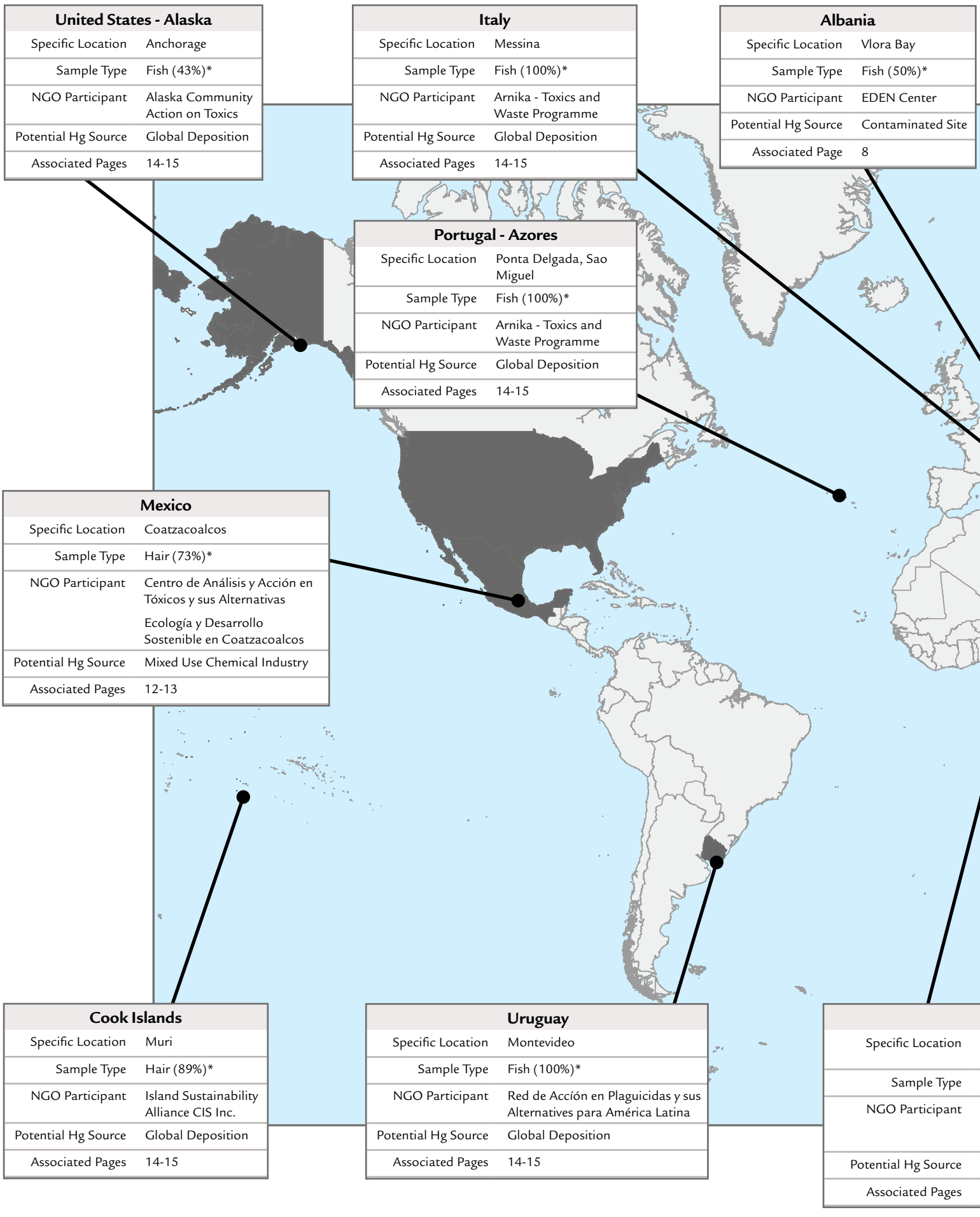


Figure 2. Global mercury emissions to air from human-generated sources for 2010. Value represents an average emissions estimate from each sector. Data obtained from the AMAP/UNEP global assessment of mercury emissions into the atmosphere (AMAP/UNEP 2013).

Global Treaty on Mercury

In 2010, an intergovernmental treaty negotiation process began to develop a global treaty to control mercury. UNEP led the effort and the treaty was finalized for signing in 2013. IPEN's global network of public health and environmental organizations brings a public interest perspective to treaty negotiations and implementation. BRI is a member of both the UNEP Mercury Air Transport and Fate Research and the Artisanal and Small-scale Gold Mining (ASGM) Partnership Groups and is contributing with new research related to global mercury monitoring.



United States - Alaska	
Specific Location	Anchorage
Sample Type	Fish (43%)*
NGO Participant	Alaska Community Action on Toxics
Potential Hg Source	Global Deposition
Associated Pages	14-15

Italy	
Specific Location	Messina
Sample Type	Fish (100%)*
NGO Participant	Arnika - Toxics and Waste Programme
Potential Hg Source	Global Deposition
Associated Pages	14-15

Albania	
Specific Location	Vlora Bay
Sample Type	Fish (50%)*
NGO Participant	EDEN Center
Potential Hg Source	Contaminated Site
Associated Page	8

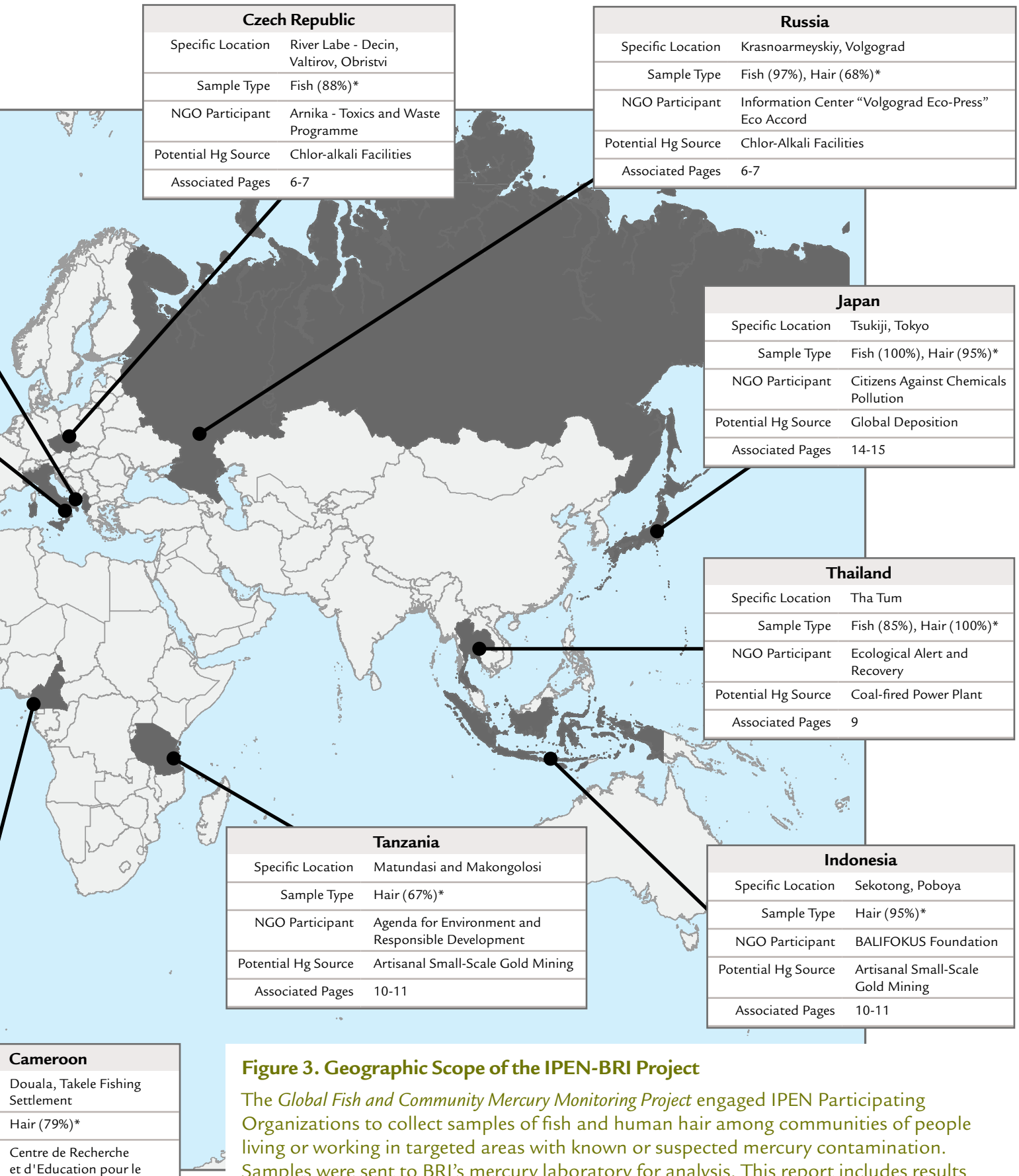
Portugal - Azores	
Specific Location	Ponta Delgada, Sao Miguel
Sample Type	Fish (100%)*
NGO Participant	Arnika - Toxics and Waste Programme
Potential Hg Source	Global Deposition
Associated Pages	14-15

Mexico	
Specific Location	Coatzacoalcos
Sample Type	Hair (73%)*
NGO Participant	Centro de Análisis y Acción en Tóxicos y sus Alternativas Ecología y Desarrollo Sostenible en Coatzacoalcos
Potential Hg Source	Mixed Use Chemical Industry
Associated Pages	12-13

Cook Islands	
Specific Location	Muri
Sample Type	Hair (89%)*
NGO Participant	Island Sustainability Alliance CIS Inc.
Potential Hg Source	Global Deposition
Associated Pages	14-15

Uruguay	
Specific Location	Montevideo
Sample Type	Fish (100%)*
NGO Participant	Red de Accíón en Plaguicidas y sus Alternatives para América Latina
Potential Hg Source	Global Deposition
Associated Pages	14-15

Specific Location	
Sample Type	
NGO Participant	
Potential Hg Source	
Associated Pages	



Czech Republic	
Specific Location	River Labe - Decin, Valtirov, Obristvi
Sample Type	Fish (88%)*
NGO Participant	Arnika - Toxics and Waste Programme
Potential Hg Source	Chlor-alkali Facilities
Associated Pages	6-7

Russia	
Specific Location	Krasnoarmeyskiy, Volgograd
Sample Type	Fish (97%), Hair (68%)*
NGO Participant	Information Center "Volgograd Eco-Press" Eco Accord
Potential Hg Source	Chlor-Alkali Facilities
Associated Pages	6-7

Japan	
Specific Location	Tsukiji, Tokyo
Sample Type	Fish (100%), Hair (95%)*
NGO Participant	Citizens Against Chemicals Pollution
Potential Hg Source	Global Deposition
Associated Pages	14-15

Thailand	
Specific Location	Tha Tum
Sample Type	Fish (85%), Hair (100%)*
NGO Participant	Ecological Alert and Recovery
Potential Hg Source	Coal-fired Power Plant
Associated Pages	9

Tanzania	
Specific Location	Matundasi and Makongolosi
Sample Type	Hair (67%)*
NGO Participant	Agenda for Environment and Responsible Development
Potential Hg Source	Artisanal Small-Scale Gold Mining
Associated Pages	10-11

Indonesia	
Specific Location	Sekotong, Poboya
Sample Type	Hair (95%)*
NGO Participant	BALIFOKUS Foundation
Potential Hg Source	Artisanal Small-Scale Gold Mining
Associated Pages	10-11

Cameroon
Douala, Takele Fishing Settlement
Hair (79%)*
Centre de Recherche et d'Education pour le Développement
Mixed-Use Industry
12-13

Figure 3. Geographic Scope of the IPEN-BRI Project

The *Global Fish and Community Mercury Monitoring Project* engaged IPEN Participating Organizations to collect samples of fish and human hair among communities of people living or working in targeted areas with known or suspected mercury contamination. Samples were sent to BRI's mercury laboratory for analysis. This report includes results from 14 countries from all UN regions.

** (% above health advisory)*

Mercury Source: Chlor-Alkali Facilities

Hotspots in Czech Republic and Russia

From the 1890s through the mid-20th century, mercury-cell technology was the main commercial process used for the production of chlorine and sodium hydroxide—two of the most commonly used chemicals worldwide. The process, still used today, involves large quantities of mercury and is a major source of mercury pollution. Each mercury-cell plant facility may contain hundreds of tons of elemental mercury (see Box 1).

Spolana in Neratovice and Spolchemie in Ústí nad Labem, Czech Republic

Two plants using mercury-cell processes in the Czech Republic, Spolana in Neratovice and Spolchemie in Ústí nad Labem, are located close to the River Labe, which flows to Germany and into the North Sea. Government reporting data by the plants in 2011 shows releases of mercury to air (125 kg) and water (10 kg), and transfers to wastewater (19 kg) and wastes (>2000 kg).

Volgograd, Russia

The JSC "Kaustik" chlor-alkali plant in Volgograd is close to the Volga River. The plant uses mercury cell and diaphragm processes, which release mercury directly into the air. A waste water disposal system releases almost 400 kg of mercury per year into local waterways. Mercury contamination is also found at waste sites where large drums are stored on the bare ground without protective covers.

Results of Mercury Exposure—Czech Republic

Eighty-three percent of the freshwater bream and 50 percent of the crucian carp sampled downstream from the plants in the Czech Republic exceeded the fish consumption advisory level of 0.22 ppm (Figure 4). Three of the eight freshwater bream from Obristvi near Neratovice also exceeded the EU limit for mercury in fish (0.5 ppm). The highest mercury levels in the Czech Republic samples were more than seven times greater (1.58 ppm) than the monthly fish consumption advisory level.

Relevance to the Global Mercury Treaty

The treaty prohibits the use of mercury in chlor-alkali production by 2025 with the possibility of two, five-year exemption periods (Article 5). Identification and characterization of mercury use at chlor-alkali facilities is voluntary. Countries are required to take measures to ensure that when a chlor-alkali plant closes, the excess mercury is disposed of according to treaty requirements and not subject to recovery, recycling, reclamation, direct re-use, or alternative uses (Article 3).

The chlor-alkali plant Spolana in Neratovice lies on the River Labe.

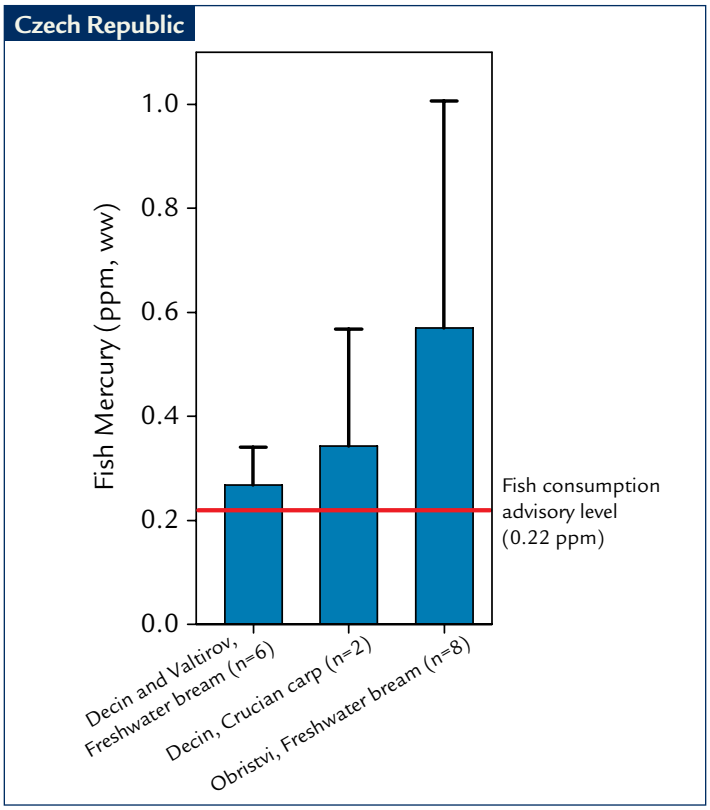
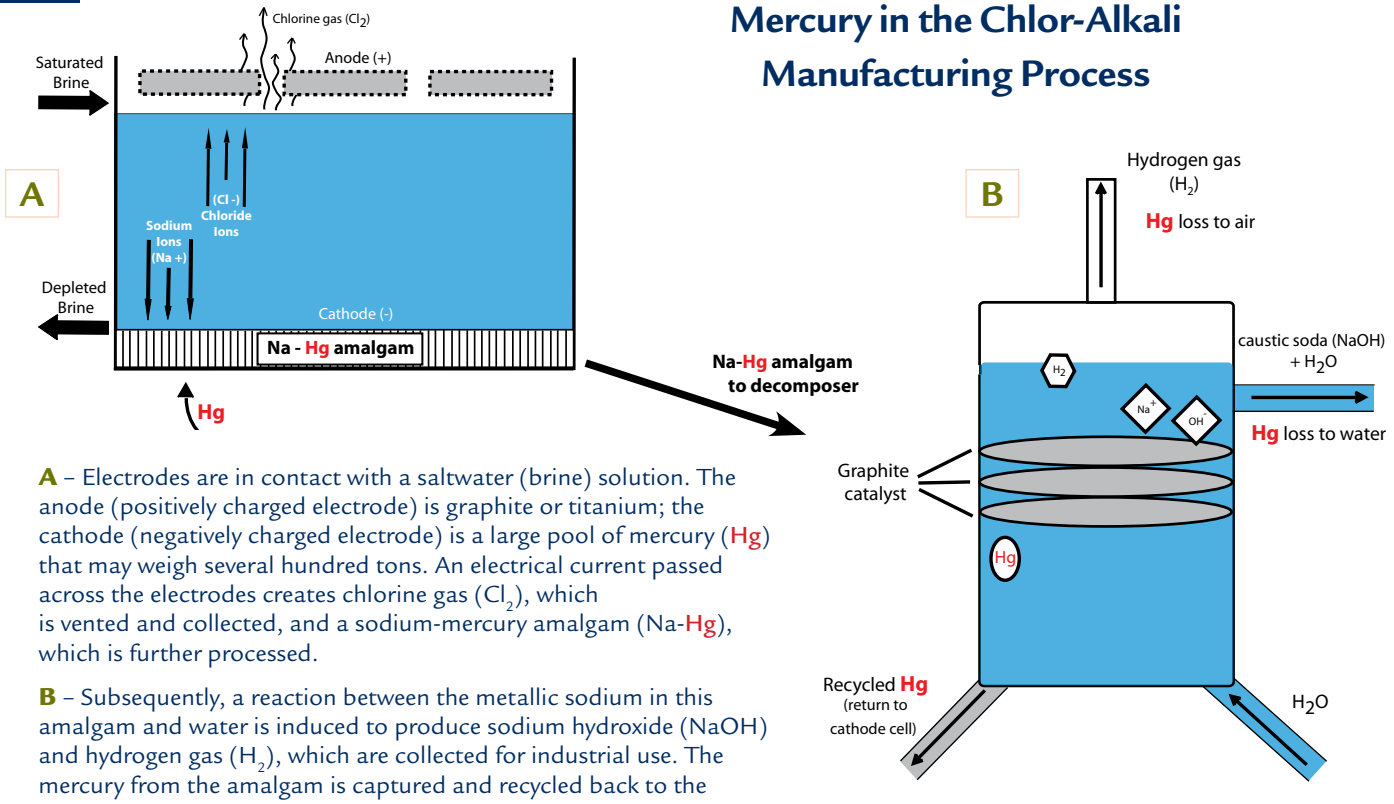


Figure 4. Mercury concentrations of fish sampled from the River Labe, Czech Republic.

Box 1

Mercury in the Chlor-Alkali Manufacturing Process



A – Electrodes are in contact with a saltwater (brine) solution. The anode (positively charged electrode) is graphite or titanium; the cathode (negatively charged electrode) is a large pool of mercury (Hg) that may weigh several hundred tons. An electrical current passed across the electrodes creates chlorine gas (Cl_2), which is vented and collected, and a sodium-mercury amalgam (Na-Hg), which is further processed.

B – Subsequently, a reaction between the metallic sodium in this amalgam and water is induced to produce sodium hydroxide (NaOH) and hydrogen gas (H_2), which are collected for industrial use. The mercury from the amalgam is captured and recycled back to the cathode of the mercury cell. During this process, mercury is released both into the atmosphere and into wastewater.

Russia

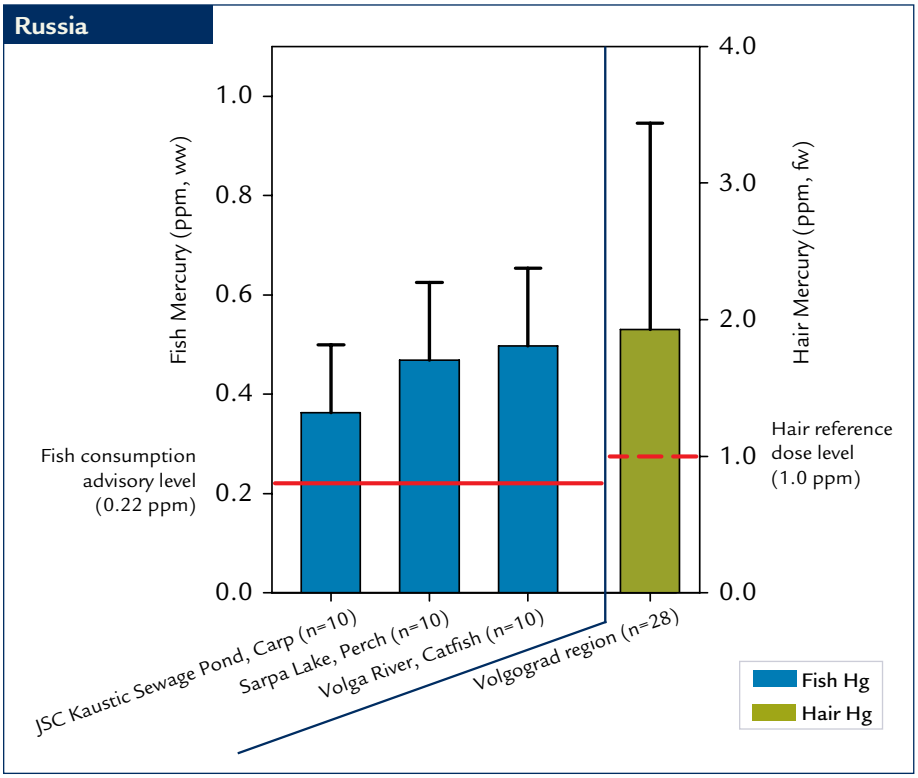


Figure 5. Fish samples were collected from three different locations in Russia including a sewage pond adjacent to the plant along the Volga River and Sarpa Lake, further downstream from where the Volga River drains.

Results of Mercury Exposure—Russia

Mercury levels in fish from the surface waters in Volgograd, Russia, exceeded the fish consumption advisory level of 0.22 ppm. (Figure 5).

The highest mercury levels in these samples were nearly four times greater than the fish consumption advisory level. Nine of 10 carp samples (90 percent) from the sewage pond and all of the fish sampled in the Volga River and Sarpa Lake were above the fish consumption advisory level.

Hair samples collected from two communities near the facility had a mean mercury concentration of 1.93 ± 1.50 ppm, with 67 percent of the samples being above the U.S. EPA reference dose level of 1.0 ppm in hair (Figure 5).

Mercury Source: Contaminated Sites

Hotspot in Albania

Contaminated sites contribute to remobilization and and release of mercury into adjacent terrestrial and freshwater ecosystems. Contaminated sites can also be a significant source of re-emission of mercury to the atmosphere.

Vlora Bay, Albania

The former chlor-alkali and PVC plant in Vlora used a mercury-cell process, discharged its waste directly into Vlora Bay, and dumped polluted sludge near the seashore where it remains today. The plant operated from 1967–1992; its buildings have been completely destroyed since then. No precautions have been taken to prevent further contamination of the bay or nearby residents. In 2002, an identification mission of UNEP/MAP (GEF Project GF/ME6030-00-08) identified this area as a hotspot after a soil sample showed mercury levels greater than 10,000 ppm in the area of the former plant—1000 times greater than typical EU thresholds. Vlora Bay is an important fishing area; fish from the area are distributed to all cities in Albania.

Results of Mercury Exposure

European hake and surmullet (or red mullet) were collected from Vlora Bay. Four of the eleven hake (36 percent) contained mercury concentrations above the fish consumption advisory level of 0.22 ppm (Figure 6).

Representatives of a local public interest organization visit an abandoned PVC plant in Albania, the site where waste products from the working plant (including mercury chloride) were dumped. There are no restrictions for public exposure to this site.

All surmullet (100 percent) were above the fish consumption guideline with a mean concentration of 0.62 ± 0.31 ppm (ww). Other studies in Vlora Bay have also documented high mercury levels in fish and plants in this area (Storelli et al. 1998; Mankolli et al. 2008).

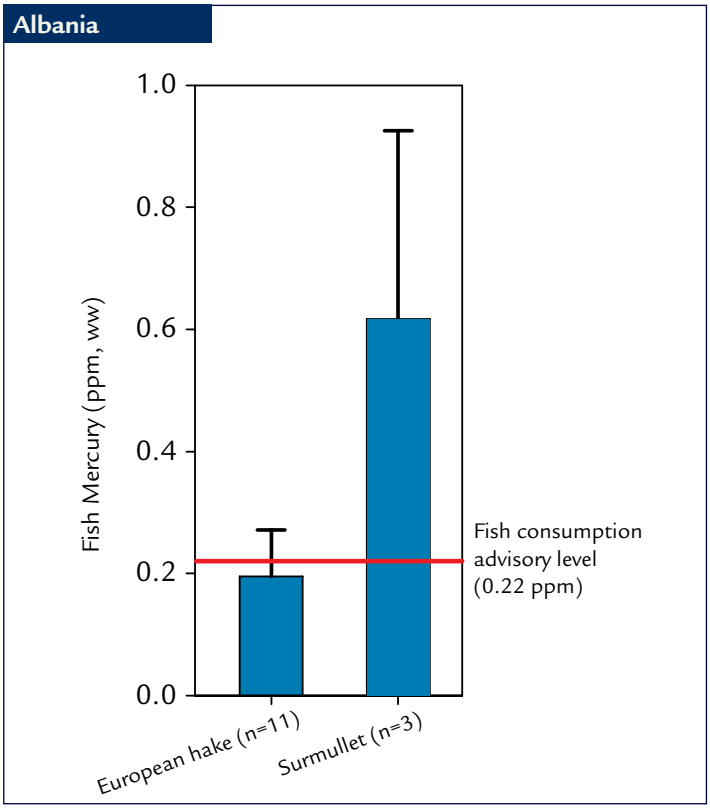


Figure 6. Mercury concentrations of fish sampled in Vlora Bay.

Relevance to the Global Mercury Treaty

Action on contaminated sites under the treaty is voluntary so identification and cleanup is not required (Article 12). In addition, there is no mention of a role for polluters to contribute financially to the cleanup of sites or any requirement to compensate victims. The Conference of the Parties is obligated to develop guidance on managing contaminated sites but the treaty does not provide a deadline for it. The guidance may include methods and approaches for identifying and characterizing sites; public engagement; human health and environmental risk assessments; options for managing the risks; evaluation of costs and benefits; and validation of outcomes.

Mercury Source: Coal-Fired Power Plants

Hotspot in Thailand

The combustion of coal accounts for approximately 24 percent of global mercury emissions, making it the second largest emitter of mercury to the atmosphere. Particle-bound mercury is often deposited proximate to its source (i.e., coal-fired power plants), while elemental mercury released during combustion can stay entrained in the atmosphere for months to years before being redeposited. In addition to coal combustion, the hotspot in Thailand includes a pulp and paper mill. Pulp and paper mills can be sources of mercury when phenylmercury acetate that is used to control fungal growth is released into adjacent waterways.

Tha Tum, Thailand

The Tha Tum site contains 75 factories including a coal-fired power plant that consumes 900,000 tons per year of coal and a pulp and paper mill producing 500,000 tons per year of paper (Kim et al. 2010). Fish are commonly eaten from the Shalongwaeng Canal, which runs adjacent to the open-air storage facility for coal and fly ash from the power plant and also the pulp and paper mill.

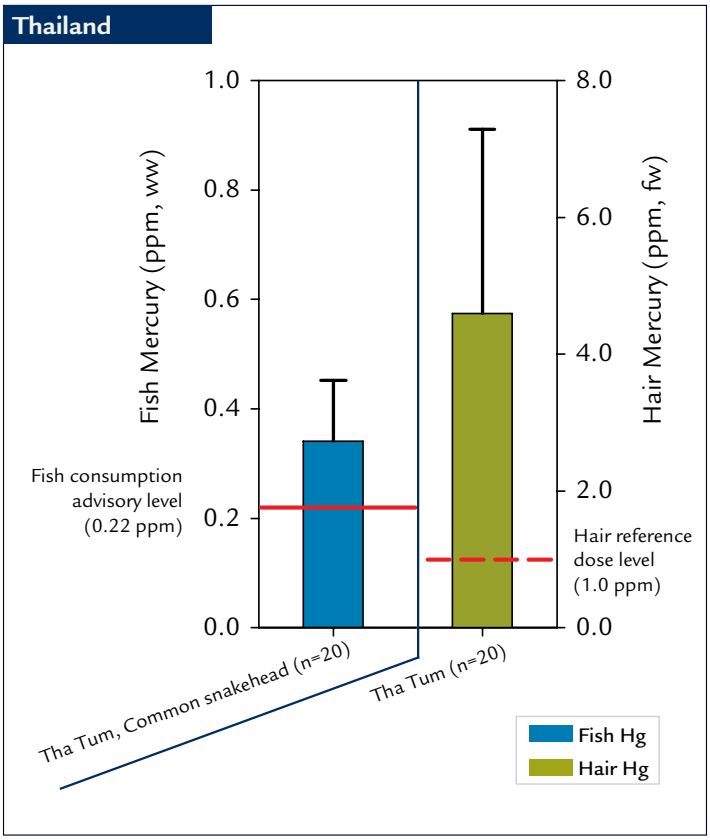


Figure 7. Mercury concentrations in fish and hair sampled from a site near a coal-fired power plant in Tha Tum, Thailand.

Top: Hair samples were taken from people who lived near mercury sources.

Left: Fish most often consumed by the local population, like this common snakehead, were sampled for mercury content.

Results of Mercury Exposure

Snakehead fish regularly exceeded the fish consumption advisory level (over 85 percent of the samples; Figure 7). In addition, all 20 hair samples from residents living 0.5–2.0 km from the power plant and pulp mill exceeded the U.S. EPA reference dose, and average levels were more than 4.5 times higher than 1.0 ppm (Figure 7).

Relevance to the Global Mercury Treaty

The treaty objective for coal-fired power plants and other sources of mercury air emissions is "controlling and where feasible reducing emissions" (Article 8). New sources have stronger control measures than existing sources. All reductions are taken on a "per facility" basis, so an increased number of facilities will increase total mercury emissions. Parties have to establish an inventory of air emissions from relevant sources but preparing a national plan to control air emissions is optional. Pulp and paper mills are not listed as a mercury source in the current treaty text, although the UNEP Mercury Toolkit and U.S. Toxics Release Inventory data suggest it is a significant source of emissions.

Mercury Source: Artisanal Small-Scale Gold Mining

Hotspots in Tanzania and Indonesia

Artisanal and small-scale gold mining (ASGM) is estimated to be responsible for more than 700 tonnes per year of mercury emissions to the atmosphere and an additional 800 tonnes per year of mercury releases to land and water, making it the largest anthropogenic source of mercury (AMAP/UNEP 2013). Individuals in or near ASGM communities can be exposed directly to mercury vapor produced during the burning of amalgam, or can be indirectly exposed to mercury in fish caught downstream of ASGM sites.

Matundasi and Makongolosi, Tanzania

The Tanzanian ASGM sites in the Matundasi and Makongolosi areas burn mercury-gold amalgam in the open air without recovery systems (see Box 2). Most of the water that is used for sluicing and amalgamation drains into the Lupa River, which flows into Lake Rukwa, an important waterway that supports livelihoods in the southern highland part of Tanzania and borders a large Ugandan game reserve.

Sekotong and Poboya, Indonesia

In 2010, about 280 tons of illegal mercury was imported to Indonesia for ASGM. This figure doubled in 2011 (2012 Ismawati personal communication). In Sekotong Village, almost every household operates a ball-mill unit, located in the backyard or near the rice field. Miners process ore all day long without personal protection equipment.

In Poboya, the ball-mills are concentrated in clusters and release very high levels of mercury vapor to the air and the environment (Serikawa et al. 2011; Ismawati and Gita 2011). In both hotspots, the mercury-contaminated tailings are either processed further in a cyanide leaching plant or disposed directly into rivers.

Results of Mercury Exposure

In Tanzania, two-thirds of the samples exceeded the U.S. EPA reference dose. The average mercury concentration was 2.74 ± 3.4 ppm (fw), excluding a significant outlier of 236 ppm (fw). The average mercury level in human hair at both sites in Indonesia (Sekotong Village and the Poboya area in Palu) was more than three times greater than the U.S. EPA reference dose. The mean mercury level in hair from Sekotong Village was 3.6 ± 1.3 ppm (fw). The mean mercury level in hair from Poboya was 5.0 ± 4.7 ppm (fw) with a maximum concentration of 13.3 ppm. Overall, 19 of the 20 samples collected from these Indonesian villages exceeded the U.S. EPA reference dose (see Figure 8).

Although mercury use for ASGM is illegal in Tanzania, there are approximately 150–200 miners working at the two sites noted in this report. The Indonesian sites in Poboya and Sekotong encompass 40,000 miners and 300 active milling operations.

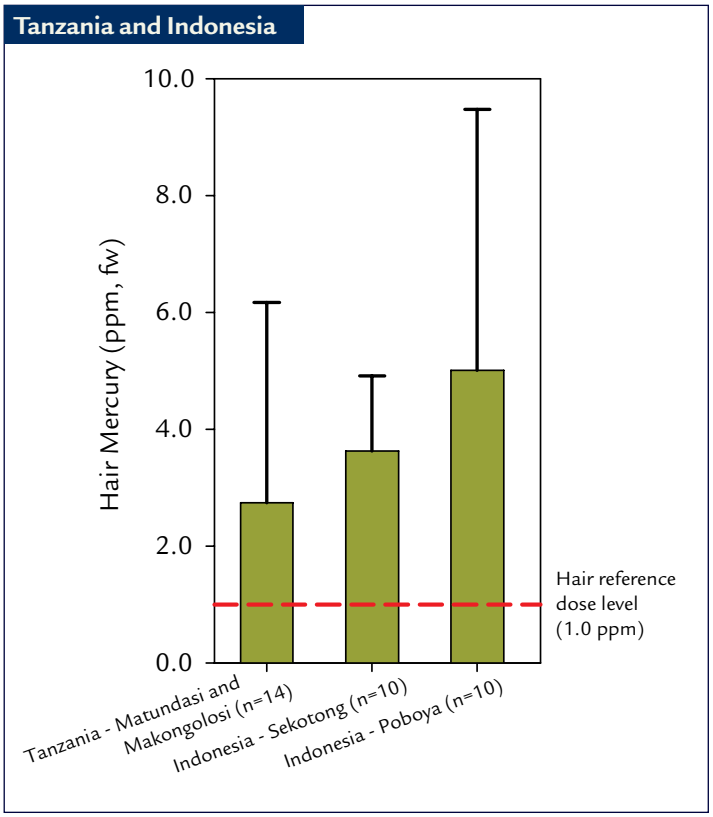


Figure 8: Mercury concentrations in human hair from ASGM sites in Tanzania and Indonesia.

Box 2

Mercury in the Artisanal Small-Scale Gold Mining Process

Mercury is used to extract gold particles that have been liberated from ore. Mercury and gold bind together to form a metal alloy called an amalgam, which is then heated to vaporize the mercury, leaving behind gold and some impurities that can be removed by further heating.

This mercury-based process is favored by many ASGM miners over other methods of gold extraction because mercury is currently affordable relative to the price of gold, accessible, simple to use, and can be processed anywhere, allowing miners to produce gold quickly and independently.

However, inefficient mining practices coupled with improper use and disposal of mercury have resulted in large amounts of mercury emitted and released into the environment. ASGM sites are often associated with significant ecological and human health impacts. Miners, mining communities, and communities located downstream/downwind of mining operations often show signs of mercury exposure.

Relevance to the Global Mercury Treaty

The treaty requires actions if Parties determine that ASGM is "more than insignificant," however there are no guidelines to determine "significance" (Article 7). Parties that report ASGM activities must develop a national action plan which includes measures to eliminate worst practices; public health strategies to prevent exposures; and strategies for awareness-raising. Since ASGM is an allowed use under the treaty, it qualifies for mercury trade without any specific import limit (Article 3). However, the national action plan requires countries to develop strategies for managing trade and preventing the diversion of mercury into ASGM. There is no obligation to identify or clean up contaminated ASGM sites and there is no sunset date or reduction target for mercury use in ASGM.

Photos from top: In the Indonesian village of Sekotong, workers add liquid mercury to the ball-mill; the mercury-gold amalgam is heated, releasing mercury into the air; in Poboya, burning of amalgam (in stacked barrels) is done within a residential area, creating a high risk to local residents of exposure to mercury vapor.

Mercury Source: Mixed-Use Chemical Industrial Sites

Hotspots in Mexico and Cameroon

Mixed-use industrial sites can include chlor-alkali production, oil refining, waste incineration, cement manufacturing, and other potential mercury sources that contribute varying amounts of mercury to total releases. This type of hotspot represents a real-world situation that most cities and countries will face—identifying and dealing with mercury pollution released by a complex mixture of mercury sources.

The industrial sites examined in this study are adjacent to rivers that flow into the ocean. These sites were analyzed to determine whether a mixture of mercury sources can result in human body burdens of mercury.

Coatzacoalcos and Minatitlán, Mexico

In Mexico, the city of Coatzacoalcos, Veracruz contains a mercury-cell chlor-alkali plant inside of a petrochemical complex that includes a waste incinerator. Another site in Mexico, located in Minatitlán, Veracruz, contains an oil and gas refinery which was recently configured to increase processing capacity to 350,000 barrels per day. Both sites are located on the Coatzacoalcos River, which flows into the Gulf of Mexico.

Douala, Cameroon

Douala, the largest and most industrial city in Cameroon is located at the mouth of the Wouri River which empties into the Gulf of Guinea. Douala contains a cement plant (more than 1.2 million tons produced in 2009), waste incinerator, e-waste dumping and open burning, and a variety of other potential mercury sources including skin-whitening products. The study focused on the fishing community of Youpwe-Takele.

A woman on the way back from fishing in Douala, Cameroon. Wetland areas are especially prone to creating high concentrations of mercury in fish.

In Douala, Cameroon, local fishermen clean their catch from the Wouri River.

Relevance to the Global Mercury Treaty

The treaty objective for mercury air emissions from cement kilns and waste incinerators is "controlling and where feasible reducing emissions" (Article 8).

New sources have stronger control measures than existing sources. All reductions are taken on a "per facility" basis, so an increased number of facilities will increase total mercury emissions. The treaty does not contain a list of facilities identified as sources of mercury to land and water (Article 9).

However, Parties have to identify mercury sources and establish an inventory of air emissions and releases to land and water from relevant sources. Preparing a national plan to control emissions and releases is optional. Cosmetics including skin lightening products will be phased out if they contain mercury above 1 ppm except mascara and other eye area cosmetics. Used electronic devices such as computers and/or e-waste could also be one of the potential sources of mercury releases in Douala, as it is in other African countries.

However, the treaty does not include open burning of these types of wastes as an air emission source, nor releases from oil and gas facilities.

The sprawling Pajaritos petrochemical complex in Coatzacoalcos, a major port city in Veracruz, Mexico, that lies on the Coatzacoalcos River.

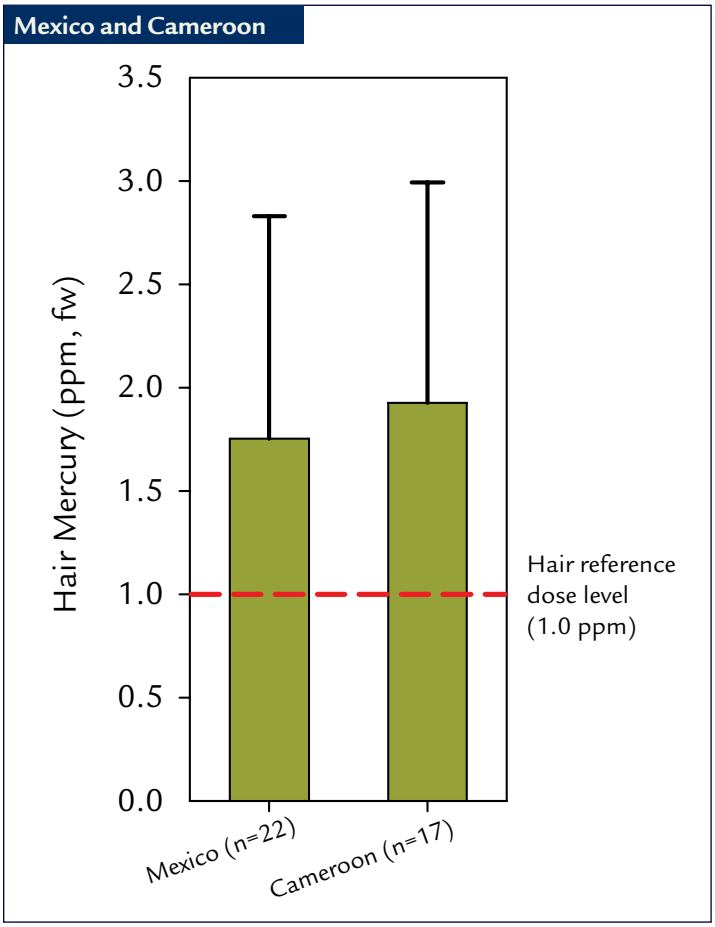


Figure 9. Mercury concentrations in human hair near mixed-use industrial sites in Mexico and Cameroon.

Results of Mercury Exposure

The average mercury level in human hair from Mexico was 1.75 ± 1.1 ppm (fw) with 73 percent of samples exceeding the U.S. EPA reference dose of 1.0 ppm (fw) (Figure 9). The maximum concentration of 4.32 ppm was more than four times higher than the reference dose.

In Cameroon, the average mercury level in human hair was 1.93 ± 1.1 ppm (fw) with 76 percent of the samples exceeding the U.S. EPA reference dose of 1.0 ppm (fw) (Figure 9). The maximum concentration of 3.77 ppm was nearly four times higher than the reference dose.

This excludes two samples with extremely high mercury levels of 541 and 546 ppm (fw). Pathways for such high mercury exposure in humans could include cosmetics such as skin-lightening products. These individual hair samples were re-analyzed to confirm the accuracy of the initial analysis, and the second round of analysis confirmed highly elevated mercury levels in the hair.

Mercury Sources: Global Atmospheric Deposition

Hotspots—The World's Oceans as Reservoirs for Mercury

Mercury is a pollutant of global importance because once released into the atmosphere it can travel great distances, often impacting areas far from its original source. (Figure 10). It is released into the environment predominantly through human activities and such inputs over time have increased mercury concentrations in the global biosphere by at least three-fold (Mason et al. 2012).

Atmospheric processes can carry emitted mercury around the world for as long as two years until being deposited on the Earth's surface. The world's oceans are one of the primary environmental reservoirs for anthropogenic mercury, receiving mercury as atmospheric deposition as well as direct inputs from riverine transport. While atmospheric deposition is the greatest source of mercury to oceans, internal production from the upper 3,300 feet (1,000 meters) of water in the open ocean provides the greatest input of methylmercury in marine fish (Mason et al. 2012).

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 likely to result in significant mercury increases in pelagic marine fish, such as the Pacific bluefin tuna, if methylmercury production and accumulation mimics projected mercury additions. Fish mercury concentrations vary by ocean basin because of mercury inputs, large-scale ocean circulation, vertical transport processes (Mason et al. 2012), and species composition and harvest pressure (Evers et al. 2012).

Relevance to the Global Mercury Treaty

The treaty includes coal-fired power plants and various other air emission sources but control measures for existing facilities are weaker than for new ones (Article 8). UNEP has identified ASGM as the largest source of mercury air emissions but trade of mercury for use in ASGM is allowed and there is no sunset date or reduction target for mercury use in ASGM (Articles 3 and 7). Parties are to reduce mercury per unit VCM production by 50% in 2020 compared to 2010 use (Article 5). However, all reductions in air emissions are taken on a "per facility" basis, so an increased number of VCM or mercury air emitting facilities will increase total mercury emissions. Rigorous implementation of treaty objectives will be required to reduce total emissions and releases of mercury.

Indicators of Ocean Basins

Apex marine predators such as tuna, swordfish, and other large pelagic fishes are important species for the global marine fisheries (Evers et al. 2012, FAO 2012, Karimi et al. 2012). However, these same species are also most susceptible to mercury exposure because of their position at the top of the marine food web.

We selected six sites from across the Earth's oceans (Table 1) to examine mercury concentrations in top marine predatory fishes and also the potential risks of exposure in human populations that rely on marine fisheries for their diet.

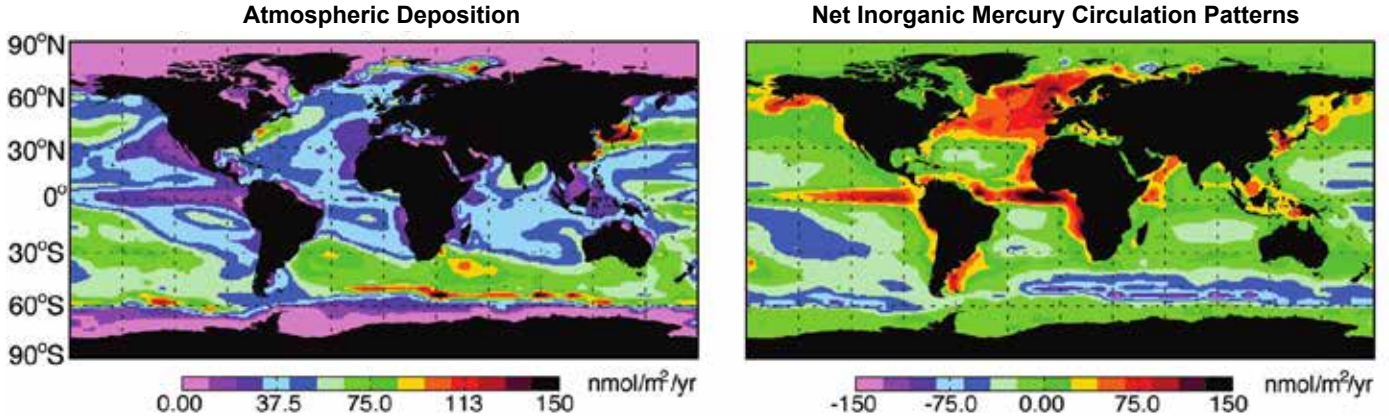


Figure 10. Map shows global mercury (Hg) deposition and total Hg entrainment across the Earth's oceans. Global deposition including wet, dry, and particulate Hg, shows peaks in the North Atlantic, adjacent to the northeastern U.S. as well as in the North Pacific, adjacent to Asia. Additional peaks in deposition at higher latitudes are associated with long-term transport of Hg in the upper atmosphere and subsequent deposition. High concentrations of inorganic Hg in the North Atlantic and the tropical regions are largely controlled by surface ocean circulation patterns. (Image derived from Soerensen et al. 2010.)

Table 1. Ocean basins and countries where samples were collected.

Ocean Basin	Country	Tissue Type Sampled
Northern Pacific	Japan	fish / hair
Northern Pacific	United States (Alaska)	fish
Southern Pacific	Cook Islands	hair
Eastern Atlantic	Portugal - Azores	fish
Southern Atlantic	Uruguay	fish
Mediterranean Sea	Italy	fish

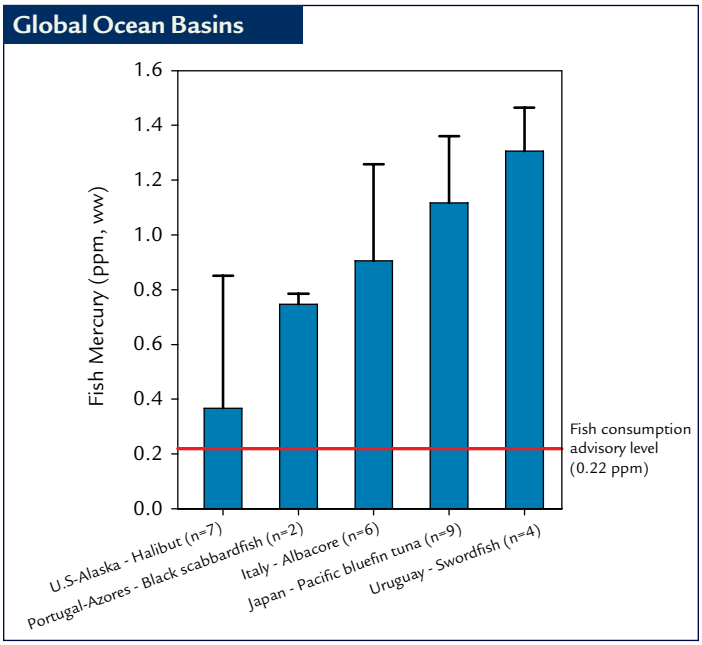


Figure 11. Mercury concentrations in large pelagic fish.

Results of Mercury Exposure

Of the 28 fish samples collected from the global atmospheric deposition sites, 86 percent were above the fish consumption guideline of 0.22 ppm (Figure 11). Forty-three percent were above the EU and WHO limit of 1.0 ppm.

Swordfish from the Southern Atlantic Ocean (Uruguay) had the highest average mercury level of 1.31 ± 0.16 ppm (ww), followed by Pacific bluefin tuna (1.12 ± 0.24 ppm, ww) from the Northern Pacific Ocean (Japan). Albacore tuna from the Mediterranean Sea (Italy) had an average mercury level of 0.91 ± 0.35 ppm (ww).

Average mercury levels in hair from Tokyo were 2.7 times higher than the U.S. EPA reference dose, and the Cook Islands hair samples contained average mercury levels that were 3.3 times higher than the reference dose (Figure 12).

Overall, 95 percent of the hair samples from Japan and 89 percent of the samples from the Cook Islands exceeded the U.S. EPA reference dose for mercury.

Bluefin tuna sold at the Tsukiji market in Tokyo, Japan. The bluefin tuna sampled in this project, purchased from this market, contained among the highest mercury levels detected.

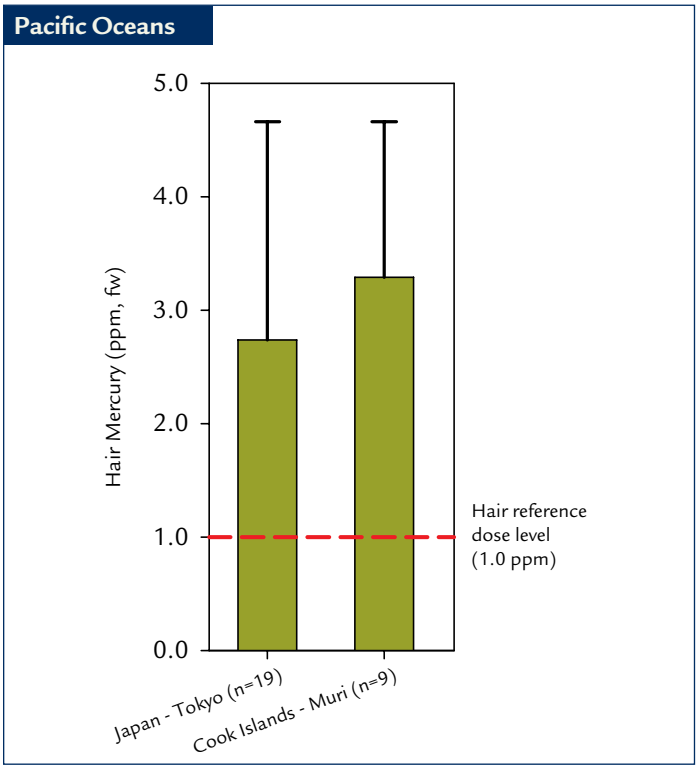


Figure 12. Mercury concentrations in human hair from local populations in Japan and the Cook Islands.

Summary

This study identified global biological mercury hotspots that are of particular concern to human populations and the ecosystems on which they depend. Five types of major mercury point sources were chosen to examine mercury pathways from their origins to mercury exposure in fish and people.

Sites represent releases of mercury to air, land, and water. The major source type of global deposition originates from nonpoint sources. The data in this report represents 108 fish samples from nine countries and 152 human hair samples from eight countries. The countries span all the major United Nations regions and include a mix of developed countries, developing countries, and countries with economies in transition along with one Small Island Developing State.

Mercury in Fish

The IPEN-BRI collaboration generated fish mercury concentrations from three types of common mercury point sources: contaminated sites, chlor-alkali facilities, and coal-fired power plants. Sites likely related primarily to nonpoint sources, or global deposition, are also identified. Each of the nine countries contained high proportions of fish over the U.S. EPA reference dose-based consumption guideline of 0.22 ppm (where only one fish meal of 170 grams [or 6 ounces] per month should be consumed). Our findings demonstrate that 84 percent of the fish sampled were not safe for consumption for more than one meal per month (Figure 13). More than 13 percent of the fish sampled would not be recommended by The World Health Organization and the European Commission for commercial sale.

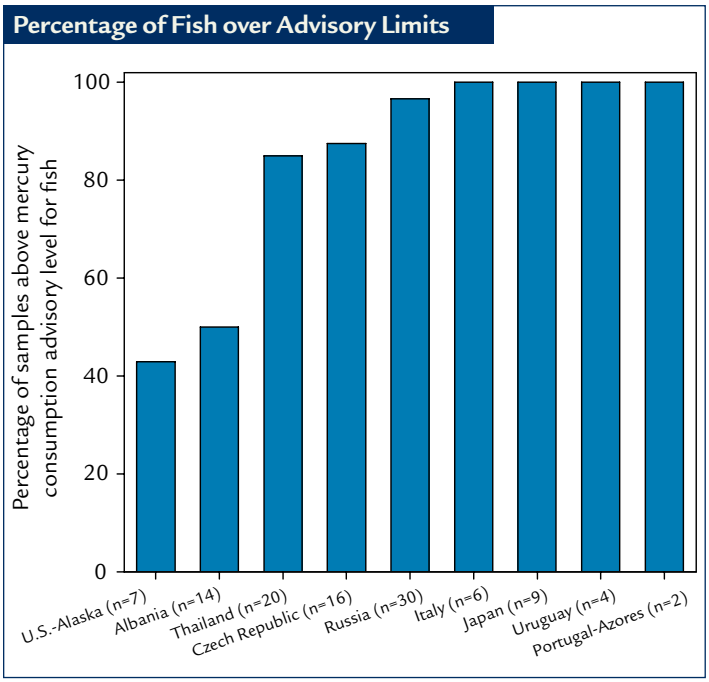


Figure 13. The percentage of fish samples from nine countries above the fish consumption advisory guideline of 0.22 ppm mercury.

Mercury in Human Hair

Human hair was analyzed from countries with different sources of mercury pollution. Global deposition is the main source of pollution in two countries, while mercury pollution in the other countries is directly related to three types of point source releases: artisanal small-scale gold mining (ASGM); coal-fired power plants; and mixed industrial sites that contain mixtures of chlor-alkali production, oil refining, waste incineration, and cement manufacturing. More than 82 percent of the 152 individuals contained mercury concentrations greater than the U.S. EPA reference dose level of 1.0 ppm.

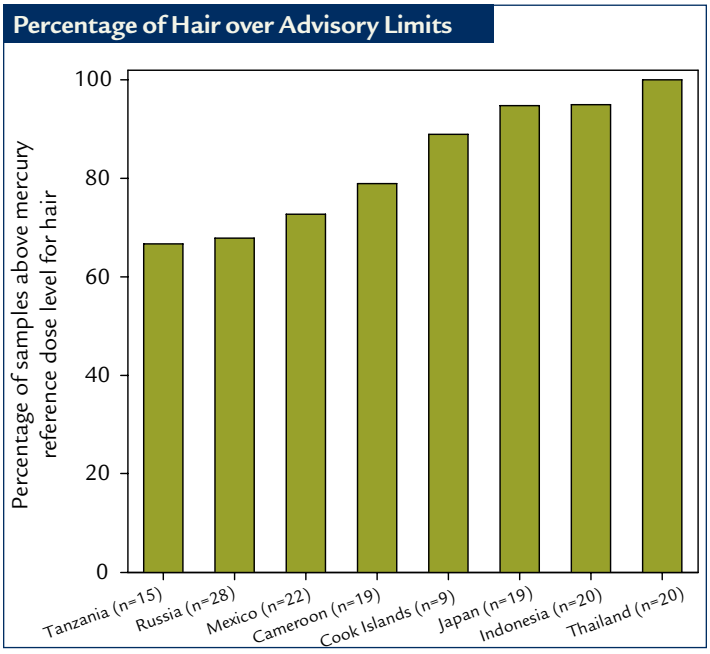


Figure 14. The percentage of human hair samples from eight countries above the U.S. EPA reference dose of 1.0 ppm mercury.

Relevance to the Global Mercury Treaty

The mercury treaty was finalized and adopted in 2013 with the objective of protecting human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. This IPEN-BRI study highlights the global scale and ubiquitous nature of mercury contamination and reinforces efforts to rapidly and rigorously implement the global mercury treaty.

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APPENDIX: Methods Behind the Data

Identifying Potential Hotspots and Sample Collection

Work on the Global Fish and Community Mercury Monitoring Project was conducted in three phases. In Phases 1 and 2, IPEN and its network of more than 700 public interest NGOs from across the globe collected hair and fish samples and identified potential mercury contamination hotspots. During Phase 3, BRI utilized its Global Biotic Mercury Synthesis (GMBS) database to further identify potential hotspots.

Fish and hair sampling protocols were adapted from approved sampling methods for mercury risk assessment in fish (U.S. EPA 2000) and human hair (UNEP/WHO 2008). For fish sampling, we targeted high trophic level fish and fish commonly consumed by the local population.

Hair samples were collected from individual volunteers (of legal age) who live adjacent to the hotspot.

The majority of samples (fish and hair) were shipped by expedited international shipping to BRI's Wildlife Mercury Research Lab for analysis. Results are shown in this report using bar graphs that depict the average mercury measured in parts per million (Box 3).

Samples were analyzed on BRI's Milestone DMA 890, using a U.S. EPA-approved method (SW-846 Method 7473).

Evaluating the Results

Based on the U.S. EPA's reference dose of 0.0001 mg methylmercury per kg of body mass per day, we calculated fish consumption guidelines using an average body mass of 60 kg (132 pounds) and an average fish meal size of 170 grams (6 ounces). Fish containing mercury concentrations of 0.22 parts per million (ppm) should be consumed no more than once per month. Fish with mercury concentrations less than this value (<0.22 ppm) can be consumed more frequently. Fish with mercury concentrations greater than 0.95 ppm should be avoided entirely. (Table 2.)

Box 3. Interpreting the Bar Graphs

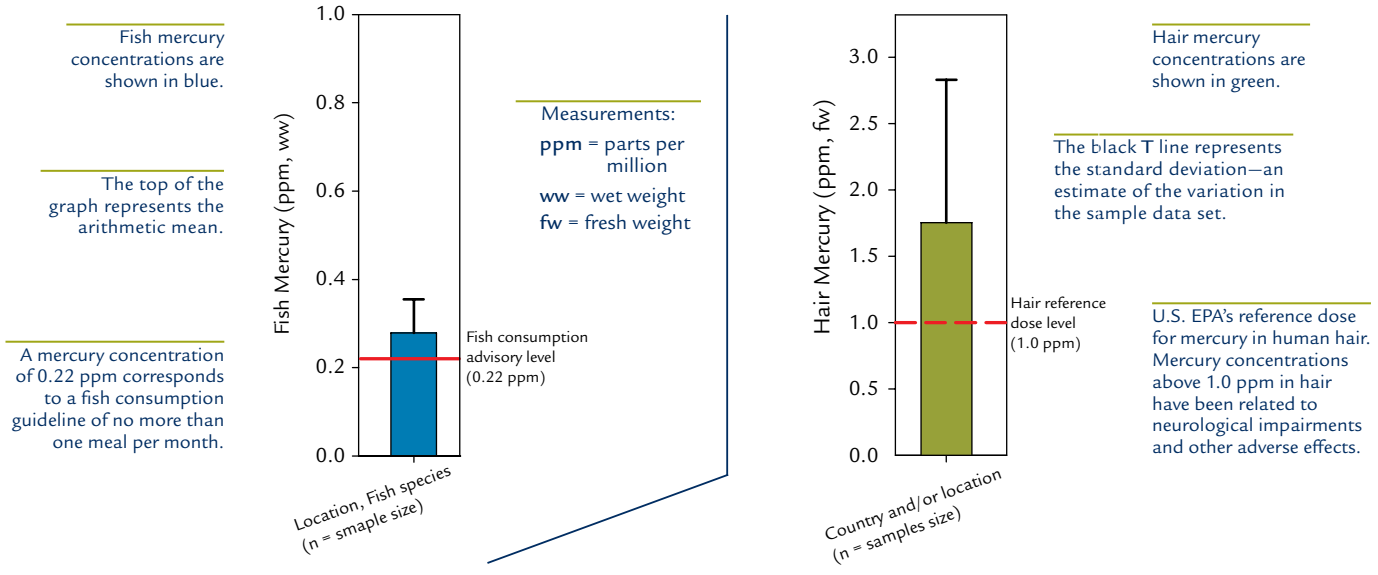

Table 2. Fish consumption guidelines for methylmercury based on the U.S. EPA reference dose.

Fish Methylmercury Concentrations (ppm/ww)	Recommended Consumption
<0.05	unrestricted
>0.05-0.11	2 meals/week
>0.11-0.22	1 meal/week
>0.22-0.95	1 meal/month
>0.95	no consumption

The Global Biotic Mercury Synthesis Database

A Platform for Evaluating the Effectiveness of the Global Mercury Treaty

There is a gap in our understanding about the relationship between human-generated releases of mercury into the environment (through air, water, and land), subsequent biomagnification and bioaccumulation of methylmercury (how the toxicity of mercury intensifies as it moves up the food web over time), and how this translates to exposure and risks at local, regional, and global scales.

BRI has compiled a Global Biotic Mercury Synthesis (GBMS) database in association with the Global Mercury Partnership's Mercury Air Transport and Fate Research Group (Evers et al. 2012).

The GBMS database contains a large number of data sets on mercury concentrations in shellfish, sharks and rays, fin fish, birds, and marine mammals from various regions of the world over the past several decades. It provides an important tool to:

1. Understand the spatial patterns and temporal trends of mercury concentrations in the ecosystem;
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; and
5. Evaluate the effectiveness of the global mercury treaty.

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 (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 natural resources (Lambert et al. 2012).

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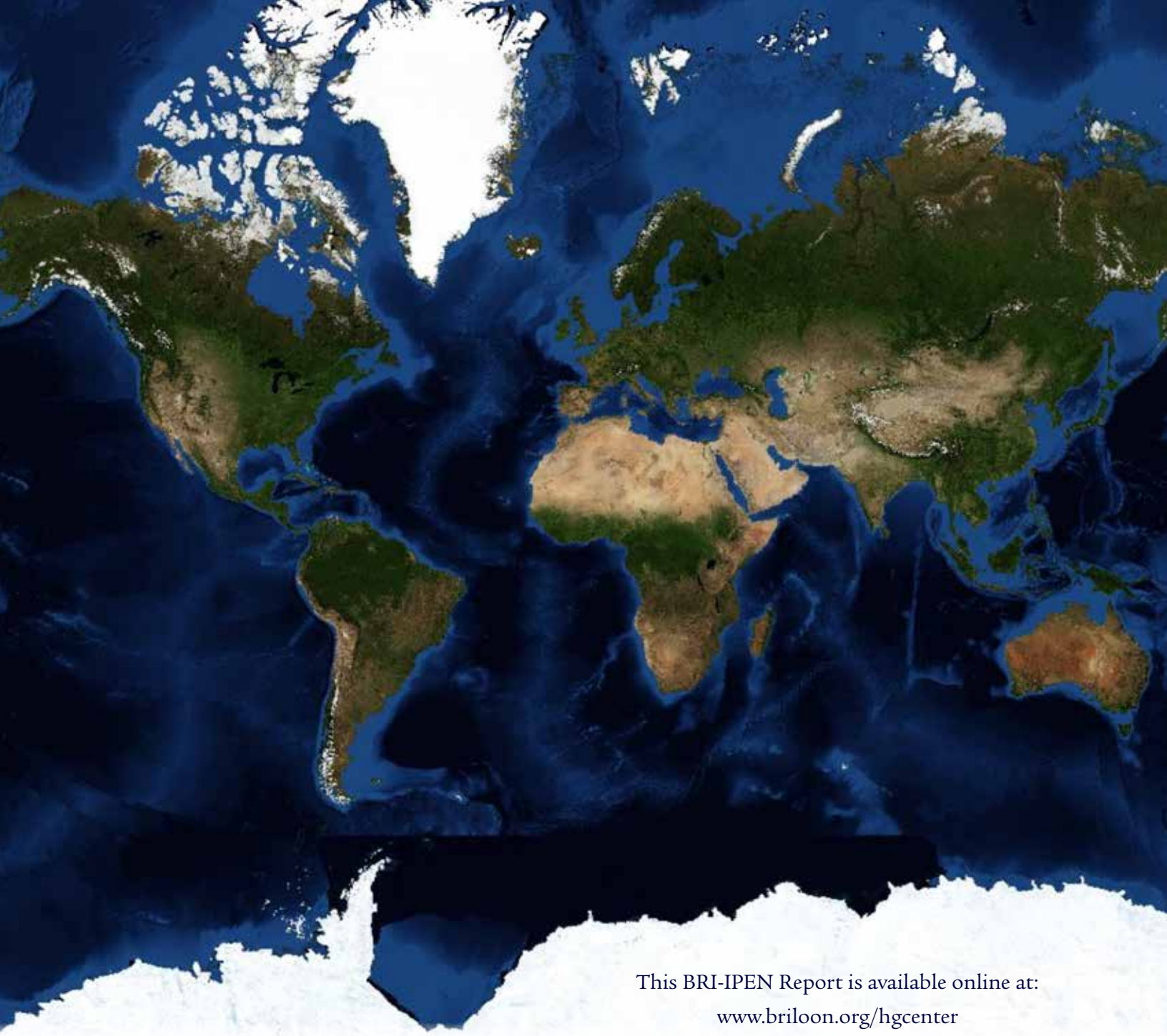

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