Mercury in the Global Environment

Understanding Spatial Patterns for Biomonitoring Needs of the Minamata Convention on Mercury

November 2018

Contents

Introduction: Mercury in the Global Environment

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 human industrial 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 birds and marine mammals. However, there is a gap in our understanding of the relationship between anthropogenic releases of mercury and its subsequent bioaccumulation and biomagnification in marine and freshwater food webs, and how that may translate to human exposure and risk at the local, regional, and global scale (Gustin et al. 2016).

Global Biotic Mercury Synthesis Database

Biodiversity Research Institute (BRI) has compiled mercury data from published literature into a single database, the Global Biotic Mercury Synthesis (GBMS) Database. This database includes details about each organism sampled, its sampling location, and its basic ecological data. From each reference, mercury concentrations are averaged (using weighted arithmetic means) for each species at each location.

Data from the GBMS database can be used to understand spatial and temporal patterns of mercury concentrations in biota. This information can also help establish baseline concentrations for a particular species and identify ecosystems most at risk to mercury inputs.

Mercury in the Global Environment

This report, *Mercury in the Global Environment*, presents data on mercury concentrations in biota of concern in Article 19 of the Minamata Convention (i.e., marine and freshwater fish, sea turtles, birds and marine mammals), which are extracted from the GBMS database. Mercury concentrations from key biota are presented and compared geographically and taxonomically through Case Studies.

Data for this report have been compiled from 1,095 different references, representing 119 countries, 2,781 unique locations, and 11,466 averaged mercury samples from 375,677 total individual organisms.

Together, these data can help raise awareness of potential risks and benefits of consuming key food items and thereafter help inform resource managers and decision makers about the species and places in which mercury represents a potential risk to human health, which can be partly based on harvest data by the Food and Agriculture Organization (FAO; Figure 12).

The GBMS database also represents a valuable tool for: (1) integrating mercury science into important policy decisions related to the Minamata Convention on Mercury (see page 2); (2) use by existing networks such as the Arctic Monitoring Assessment Programme (AMAP); and (3) protecting human health and the environment from the risks of mercury exposure (UN Environment 2013a).

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 (Kocman et al. 2017).

Report Highlights

- Mercury contamination is ubiquitous in global marine and freshwater ecosystems.
- Mercury concentrations in sea turtles, birds, fish, and marine mammals vary by species and by ocean basin.
- Many potential food items, especially certain fish and marine mammals species, often 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).
- Biota, especially fish and birds, can serve as important and policy-relevant bioindicators for monitoring the impacts of environmental mercury loads for both human and ecological health.
- BRI's GBMS database provides a standardized and comprehensive platform for understanding mercury concentrations that can aid Parties to the Minamata Convention during the ratification and implementation process.

BRI's Contributions to the Minamata Convention on Mercury

BRI is assisting in multiple ways with the ratification and implementation of the Minamata Convention on Mercury—a globally binding agreement facilitated by United Nations Environment that addresses the management of mercury and the risks this contaminant poses to human health and the environment (UNEP 2013b).

BRI is a co-lead of UN Environment's Mercury Air Transport and Fate Research Partnership Area and a member of the Artisanal and Small-scale Gold Mining (ASGM) Partnership Area. BRI is also an Executing Agency of the United Nations Industrial Development Organization (UNIDO) and serves as an international advisor for the United Nations Development Program (UNDP) and UN Environment to help coordinate and facilitate enabling activities to conduct Minamata Initial Assessments for more than 30 countries.

GBMS and the Minamata Convention

The GBMS database is designed to assist with tracking long-term trends of mercury in the environment and for identifying biological mercury hotspots around the world. In addition, GBMS helps us to identify fish and wildlife species that are at risk of high mercury exposure, which may also provide insight on risk to humans (from fish consumption or other means of methylmercury transfer in the foodweb). Overall, GBMS has applications to several articles within the Minamata Convention (Table 1).

GBMS and the Global Mercury Assessment 2018

The GBMS database is the basis for a new chapter about mercury in biota for the 2018 Global Mercury Assessment (GMA) published by the Arctic Monitoring and Assessment Programme (AMAP) and UN Environment. For the first time, mercury exposure is provided for major taxonomic groups (i.e., fish, sea turtles, birds, and marine mammals) at a global level.

Spatial gradients of methylmercury availability across the world provide a unique platform for beginning to understand regional biological mercury hotspots (those geographic areas where environmental mercury concentrations are of biological concern).

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

Objectives of *Mercury in the Global Environment* Project	Minamata Convention Article	Linkages between GBMS and Minamata Convention Articles
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 using mercury isotopes. • Biotic mercury concentrations can be used to inform human and environmental risk assessments.
Compile and present mercury data in an easy-to-access and easy-to-understand format through website portals.	**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 bioindicators (fish, sea turtles, birds, and marine mammals) 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 countries with important information 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.

*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 predators, that are sensitive to environmental change is an integral part of a long-term monitoring program. 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 local, regional, and global resources.

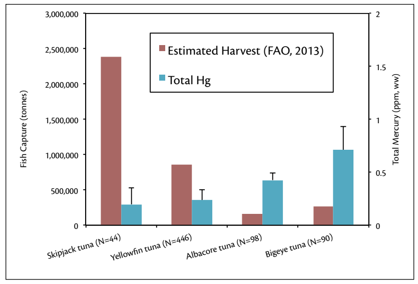
BRI's Five-Step Process for Translating Science to Policy

STEP 1: Collaborate on Scientific Research and Data Collection

Develop Regional Monitoring Hubs

Forming mercury monitoring hubs for field sampling and lab analysis improves local capacity and interest.

Form Databases



An integrated database on mercury provides a basis for understanding global temporal and spatial patterns.

Create Global Mercury Partnerships

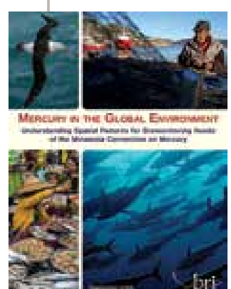
International collaborations with other scientists, governments, and nonprofits help galvanize working relationships on a global scale.

STEP 2: Publish Scientific Findings

Peer-reviewed Journals

Scientific findings published in professional journals help provide a strong basis for confident policy decisions.

STEP 3: Translate Science

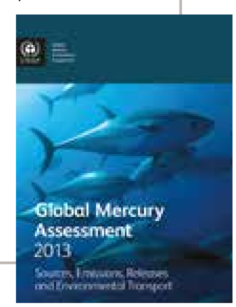


Science Communications and Public Outreach

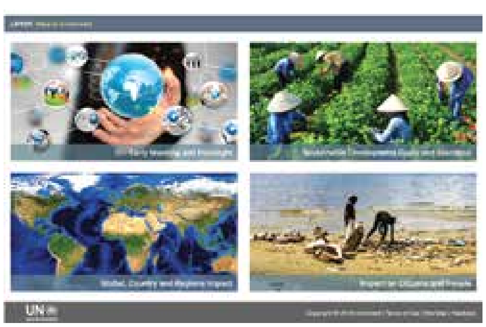
Translation of published findings into succinct, clear language, engages readers who are not experts in the field; photography and infographics help convey complex scientific concepts.

These outreach materials serve as a foundation for:

- press conferences
- policy development workshops
- legislative hearings
- public events



STEP 4: Increase Capacity and Raise Stakeholder Awareness



Website Portals

Improving access to information and worldwide activities related to mercury research and policy can be efficiently achieved through the Internet.

STEP 5: Inform Policymakers

Policy and Regulations

Clear, concise translations of scientific findings relevant to policy help standardize best practices needed by the Minamata Convention.

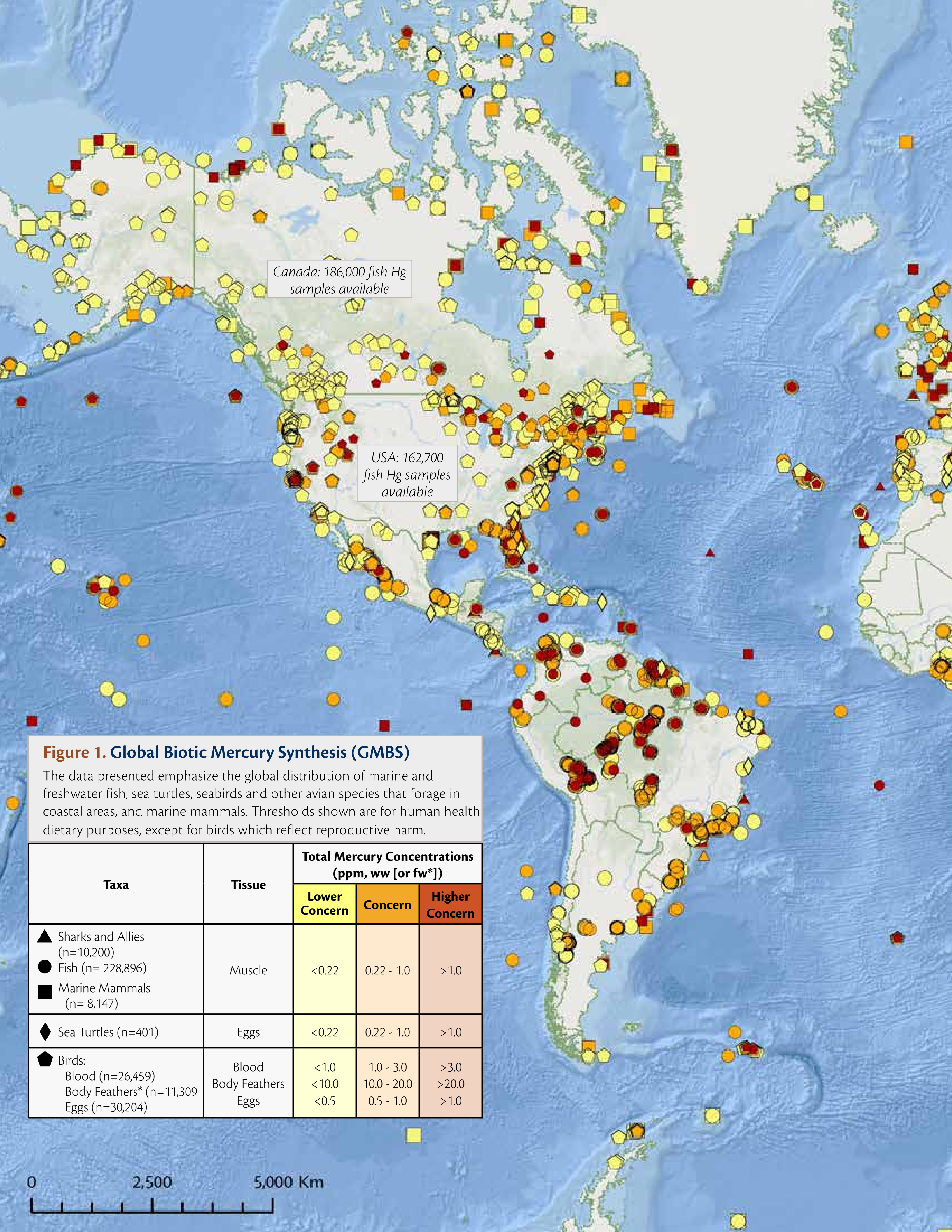


Figure 1. Global Biotic Mercury Synthesis (GMBS)

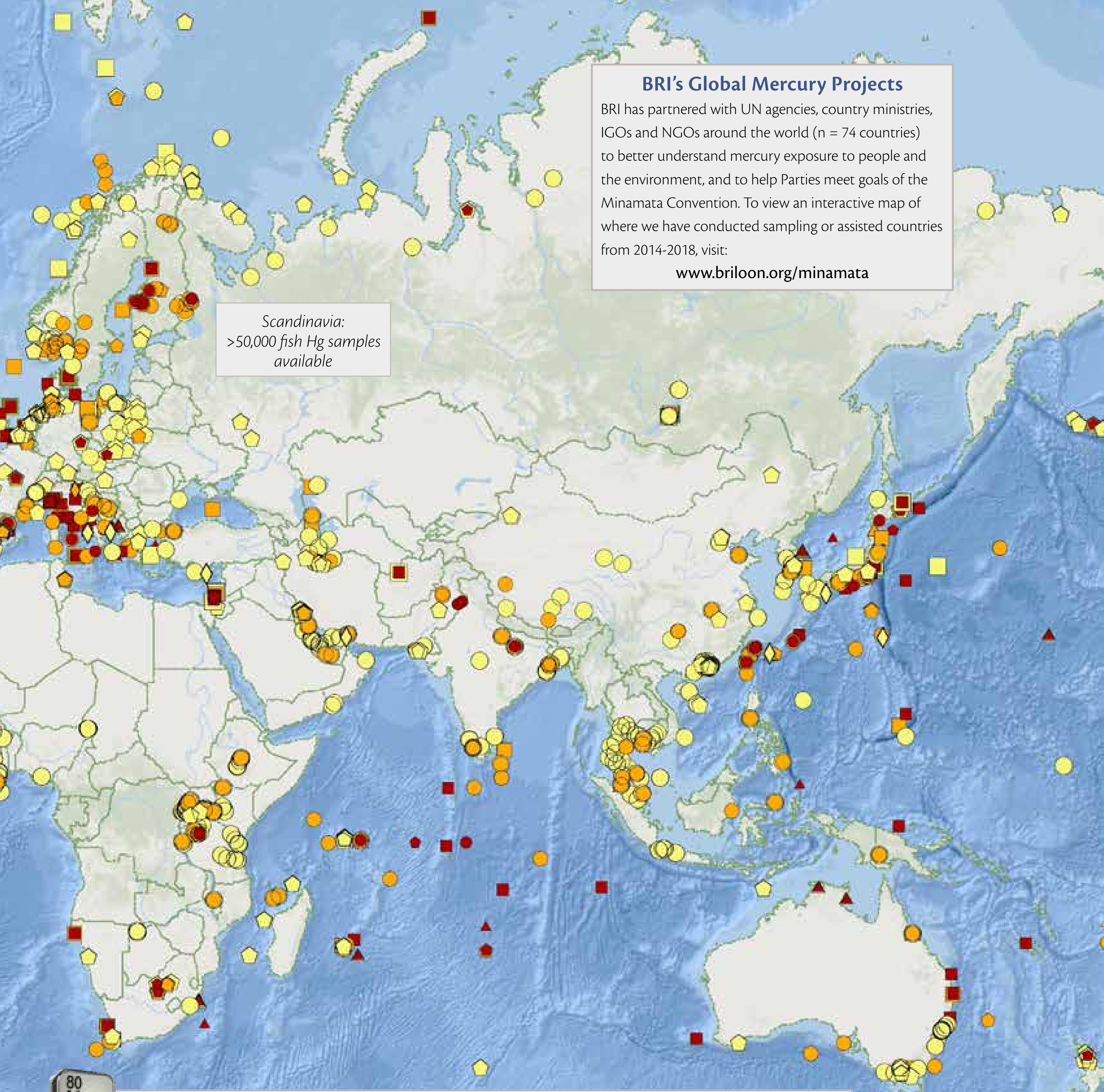
The data presented emphasize the global distribution of marine and freshwater fish, sea turtles, seabirds and other avian species that forage in coastal areas, and marine mammals. Thresholds shown are for human health dietary purposes, except for birds which reflect reproductive harm.

Taxa	Tissue	Total Mercury Concentrations (ppm, ww [or fw*])		
		Lower Concern	Concern	Higher Concern
▲ Sharks and Allies (n=10,200) ● Fish (n= 228,896) ■ Marine Mammals (n= 8,147)	Muscle	<0.22	0.22 - 1.0	>1.0
♦ Sea Turtles (n=401)	Eggs	<0.22	0.22 - 1.0	>1.0
⬟ Birds: Blood (n=26,459) Body Feathers* (n=11,309) Eggs (n=30,204)	Blood Body Feathers Eggs	<1.0 <10.0 <0.5	1.0 - 3.0 10.0 - 20.0 0.5 - 1.0	>3.0 >20.0 >1.0

BRI's Global Mercury Projects

BRI has partnered with UN agencies, country ministries, IGOs and NGOs around the world (n = 74 countries) to better understand mercury exposure to people and the environment, and to help Parties meet goals of the Minamata Convention. To view an interactive map of where we have conducted sampling or assisted countries from 2014-2018, visit:

www.briloon.org/minamata



Our Analytical Approach

Throughout this booklet we use the terms mercury (Hg), methylmercury (MeHg) and total mercury (THg). For analytical techniques we specify wet weight (ww), fresh weight (fw), or dry weight (dw) in parts per million (ppm).

Mercury concentrations in the GBMS database[1] represent various tissue types depending on the taxon reported. All teleost fish, shark, and marine mammal Hg concentrations represent muscle tissue on a ppm, ww basis.

The database also summarizes Hg concentrations in sea turtle eggs (ppm, ww); bird blood and eggs (ppm, ww); and bird body feathers (ppm, fw).

Where appropriate, Hg data reported as dw are converted to ww using a percent moisture content specific to the taxon and tissue type—fish tissue, eggs, and blood: 80% moisture; marine mammal muscle: 72%; liver: 70%; kidney: 77%; and skin: 73% (Yang et al. 2003). In instances where marine mammal Hg concentrations are reported in literature for only liver, kidney, or skin, tissue data are converted to muscle equivalents using regressions created using paired muscle-tissue Hg concentrations reported in other published literature included in the database.

[1]Because >95% of the Hg in all tissues herein is methylmercury (e.g., Bloom 1992), THg concentrations from the published sources are not converted to methylmercury. Hg concentrations are not normalized by organism size.

Regional Spotlight: South America

UN Environment and AMAP identify approximately 262 tonnes of mercury emissions and releases in South America with the primary source from artisanal and small-scale gold mining (ASGM; AMAP/UN Environment 2013). The GBMS database includes 214 references, totaling 28,940 of fish mercury concentrations from inland and nearshore locations in South America (Figure 2). New data are being generated for the southern Caribbean Sea.

Numerous references also document mercury concentrations in humans, particularly from rural, riverine communities living within the Amazon Basin. These sources are in a separate human health database.

Mercury, Mining, and the Environment

The majority of data on mercury in fish from South America has been collected from areas affected by ASGM. Mercury use is widespread in ASGM communities and much of the mercury used in the gold mining process is released into adjacent water bodies. This mercury can then accumulate within aquatic food webs, affecting the environment and adjacent communities that rely on these waterbodies for their fisheries.

The GBMS database provides a baseline of historic and current fish mercury concentrations from areas affected by ASGM and can provide a tool for monitoring the effectiveness of future mercury reduction strategies.

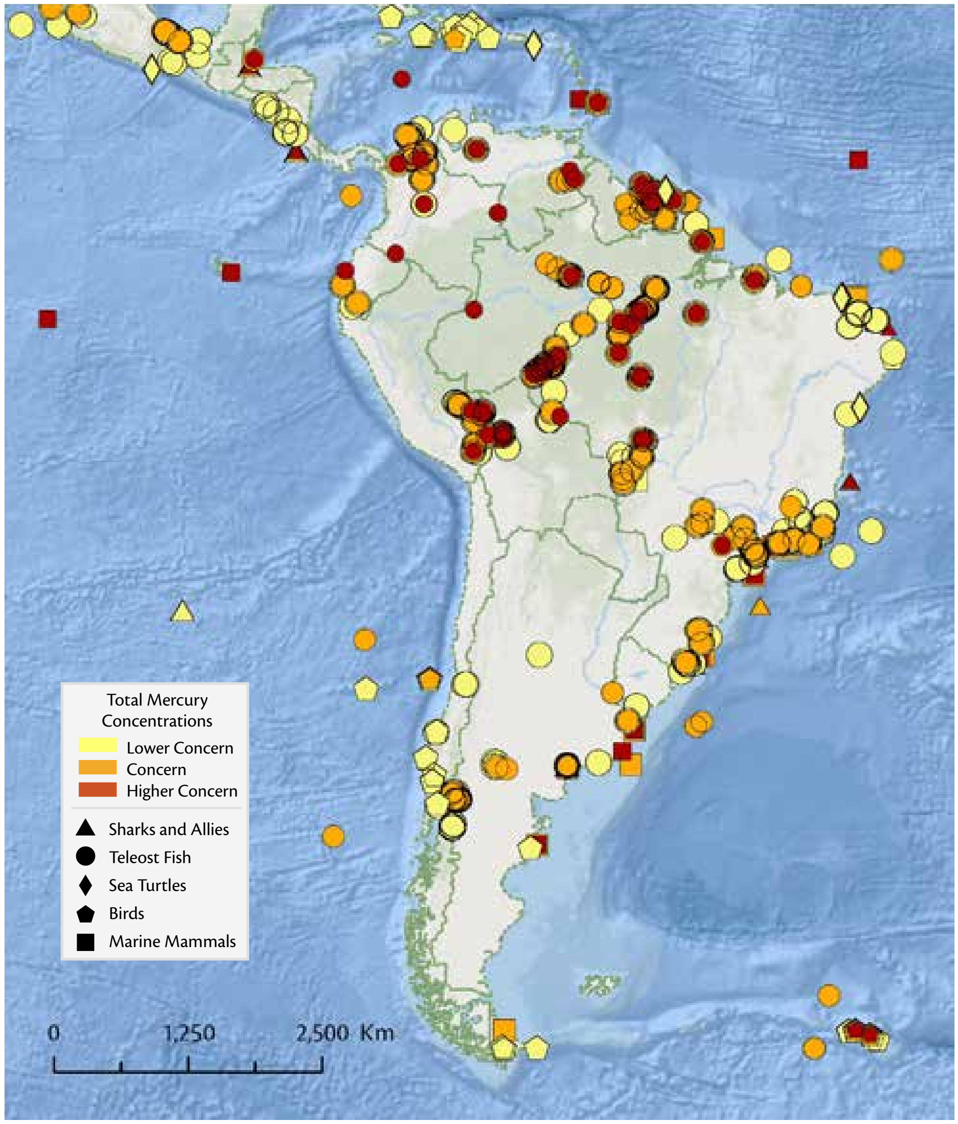


Figure 2. Total mercury concentrations in sampled fish, sea turtles, birds, and marine mammals, varies across South America.

ASGM activities are often carried out along rivers where mercury that is released can be methylated downstream and can biomagnify in the food web.

Artisanal and Small-scale Gold Mining (ASGM)

ASGM is the single largest anthropogenic source of mercury into the environment. Globally, emissions to air total approximately 727 tonnes per year while direct releases to land and water are estimated to be 800 tonnes per year.

The Minamata Convention seeks to reduce and, where possible, eliminate the use of mercury in ASGM. UN Environment's Global Mercury Partnership includes a special partnership area that is focused on supporting governments in their efforts to meet the goals of the Convention and to provide advice on transitioning away from the use of mercury in ASGM (UN Environment 2013a).

Regional Spotlight: Africa

Mercury emissions estimates for Africa total approximately 330 tonnes per year. In western Africa and parts of the East African rift valley, ASGM accounts for the majority of mercury emissions, while coal combustion and industrial-scale gold mining are the primary sectors responsible for emissions in the southern part of the continent (AMAP/UN Environment 2013).

The Need for Further Research

Overall, there is a lack of comprehensive fish mercury monitoring data across the continent of Africa. Of the more than 800 inland waterbodies on the continent, a recent study found fish mercury data reported from only 31 of them (Hanna et al. 2015).

A majority of the studies have been conducted in areas known to be contaminated by ASGM activities (Black et al. 2011) and while mercury concentrations in fishes from across Africa are generally low (Figure 3), concentrations approach, and in some cases exceed, World Health Organization (WHO) guidelines for human consumption (i.e., 0.5 ppm, ww).

There is an important need for more extensive monitoring of mercury across the African continent in order to confirm the hypothesis that mercury concentrations across the continent are "anomalously" low. Freshwater fisheries (e.g., Nile perch) are important in both domestic and international markets. A more comprehensive understanding of potential risks associated with fish consumption is an important step towards effective monitoring and evaluation for African countries that are signatories to the Minamata Convention.

Nile perch laid out on the beach for sale in Tanzania.

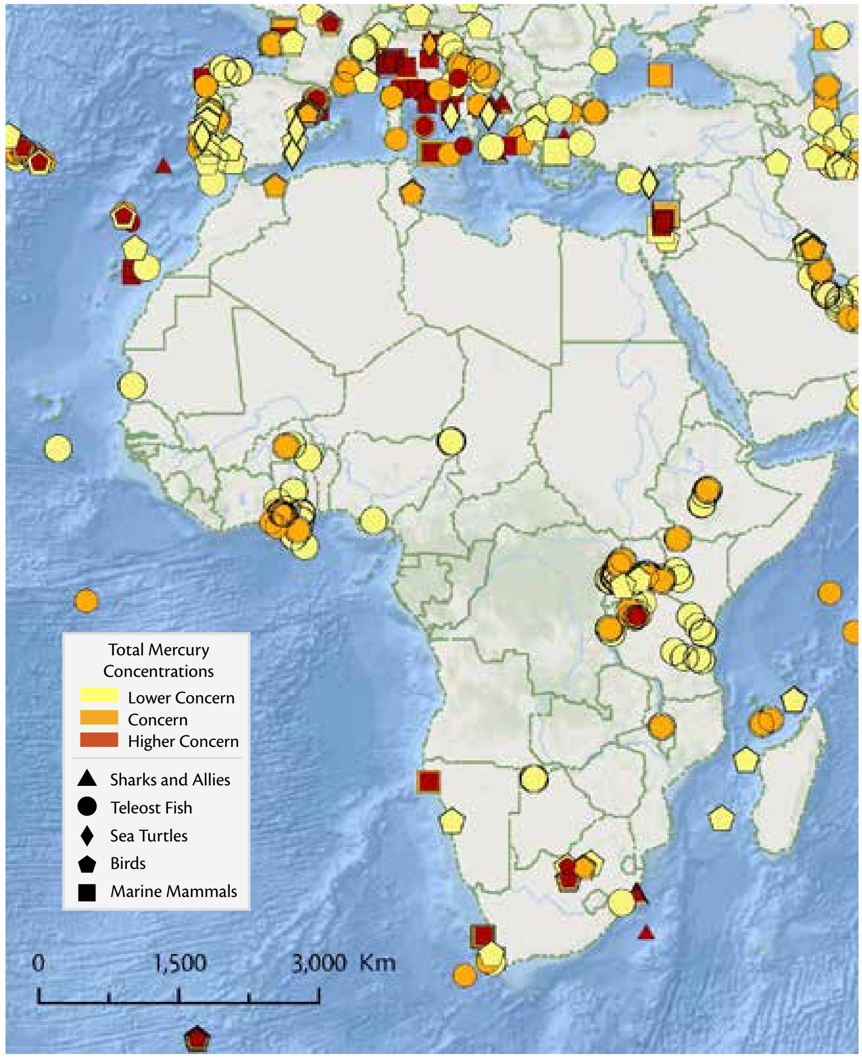


Figure 3. Total mercury (THg) concentrations in sampled fish, sea turtles, birds, and marine mammals, varies across Africa. Freshwater fish THg concentrations are generally low.

The Global Environment Facility's GOLD Program

Addressing Mercury Pollution from Artisanal Gold Mining

The Global Environment Facility (GEF) Council recently approved a program to address Global Opportunities for Long-term Development (GOLD) in the ASGM sector, including provisions to address mercury pollution from the sector. The collaborative foundation of the GOLD program brings together key players in ASGM, including governments, agencies, nongovernmental organizations, and the private sector. The program has strong private sector engagement, including major jewelers, electronics manufacturers, gold refiners, and potentially commercial banks. This collaboration creates an environment where the public and private sector can work together to support ASGM communities.

Burkina Faso and Kenya are the representative African countries of the GOLD project. Other participating countries include: Colombia, Guyana, Indonesia, Mongolia, Peru, and the Philippines.

For more information, visit: **www.thegef.org**

Regional Spotlight: Southern Asia

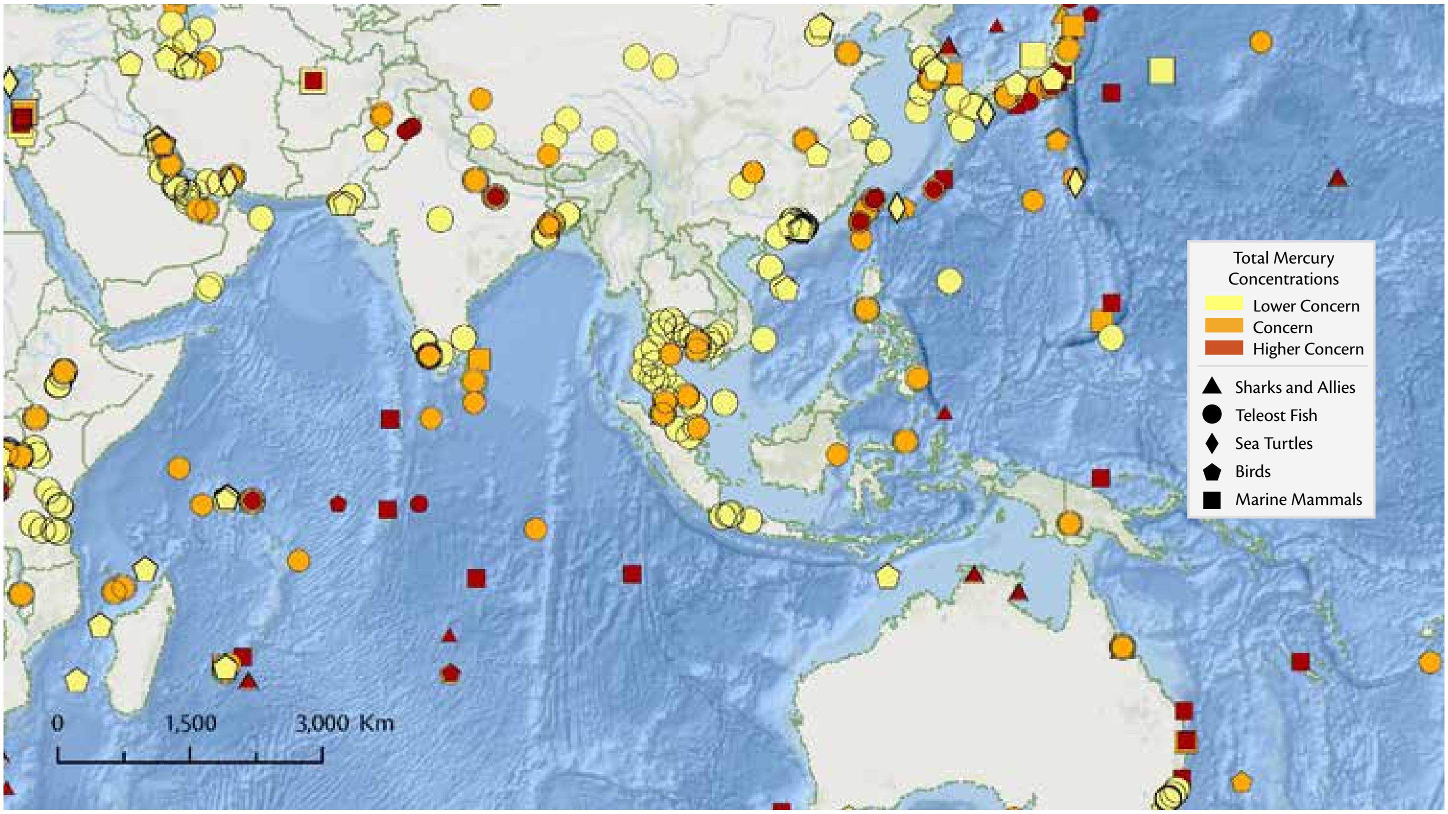


Figure 4. The distribution of mercury in biota, specifically fish, sea turtles, birds, and marine mammals, greatly varies across southern Asia and associated ocean basins and therefore requires an integrated mercury monitoring program.

Based on preliminary data from an AMAP/UN Environment mercury emissions model, 904 tonnes of mercury are being released in southern Asia primarily from coal-fired power facilities, and there continues to be an increase in coal combustion for power generation across much of Asia (AMAP/UN Environment 2013). In addition, awareness of ASGM activities in southern Asia, such as in Indonesia and the Philippines, has increased in recent years. This sector is an important source of mercury emissions to the air and of direct releases of mercury to land and water.

Mercury in Biota

Mercury concentrations in fish from freshwater ecosystems across much of Southeast Asia (as well as Africa and the Middle East) are generally low (Figure 4). However, mercury concentrations in teleost fish, sharks, and marine mammals from nearshore areas in eastern Asia and the Indian Ocean tend to be elevated. There is generally a lack of data from areas such as the South China Sea and Indonesia and associated islands.

Mercury and Human Health

Seafood represents an important source of protein for many communities in Southeast Asia (Agusa et al. 2007). BRI is partnering with UN Environment and IPEN to assess mercury exposure in people with diets high in fish. The project, which builds from a previous and similar study (Trasande et al. 2016) focuses on women of childbearing age in southern Asia as well as in Small Island Developing States in the South Pacific and Indian Ocean.

Asia Pacific Mercury Monitoring Network

The Asia Pacific Mercury Monitoring Network (APMMN), a cooperative effort involving many different entities, includes environmental ministries and federal government agencies, academic institutions, and scientific research and monitoring organizations. APMMN was established in 2013 to address growing concerns about mercury emissions in the Asia-Pacific region. The goal of the APMMN is to systematically monitor wet deposition and atmospheric concentrations of mercury in a network of stations throughout the Asia-Pacific region with potential interests to link to associated biota such as tuna (*pictured right*). To learn more, visit: **http://apmmn.org**

Global Health Trade-Off for Mercury and Omega-3 in Fish

The matrix below illustrates the interactions between the health risks posed by mercury concentrations and the health benefits of omega-3 fatty acids (Figure 5). 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.

Most fish contain omega-3 fatty acids; however, 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 (e.g., brain memory and performance) and behavioral function.

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 & Raymond 2010; Whitfield et al. 2010).

Global Health Trade-off for Mercury and Omega-3 in Seafood

Milligrams of Omega-3 Fatty Acids/4 Ounces of Cooked Fish →

← Total Mercury in Muscle Tissue µg/g (ww)

MEAL FREQUENCY RECOMMENDATIONS	<500 mg	500-1,000 mg	1,000-2,000 mg	> 2,000 mg
Unrestricted meals (< 0.05 µg/g)	Catfish (temperate waters), Clams, Crab* (most species), Croaker, Haddock, Scallops, Shrimp, Tilapia*	Blue Mussels,* Pink Salmon, Sockeye Salmon	Coho Salmon, Oysters	Healthier Choices Sardines, Shad
1-2 meals per week (0.05–0.22 µg/g)	Atlantic and Pacific Cod, Grenadier, Hake, Lobster,* Scad, Snapper, Sole	Atlantic Pollock, Mahi Mahi, Mullet, Squid, Skipjack Tuna, any canned tuna	Atlantic Horse Mackerel, Atlantic and Pacific Mackerel, Chinook Salmon,* European Sea Bass, Rays, Skates, Trout	Anchovies,* Atlantic Salmon, Herring
1 meal per month (0.22–0.95 µg/g)	Catfish (tropical waters) Flounder, Grouper, Orange Roughy, Seabream	Amberjack, Barracuda, Bigeye Tuna, Bluefish, Halibut, Jack, Tilefish, Trevally, Yellowfin Tuna, Wahoo	Albacore Tuna,* Atlantic Bluefin Tuna, Chilean Sea Bass	Mercury concentrations vary widely across shark species. To learn more, visit: www.briloon.org/hgcenter
No consumption (> 0.95 µg/g)	King Mackerel Riskier Choices	Marlin, Sailfish	Dogfish, Ground, and Mackerel Sharks; Pacific Bluefin Tuna, Swordfish*	

Figure 5. This matrix provides a general guideline for assessing healthier and riskier seafood choices.

Data Sources: BRI's GBMS Database; U.S. Environmental Protection Agency; U.S. Food and Drug Administration, University of Maryland Medical Center website
[1] Table 2 (page 10) provides background. * Species pictured

World Health Organization

The primary role of the World Health Organization (WHO) is to direct and coordinate international health within the United Nations' system. WHO supports the needs of Parties to the Minamata Convention on Mercury by gathering evidence about the health impacts of the different forms of mercury, providing guidance on identifying populations at risk from mercury exposure, and developing tools to reduce mercury exposure. For more information, visit: **http://www.who.int/en/**

Mercury concentrations in typical sharks, such as this shortfin mako shark (Isurus oxyrinchus) and others in the Mackerel Shark family, have average muscle Hg concentrations greater than 1 ppm (Figure 8).

Global Fish Mercury Concentrations

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).

Seafood mercury concentrations, best known in fish, are most studied in North America and Europe and least studied in Africa, 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). For this report, fish and marine mammal mercury concentrations are compared with consumption guidelines (Table 2).

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 6).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 Atlantic Ocean contain average mercury concentrations greater than 0.11 ppm, ww).

Interpreting Mercury Concentrations and Risks of Exposure

Mercury concentrations presented can be compared with the number of seafood meals that could be eaten to stay within the US Environmental Protection Agency's (US EPA) health-based reference dose for methylmercury (see Table 2 for the fish meal limits by methylmercury concentration, and US EPA [2001] for details on how meal limits were calculated). For further reference, WHO and the European Commission (EC) general guidance level 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, which is similar to the US EPA "no consumption" level.

Mercury 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 2. Seafood Hg concentrations and associated meal frequency guidelines. The guidance is based on the US EPA reference dose of $1x10^{-4}$ 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 gm). These guidelines, with further interpretation by the Great Lakes Consortium (GLC; Great Lakes Fish Advisory Workgroup. 2007), 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.

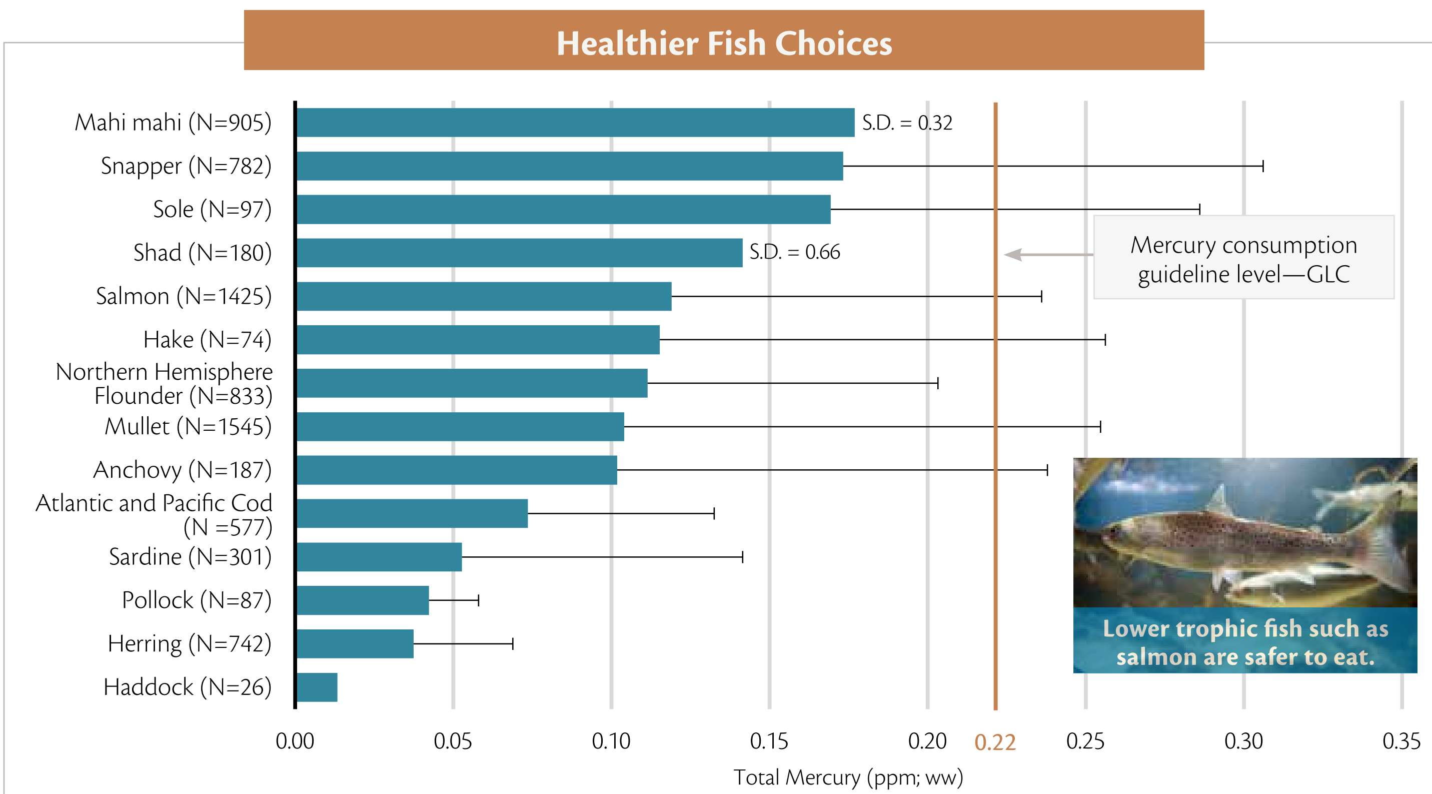


Figure 6. Average (+/– SD; N=sample size) THg concentration of fish muscle tissue shown with consumption guidance levels as outlined by the Great Lakes Consortium (GLC; Table 2). These fish represent regularly consumed species that have average Hg concentrations ≤ 0.22 ppm, ww.

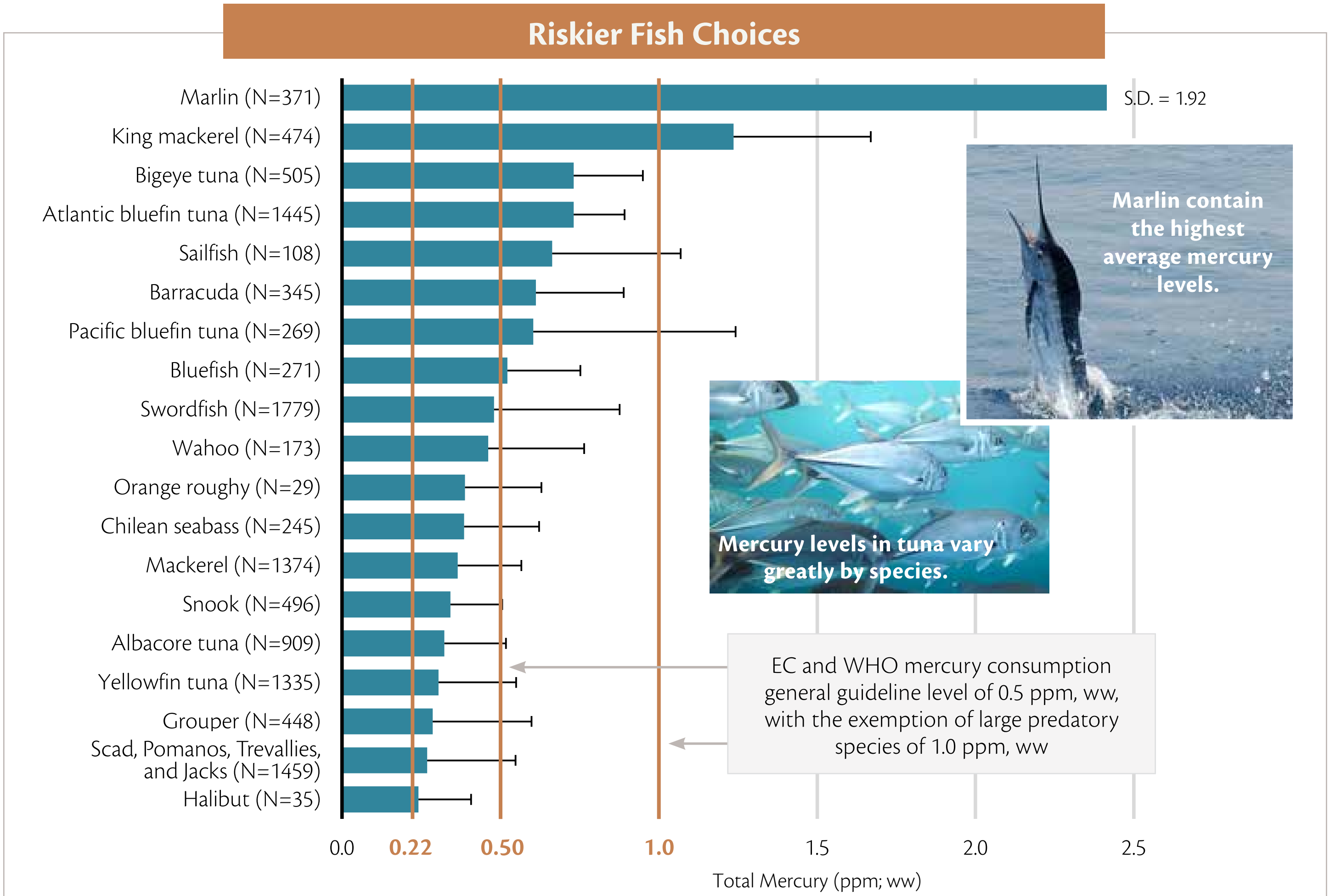


Figure 7. Average (+/– S.D.; sample size = N) THg concentration in fish muscle tissue shown with consumption guidance levels (Table 2). Fish in this chart represent species regularly consumed and having average muscle Hg concentrations > 0.22 ppm, ww.

Riskier Fish Choices

Mercury concentrations are highest in large, long-lived species, many of which are pelagic. Marlin, king mackerel, bigeye tuna, and bluefin tunas (which can approach 1,000 pounds) have some of the highest mercury concentrations of any fish in the GBMS database (Figure 7). These and other commonly consumed fish species have average mercury body burdens that approach the "no consumption" guidance level of 0.95 ppm, ww (Figure 7; Table 2).

While less than one percent of the world seafood harvest includes sharks, 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 global shark fishery (Vannuccini 1999; Musick and Musick 2011).

Generally, mercury concentrations in sharks exceed safe consumption guidelines (Figure 8; N=9,035). For commonly encountered shark species such as bull, lemon, and nurse sharks, average mercury concentrations compared globally indicate highest levels in the Mediterranean Sea and the Gulf of Mexico.

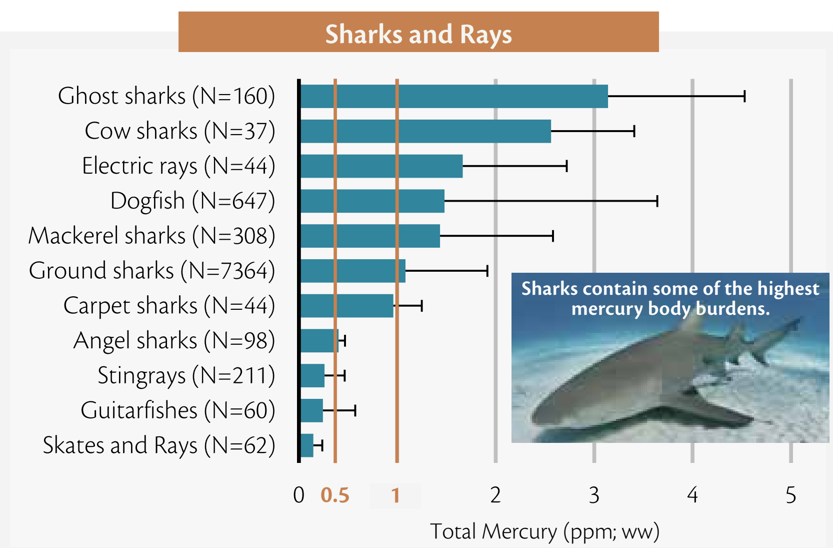


Figure 8. Average (+/– SD; N=sample size) THg concentration in muscle tissue of seven shark and four skate-ray orders shown with consumption guidance levels (Table 2).

As long-lived apex predators found in all ocean basins, sharks and rays are consistently high in their body burdens of mercury. The toxic form, methylmercury, is also high, and the potential impacts to shark physiology, behavior, and reproductive success remains relatively unknown. Recent evidence does indicate some physiological impacts (Hammerschlag et al. 2016) and more research is urgently needed.

Global Marine Fish Harvest Data

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. Fish auctions sell these prized fish to the highest bidder and subsequently drive demand for these high trophic level species.

In 2016, global fish harvest (wild caught and aquaculture) totaled 170.9 million tonnes, with wild caught fishes accounting for approximately 90.9 million tonnes (53.2 percent) of the total production (FAO 2018).

Pelagic fishes (i.e., tunas, mackerels, and billfish) and clupeiformes (i.e. herrings, anchovies, and sardines) dominate global fish capture (Figures 7 and 8); the Peruvian anchovy and the Skipjack tuna are the two most captured species by weight. Coastal fishes include a taxonomically diverse group of species (i.e., groupers, seabass, snook, and snappers, etc.); these fishes are important commercially, as well as to local fishing communities. Benthic and demersal fishes (i.e., cod, haddock, and flounder) account for a substantial portion of the global commercial fishery.

Many pelagic species are long-lived apex predators that migrate across the world's oceans. Their long lives put them at risk of accumulating high levels of mercury. Many of these long-lived pelagic species are among the riskier choices of fish for consumption (see Figure 5).

Lower trophic level fishes such as herrings, anchovies, and sardines, as well as demersal fish, all of which are harvested in substantial numbers, generally accumulate less mercury over time, making them generally healthier food choices than other species (Figure 9).

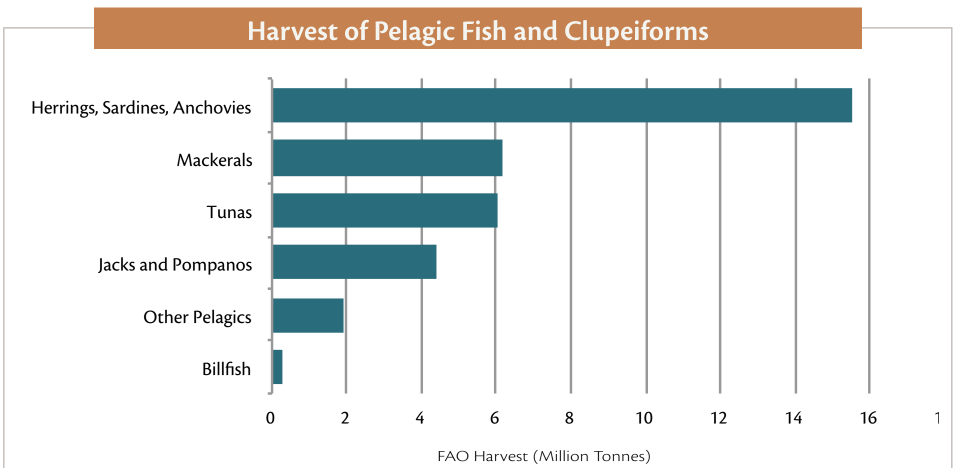


Figure 9. Pelagic and sardine-like fishes accounted for more than 50% of the global fish harvest in 2016.

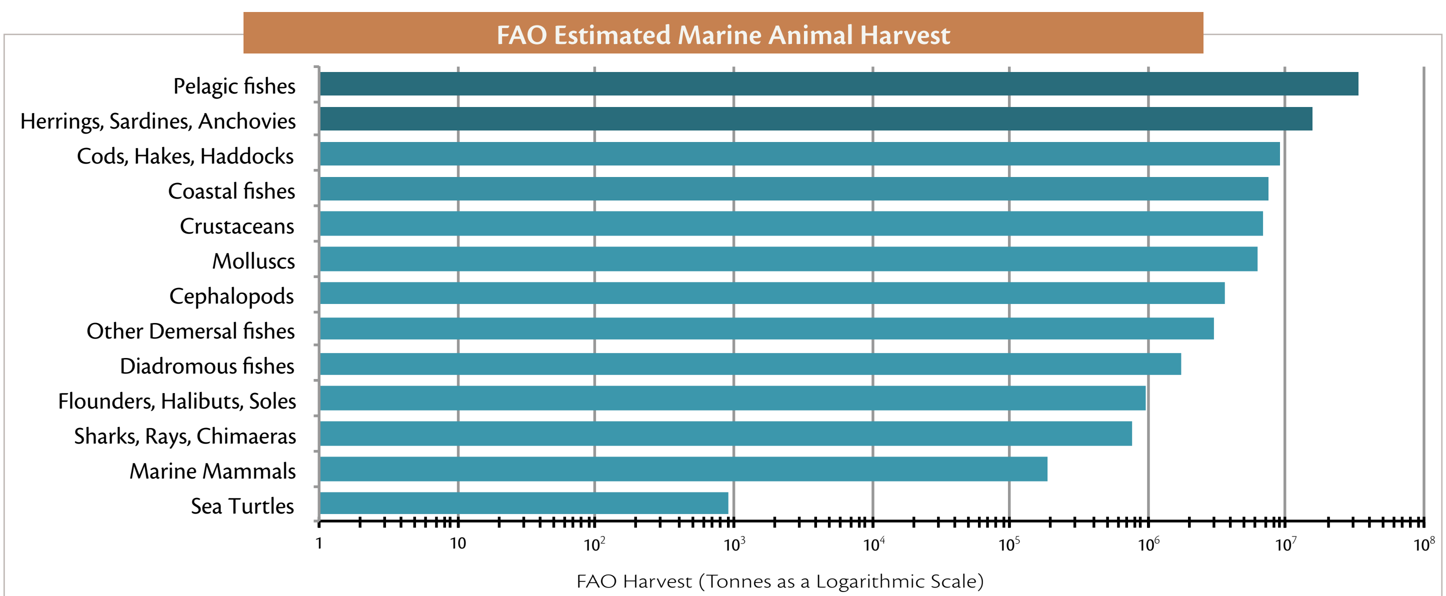


Figure 10. The Food and Agriculture Organization (FAO) of the United Nations maintains the only standardized repository of global fisheries data. Data from FAO's **FishStatJ** fisheries database totals global harvest of fishes in 2016 at 170.9 million tonnes.

Billfish

There are 12 species of billfish. These long-lived apex predators have muscle tissue mercury concentrations that are some of the highest for fish outside of known contaminated sites. Based on the GBMS database, the Atlantic and Indo-Pacific blue marlins (*Makaira* spp.; estimated annual harvest of 439 and 38,755 tonnes respectively; FAO 2015) have the highest average mercury concentrations (> 2.5 ppm, ww) for all billfish (Figure 11). This is due, in part, to their large size of more than 800 kg (or 1,700 lbs).

Based on FAO data, annual commercial harvest of all billfish is approximately 226,610 tonnes. Swordfish (*Xiphias gladius*) is the most frequently harvested species, comprising approximately 50 percent (114,435 tonnes) of the total (FAO 2015).

In addition to commercial importance, billfish are prized in the recreational fish industry. As sport fish, billfish are often tagged and released, so their movements within and among ocean basins can be tracked; more than 300,000 individuals have been tagged since the 1950s (Ortiz et al. 2003).

Because of the wide distribution and relative abundance of swordfish, mercury concentrations in this species are comparable worldwide. This provides opportunity for a global, single species comparison. Average swordfish mercury concentrations (Figure 11a inset) are lower than the 1.0 ppm, ww human consumption threshold set by WHO, but generally higher than the 0.5 ppm, ww threshold used by the European Commission (excepting the Mediterranean Sea populations).

The highest average mercury concentrations for swordfish in the GBMS database are from the Pacific, North Atlantic and Indian Ocean basins, with average mercury concentrations nearing 1.0 ppm in each basin (Figure 11a inset). The majority (49 percent) of the global harvest of swordfish also comes from the Pacific, with another 25 percent from the Indian Ocean, and the remainder split between the Atlantic Ocean (17 percent) and the Mediterranean and Black Seas (8 percent; FAO 2015).

Also of note, fish mercury concentrations in the North Pacific Ocean Basin are expected to increase because of air emissions originating from Asia (Sunderland et al. 2009). The relationship between high mercury values and high harvest areas should be considered when assessing apex predator food options such as swordfish.

Streamlined for speed, sailfish are regarded as the fastest fish in the world's oceans. There are two species—the Atlantic sailfish (Istiophorus albicans) *and the Indo-Pacific sailfish* (I. platypterus)*. Popular sport fish, sailfish have muscle mercury concentrations similar to those in the more commercially important swordfish.*

Total Mercury Concentrations in Billfish Muscle Tissue

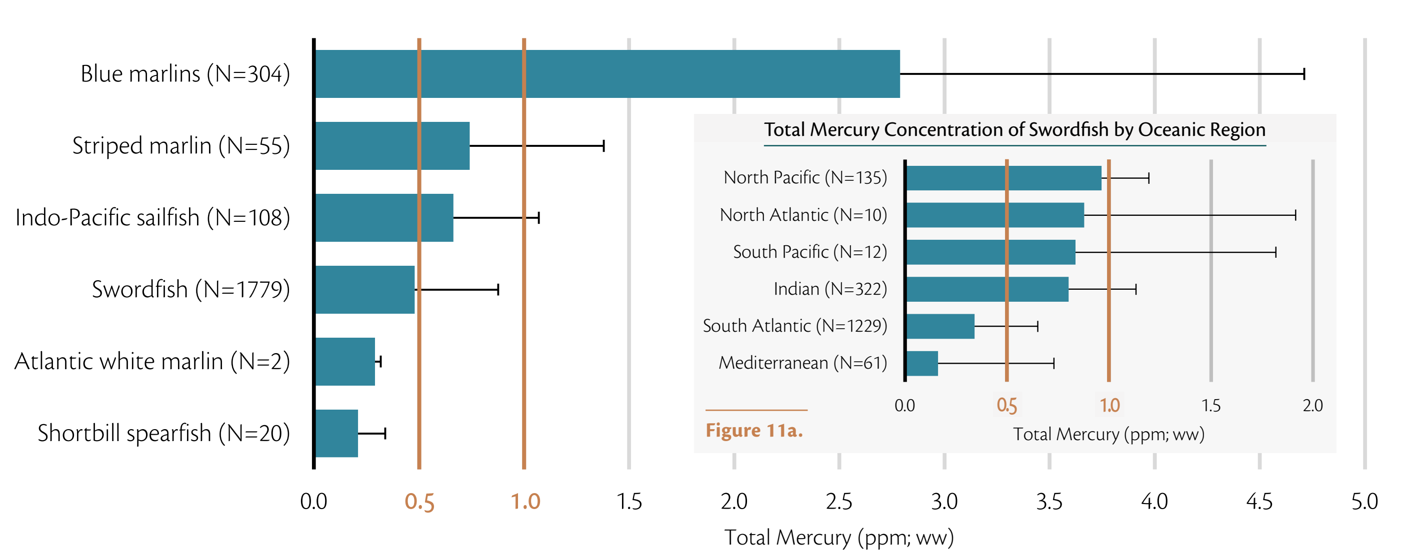


Figure 11. Average (+/− SD; N=sample size) THg concentration in muscle tissue of six billfish species (Atlantic and Indo-Pacific blue marlins are combined) compared against consumption guidance levels (Table 2, page 10). Inset graph shows average THg concentrations of swordfish (*Xiphias gladius*) muscle tissue from six ocean regions.

Tuna

Most tuna species are large marine apex predators and many are regularly listed on fish consumption advisories (Kaneko and Ralston 2007). However, tuna are consistently among the top five commodities in the global fish market. Skipjack, albacore, and yellowfin are the species most commonly utilized by the tuna canning industry, while bluefin tuna species are especially desired for direct consumption (FAO 2004).

Figure 12 compares mercury data from GBMS in nine tuna species showing FAO capture totals. The most highly sought after tuna species, skipjack tuna, also has the lowest mean mercury concentration. Yellowfin and albacore tuna have average mercury concentrations slightly above the GLC/USEPA consumption guideline of 0.22 ppm, while Atlantic and Pacific bluefin, bigeye, and blackfin tunas exceed the EC threshold guideline of 0.5 ppm. Bluefin tuna generally have high mean mercury concentrations but represent a relatively small portion of the overall tuna capture.

Recent research suggests that present atmospheric mercury deposition rates will result in an approximate doubling of mercury concentrations by 2050, particularly in the North Pacific Ocean (Sunderland et al. 2009). Assuming methylmercury production and bioaccumulation follow current patterns, such deposition rates will likely result in significant increases in mercury concentrations in apex marine predators such as tuna.

Mercury in the Global Environment: Tuna

This new BRI publication helps illustrate the impacts of methylmercury biomagnification and bioaccumulation on nine species of tuna, highlighting mercury levels in the most popular tuna food sources. To download this and other BRI publications, visit: **www.briloon.org/hgpubs**.

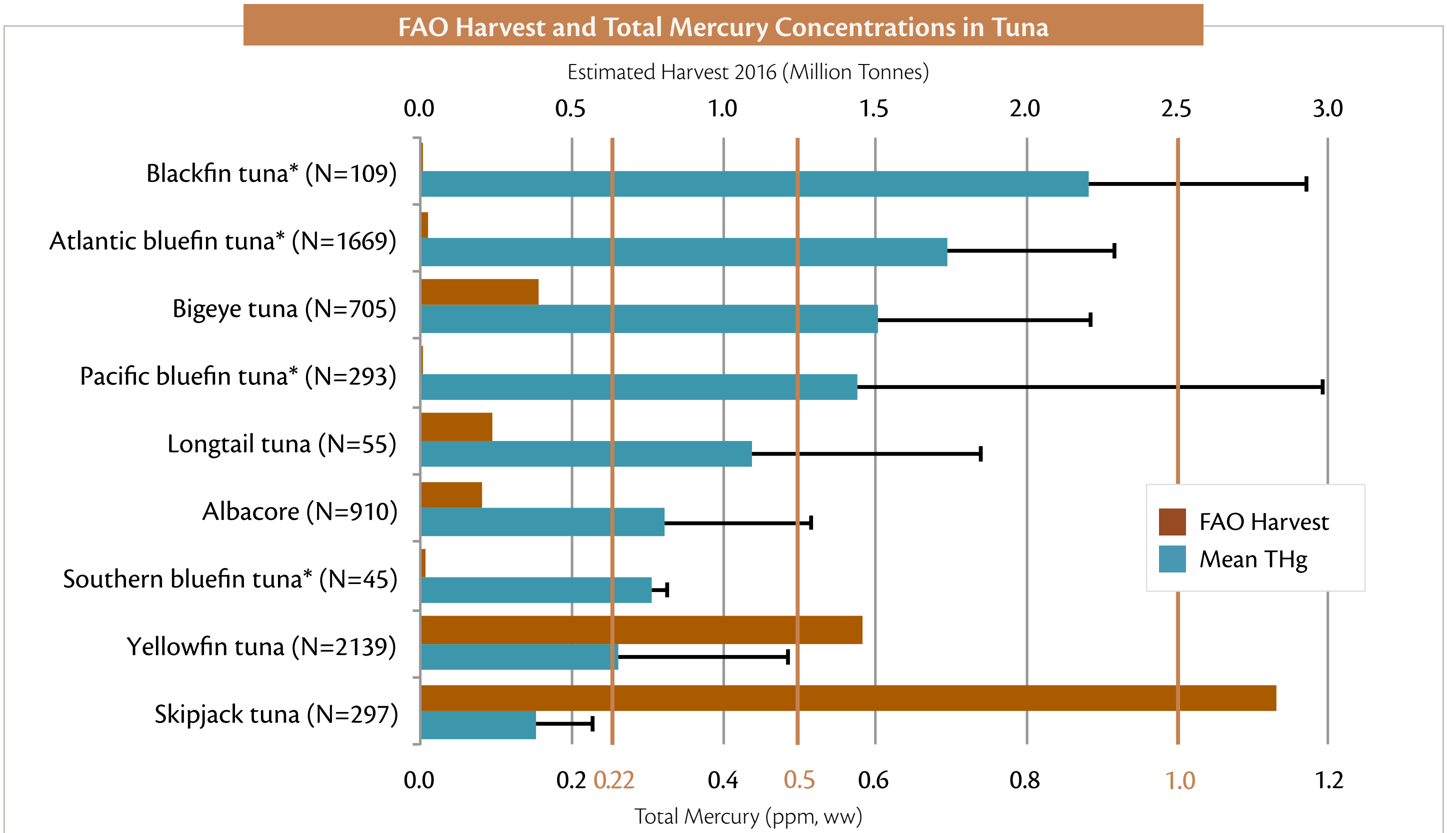


Figure 12. Average (+/– SD; N=sample size) THg concentration in muscle tissue of nine tuna species compared with the FAO harvest estimate in tonnes. See Table 2 (page 10) for mercury consumption guidelines. *FAO harvest is less than 15,000 tonnes.

Herring, Sardines, and Anchovies

Most clupeiform fishes are considered open water, pelagic species that swim in dense schools. Many species also rely heavily on near-shore environments for spawning and nursery habitat.

Clupeiform fishes (e.g., herring, sardines, and anchovies) are small, pelagic fishes often found in large schools. They dominated the overall global fisheries harvest in 2016, accounting for more than 15 percent of the total harvest (Figure 10).

The single largest clupeiform fishery is the Peruvian anchovy whose total harvest exceeded 3.2 million tonnes in 2016 (FAO 2018). Clupeiform harvest (Figure 13) is generally dominated by catches from the Atlantic and Pacific Oceans, with relatively lower harvests from the Indian Ocean and Mediterranean Sea.

Clupeiforms are forage fish that feed primarily on plankton and other small organisms. They occupy an important position within the marine food web, serving as primary prey items for other larger marine fishes.

Mercury concentrations in clupeiforms are generally low (Figure 13), in part because of their low trophic level. Menhaden, shad and anchovy average over 0.10 ppm (ww), while sprat are the lowest—averaging <0.04 ppm (ww). Menhaden are important prey items for many seabirds, especially loon, osprey, and gannets.

While clupeiforms tend to accumulate much less mercury on average than other marine biota, they are an important component of long-term mercury monitoring. Quantifying mercury concentrations from lower trophic level groups in high mercury ocean basins provides valuable insights into the short-term changes that are more challenging to understand in older and higher trophic level fish.

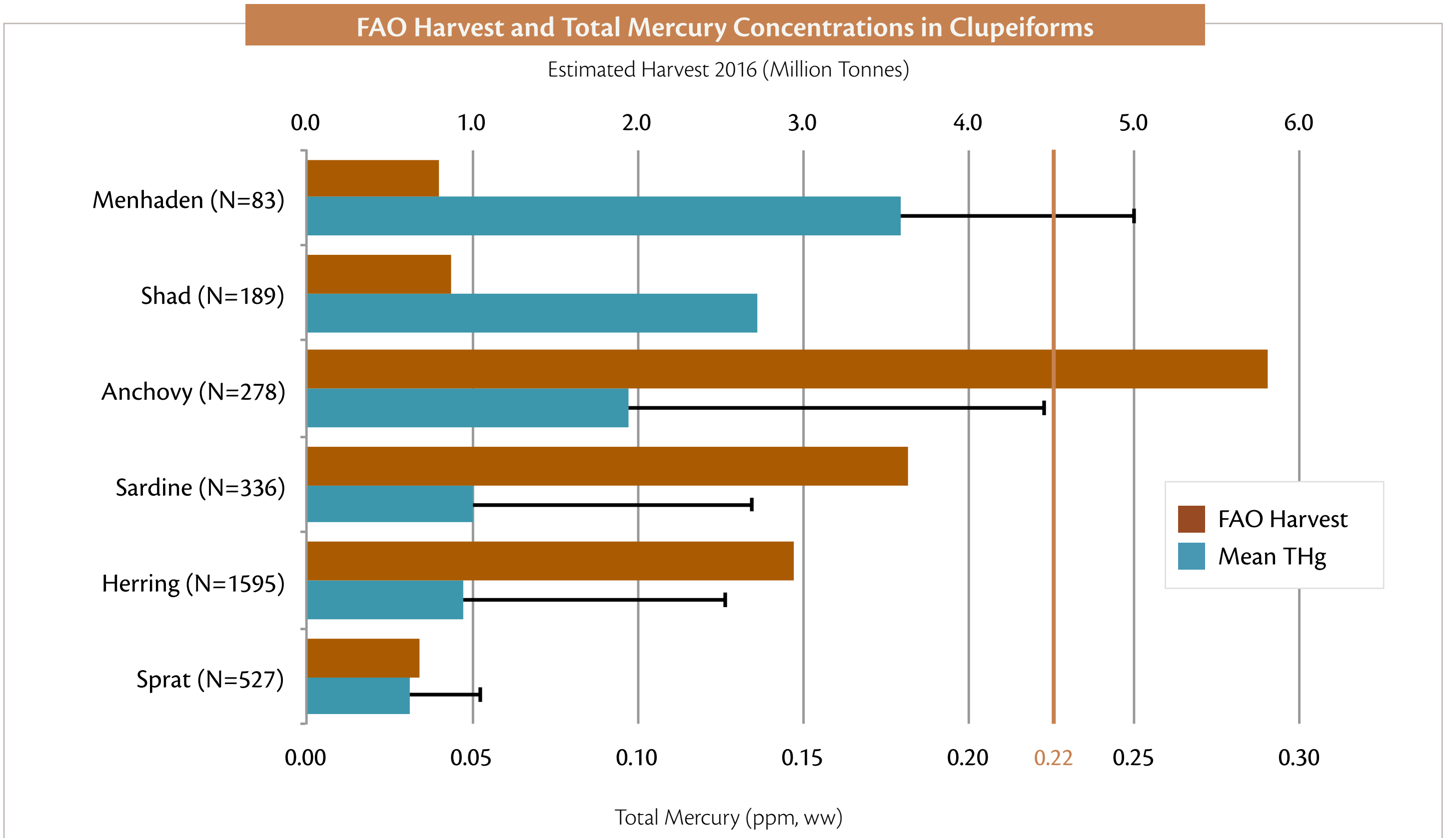


Figure 13. Average (+/– SD; N=sample size) THg concentrations of muscle tissue from six clupeiform groups compared to the 2016 FAO harvest estimate in tonnes. See Table 2 (page 10) for mercury consumption guidelines.

CASE STUDY

Freshwater Fish

Long-term mercury monitoring in freshwater fish is common for many countries and allows for spatial and temporal changes to be observed over relatively large regions (Monson 2009, Monson et al. 2011, Eagles-Smith et al. 2016). Prior to undertaking any long-term monitoring program, it is important for scientists, resource managers, and decision makers to work together to ensure that any monitoring approach can accurately evaluate the effectiveness of proposed mercury reduction strategies (Evers et al. 2011, Evers et al. 2016).

Biomonitoring in Temperate Areas

Freshwater fish are commonly used as a monitoring and assessment tool for mercury contamination in lakes. In North America (Figure 14) and across parts of Europe (e.g., Scandinavia), mercury monitoring has been conducted for decades across a wide range of freshwater ecosystems (i.e., ponds, lakes, reservoirs, rivers). Broad taxonomic differences in gamefish mercury body burdens observed in the order Perciformes and Esociformes illustrates the variation that should be considered for large-scale mercury biomonitoring efforts for temperate lakes and rivers (Figure 14).

These data provide critical information that are used in the development of fish consumption guidelines for the protection of human and ecological health.

Total Mercury Concentrations in Perciformes and Esociformes in North America

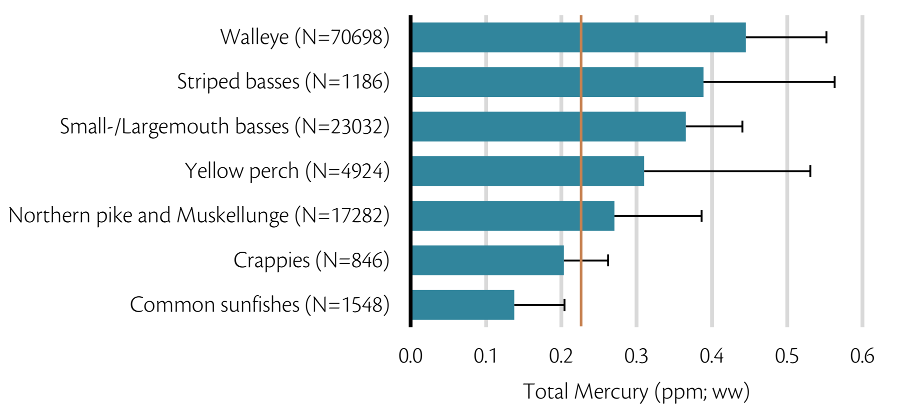


Figure 14. Average (+/– SD; N=sample size) THg in freshwater fish for seven genera showing the GLC human health threshold of 0.22 ppm, ww. See Table 2 (page 10) for mercury consumption guidelines.

Biomonitoring in Tropical Areas

The GBMS database also includes numerous studies from tropical regions where ASGM activities are perceived as the primary source of mercury released into the environment. Paired comparisons of mercury concentrations in fish from the same taxonomic classification (i.e., order) between temperate and tropical areas broadly indicates that tropical fish tend to have higher mercury concentrations than their temperate counterparts (i.e., four of six pairings are higher for tropical fish; Figure 15). For example, tropical catfish have higher average mercury concentrations—they are often associated with ASGM activities—whereas catfish from temperate areas may less likely be associated with contaminated areas.

The walleye (Stizostedion vitreum) is a common freshwater gamefish of North American lakes that is widely used in Canada and in the Great Lakes Region of the U.S. for mercury monitoring efforts related to human health.

Total Mercury Concentrations in Six Paired Orders of Fish by Region

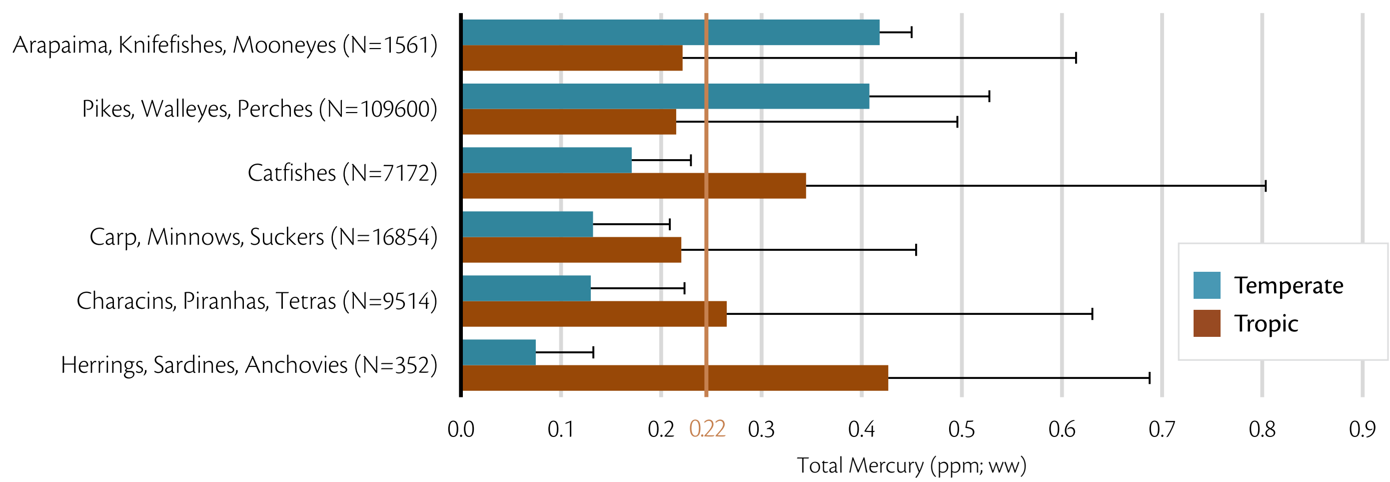


Figure 15. Average (+/– SD; N=sample size) THg in freshwater tropical and temperate fish for six orders, showing the GLC human health threshold of 0. 22 ppm, ww. See Table 2 (page 10) for mercury consumption guidelines.

Sea Turtles

The seven species of sea turtles are found across all warm and temperate waters, often migrating hundreds of miles between nesting and feeding grounds. All marine waters can create elevated levels of mercury body burdens in biota, including sea turtles. And, while sea turtles are long-lived and slow growing (creating an opportunity for methylmercury to bioaccumulate over time), most species forage on seagrass, sponges, and slow moving animals such as zooplankton and jellyfish—all of which occupy the lower parts of the food web and therefore create minimal opportunities for methylmercury to biomagnify.

Yet, sea turtles can be important bioindicators of short-term (e.g., blood sampling) and long-term changes (e.g., scute sampling) of environmental mercury loads in marine ecosystems.

Several studies have used sea turtles for developing biomonitoring efforts for mercury in coastal areas (e.g., southeastern United States; Day et al. 2005), where subtle negative impacts were measured in health parameters for the loggerhead sea turtle (Day et al. 2007). Mercury has been measured in five of the seven species of sea turtles and those data are contained in the GBMS database (Figure 16)

Areas where sea turtles may need to be monitored for elevated levels of mercury include the Caribbean Sea (especially the Gulf of Honduras), Mediterranean Sea, Arabian Sea, and other constrained marine areas such as bays.

Sea turtles and their eggs may be consumed and their mercury concentrations can have adverse impacts on human and ecological health—in some coastal Pacific communities, researchers have identified potential human health concerns of sea turtle egg consumption because of mercury and other heavy metals (Ross et al. 2016).

Turtle eggs can contain elevated levels of methylmercury and may pose a threat to human health if consumed. While all sea turtle species are protected by various national and international laws, consumption of their eggs remains a common practice in some communities and countries.

Wider Caribbean Sea Turtle Conservation Network (WIDECAST)

A network of biologists, managers, community leaders, and educators in more than 40 Caribbean nations and territories, WIDECAST seeks to bring the best available science to legislation and policy; to education, training and outreach; to conservation and advocacy; and to in situ research and population monitoring for the recovery and sustainable management of depleted sea turtle populations. Mercury biomonitoring can help track the success of environmental mercury reduction as part of the Minamata Convention. For more information, visit: **www.widecast.org**

Total Mercury Concentrations in Sea Turtle Eggs by Species

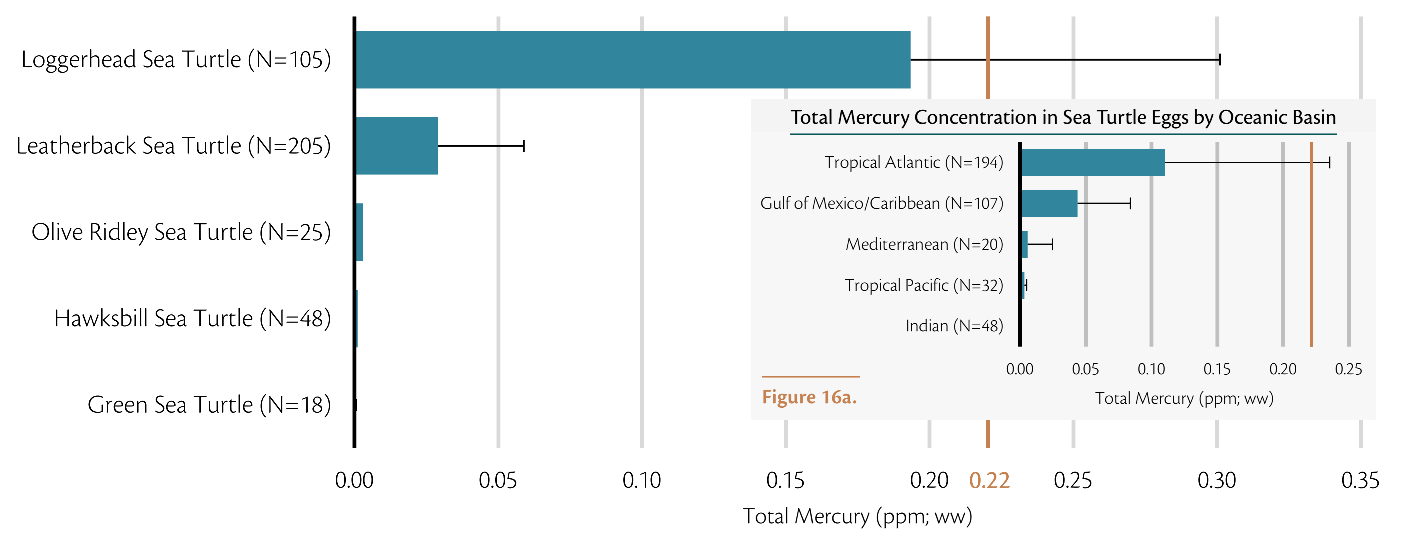


Figure 16. Average (+/– SD; N=sample size) THg in sea turtle eggs by species. Inset graph shows average total mercury concentrations of sea turtle eggs from five major ocean basins. See Table 2 (page 10) for mercury consumption guidelines.

Birds

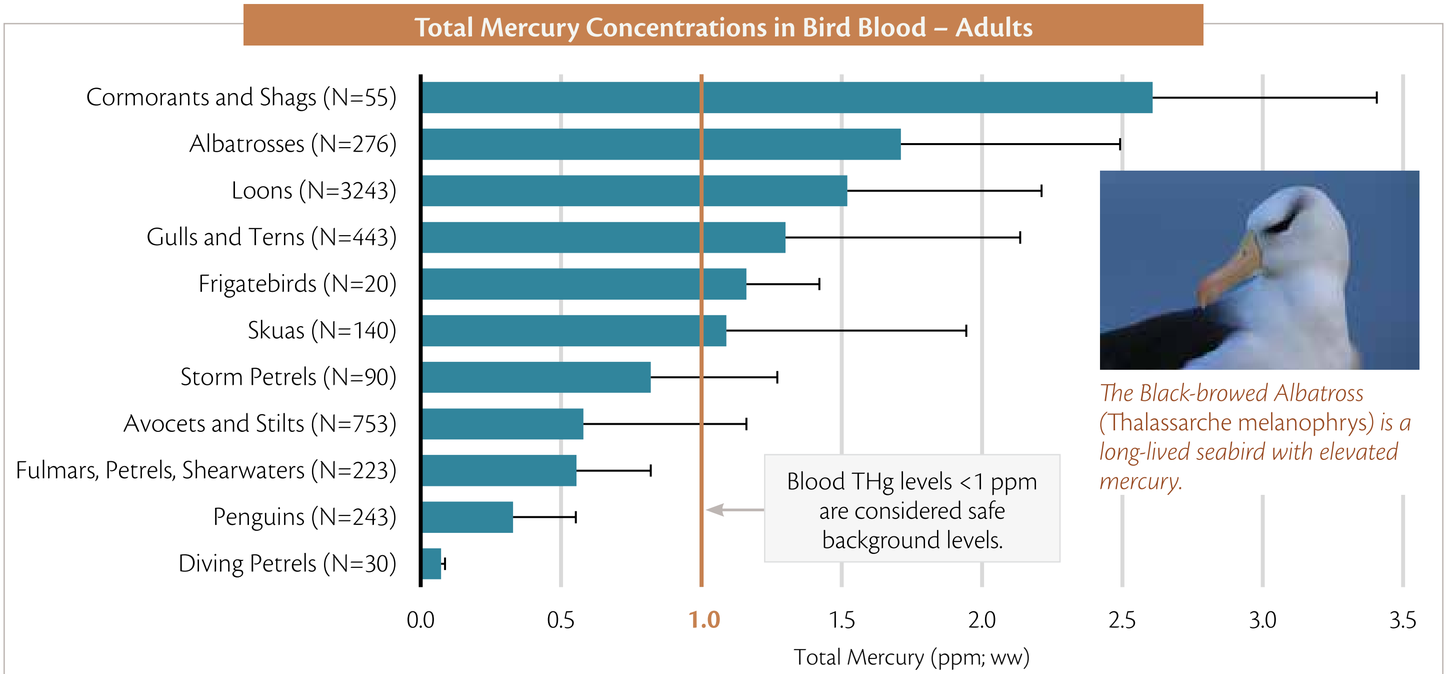
Yellow-billed Loons (Gavia adamsii) are long-lived, fish-eating birds that breed on the high tundra and are at high risk to mercury contaminations.

Birds are excellent bioindicators for measuring the availability of methylmercury in aquatic and terrestrial environments. Hundreds of studies from around the world have documented mercury body burdens in birds—using a combination of eggs, blood, and/or feathers. Importantly, the physiological, behavioral, and reproductive effects of methylmercury on birds viewed through these and other tissues can be confidently identified while using a scalable outcome, such as reproductive success. Mercury concentrations and associated toxicity thresholds vary by species, particularly among foraging guilds (e.g., piscivores versus invertivores).

Piscivores, or fish-eating birds, can regularly have elevated mercury levels from foraging in freshwater, brackish, and marine ecosystems. Within the GBMS database there are 46,572 individuals measured for mercury in 45 countries based on 294 peer-reviewed papers (mercury data compilation to date has emphasized piscivores). Bird families with average blood mercury concentrations > 1.0 ppm (below of which is relatively safe) include Phalacrocoracidae (cormorants), Diomedeidae (albatrosses), Gaviidae (loons or divers), Laridae (gulls and terns), Fregatidae (frigatebirds), and Stercorarius (skuas; Figure 17).

Across the world's freshwater and brackish ecosystems, gulls and terns are broadly used for determining environment mercury loads. Conversely, other fish-eating birds that have elevated blood mercury levels, such as cormorants, frigatebirds, and skuas, are less likely to be used for biomonitoring purposes. Finally, while the data are not shown, the Osprey, an obligate fish-eating raptor, has a wide distribution and is one of the few species that can be used as a global standard.

The Saltmarsh Sparrow (Ammodramus caudacutus), an invertivore or invertebrate-eating songbird, lives in estuaries along the North Atlantic and often has elevated mercury body burdens. Songbirds are often at higher risk to mercury than associated and larger fish-eating birds because they occupy upper levels in the food web.



The Black-browed Albatross (Thalassarche melanophrys) is a long-lived seabird with elevated mercury.

Figure 17. Average (+/- SD; N=sample size) adult blood mercury concentrations (ppm, ww) for eleven selected bird families.

Marine Mammals

Bowhead whales (Balaena mysticetus) are regularly harvested by Native peoples in Alaska and Russia for food and contain very low levels of mercury in their bodies.

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. Research suggests that mercury emissions originating at lower latitudes are regularly transported to and deposited in 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 as well as 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. Because human communities within the Arctic Ocean can depend greatly on marine mammals, mercury concentrations in those mammals are of special concern.

Beluga whales, narwhals, and pilot whales 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; Figure 18). The effect thresholds for marine mammals are poorly understood, but based on effect thresholds for terrestrial mammals, mercury exposure could be having significant adverse impacts on the reproductive success of marine mammals.

Mercury in the Global Environment: Marine Mammals

From the Antarctic to the Arctic, marine mammals move across great expanses of water. These animals are adversely affected by mercury pollution accumulating in the world's oceans. This BRI publication helps illustrate the impacts of methylmercury biomagnification (increasing toxicity as the toxin moves up the foodweb) and bioaccumulation on marine mammals, with an emphasis on Arctic ecosystems. To download this and other BRI publications, visit: **www.briloon.org/hgpubs**.

FAO Harvest and Total Mercury Concentrations in Muscle Tissue of Marine Mammals

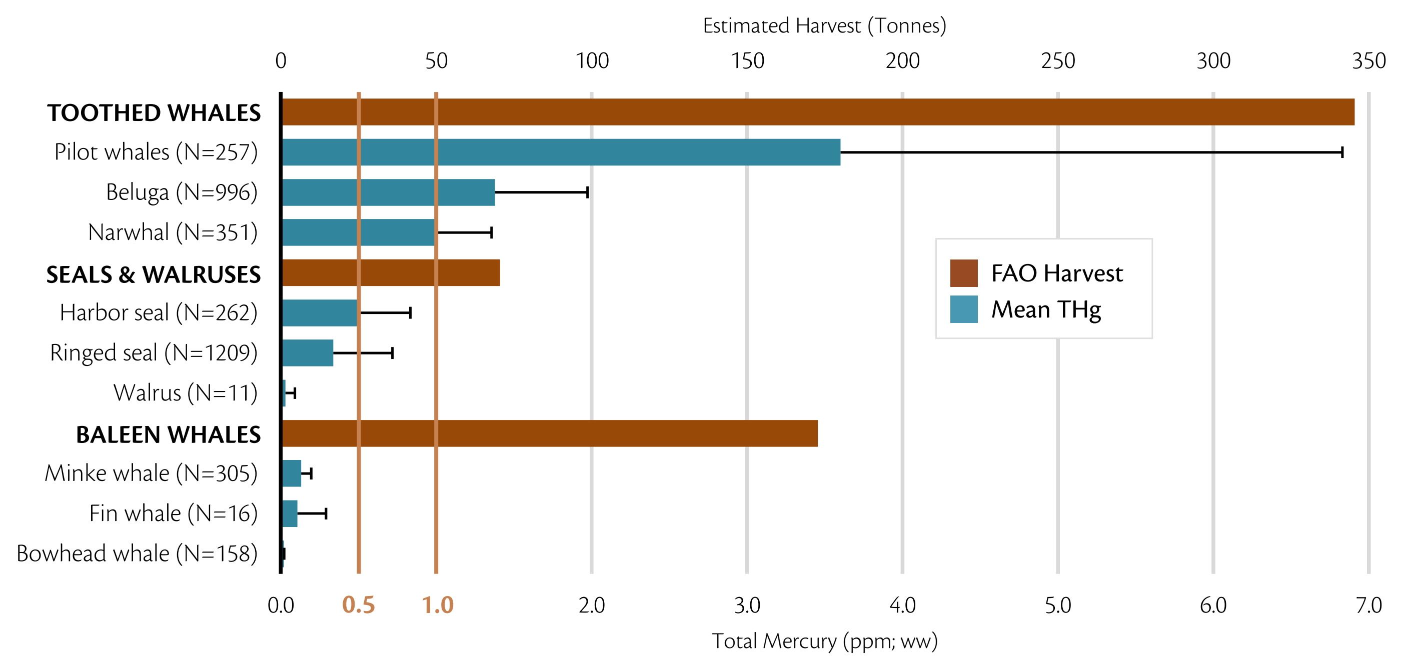


Figure 18. Average (+/− SD; N=sample size) THg concentration in muscle tissue of nine marine mammal species compared to the 2013 FAO harvest estimate in tonnes, divided by sub-order. See Table 2 (page 10) for mercury consumption guidelines.

Evaluating the Effectiveness of the Minatama Convention

Scientific Research Informs Policy

BRI was a participant in five of the meetings of the Intergovernmental Negotiating Committee (INC) that preceded the adoption of the Minamata Convention. With the Convention now in force, BRI continues to participate and is contributing to its implementation in a number of ways.

As co-lead of UN Environment's Mercury Air Transport and Fate Research Partnership Area, BRI is assisting the UN agencies and delegates with project ideas and their implementation, including developing a biomonitoring toolkit (Figure 19). BRI scientists lead a global team of experts to develop a chapter about mercury in biota for the 2018 Global Mercury Assessment. In addition, BRI is a member of the Artisanal and Small-scale Gold Mining Partnership Area.

Helping Countries Prepare for Ratification and Implementation

The INC and the Global Environmental Facility have developed a series of pre-ratification activities, Minamata Initial Assessments (MIAs), that are designed to prepare countries for ratification and early implementation of the Convention. BRI currently serves as an executing agency for and/or provides technical experts to more than 30 countries for MIA activities.

Collaboration with UN Agencies

BRI is assisting three UN agencies to implement MIA activities around the world as: (1) an Executing Agency with UNIDO; (2) an International Technical Expert with UNDP; and (3) an International Technical Expert with UN Environment.

BRI also helps with the implementation of the Convention by identifying goals for countries through targeted metrics and associated time periods (Table 3; Evers et al. 2016).

Global Mercury Assessment

BRI's GBMS database is a collection of mercury exposure data in biota that are published in peer-reviewed journals. GBMS now serves as the basis for understanding spatiotemporal patterns of exposure and risk for AMAP's and UN Environment's ***Global Mercury Assessment–2018*** (AMAP/UN Environment In Press; UN Environment In Press). To learn more. visit:

www.briloon.org/hgcenter/gbms

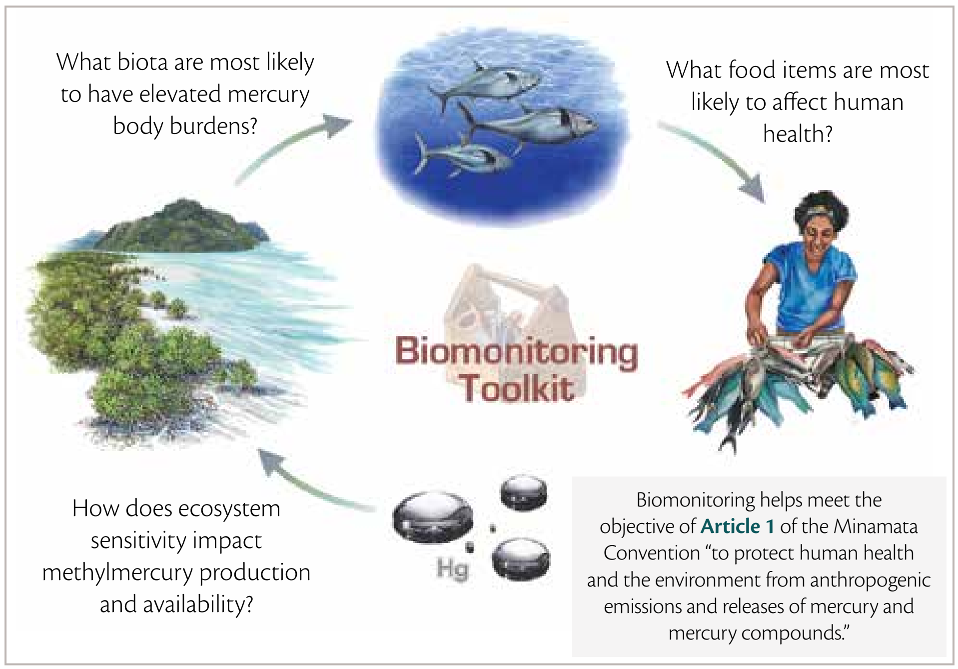


Figure 19. Biomonitoring Toolkit. Following the lead of UN Environment's template for the identification and quantification of mercury releases, this model provides quantitative information on biota.

Table 3. A provisional slate of some potential bioindicators for evaluating and monitoring environmental mercury loads for ecological and human health purpose in four target biomes. The full text can be found at: www.unep.org/chemicalsandwaste/global-mercury-partnership/mercury-air-transport-and-fate-research/reports-and-publications

Terrestrial Biomes and Associated Aquatic Areas	Ecological Health Bioindicators			Human and Ecological Health Bioindicators		
	Freshwater Birds	*Marine Birds*	*Marine Mammals & Sea Turtles*	*Freshwater Fish*	*Marine Fish*	*Marine Mammals*
Arctic Tundra and Arctic Ocean	Loons	Fulmars, Murres	Polar Bears, Seals	Arctic Char, Arctic Grayling	Halibut, Cod	Beluga, Narwhal
Boreal Forest-Taiga and N. Pacific and Atlantic Ocean	Loons, Eagles, Osprey, Songbirds	Osprey, Petrels	Mink, Otter, Seals	Catfish, Pike, Walleye	Flounder, Snapper, Tuna	Pilot Whale
Temperate Mixed Forest and Pacific and Atlantic Ocean	Loons, Grebes, Egrets, Herons, Osprey, Terns, Songbirds	Cormorants, Osprey, Terns	Otter, Sea Turtles, Seals	Bass, Bream, Mullet, Walleye	Barracuda, Mackerel, Sharks,Tuna	
Tropical Rainforest and S. Pacific and Atlantic and Indian Ocean	Egrets, Herons, Kingfishers, Songbirds	Albatrosses, Frigatebirds, Noddy, Shearwaters, Terns, Tropicbirds	Otter, Sea Turtles, Seals	Catfish, Snakehead	Barracuda, Grouper, Sharks, Snapper, Swordfish, Tuna	

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About BRI's Center for Mercury Studies

BRI's mission is to assess emerging threats to wildlife and ecosystems through collaborative research, and to use scientific findings to advance environmental awareness and inform decision makers. BRI staff have worked on the topic of mercury in the environment for the past 29 years and endeavor to collect original field data, interpret their results in scientific outlets, and relay information to decision makers in an understandable format.

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