GLOBAL MERCURY MONITORING IN BIOTA

Executive Summary

Understanding the threat of environmental mercury loads requires biotic monitoring

Environmental concentrations of mercury (Hg) have increased three-fold globally due to human industrial activities. This inorganic mercury enters ecosystems through the air (e.g., from coal-fired power plants and incinerators), water (e.g., from chlor-alkali facilities and artisanal small-scale gold mining), and land (e.g., from landfills and other contaminated sites).

The world's freshwater ecosystems, estuaries and oceans are primary reservoirs where mercury is deposited. Once in the environment, mercury can be converted by bacteria and other microbes to its organic form, or methylmercury. Methylmercury is toxic, and can accumulate in the tissues of fish, wildlife, and humans, causing numerous negative health effects.

Human exposure to mercury

People are commonly exposed to methylmercury through the consumption of fish, and some birds and marine mammals. However, there are gaps in our understanding about the relationship between anthropogenic releases of mercury and its subsequent bioaccumulation and biomagnification in freshwater and marine food webs, and how that may translate to exposure and risk at the local, regional, and global scale to fish, wildlife, and humans.

Why is it important to monitor mercury in biota?

Monitoring mercury in biota (plants and animals) provides a pathway for understanding spatial gradients, temporal trends, and environmental magnitude of concern that cannot be ascertained in air, water, or sediment. Emphasizing upper trophic level biota for monitoring (i.e., trophic level 4 or higher) ultimately provides a confident ability to assess whether the global input of anthropogenic mercury into the environment is safe

PROPOSED 3-STEP OVERARCHING FRAMEWORK FOR MONITORING MERCURY IN BIOTA ACROSS CONTINENTS AND OCEANS.

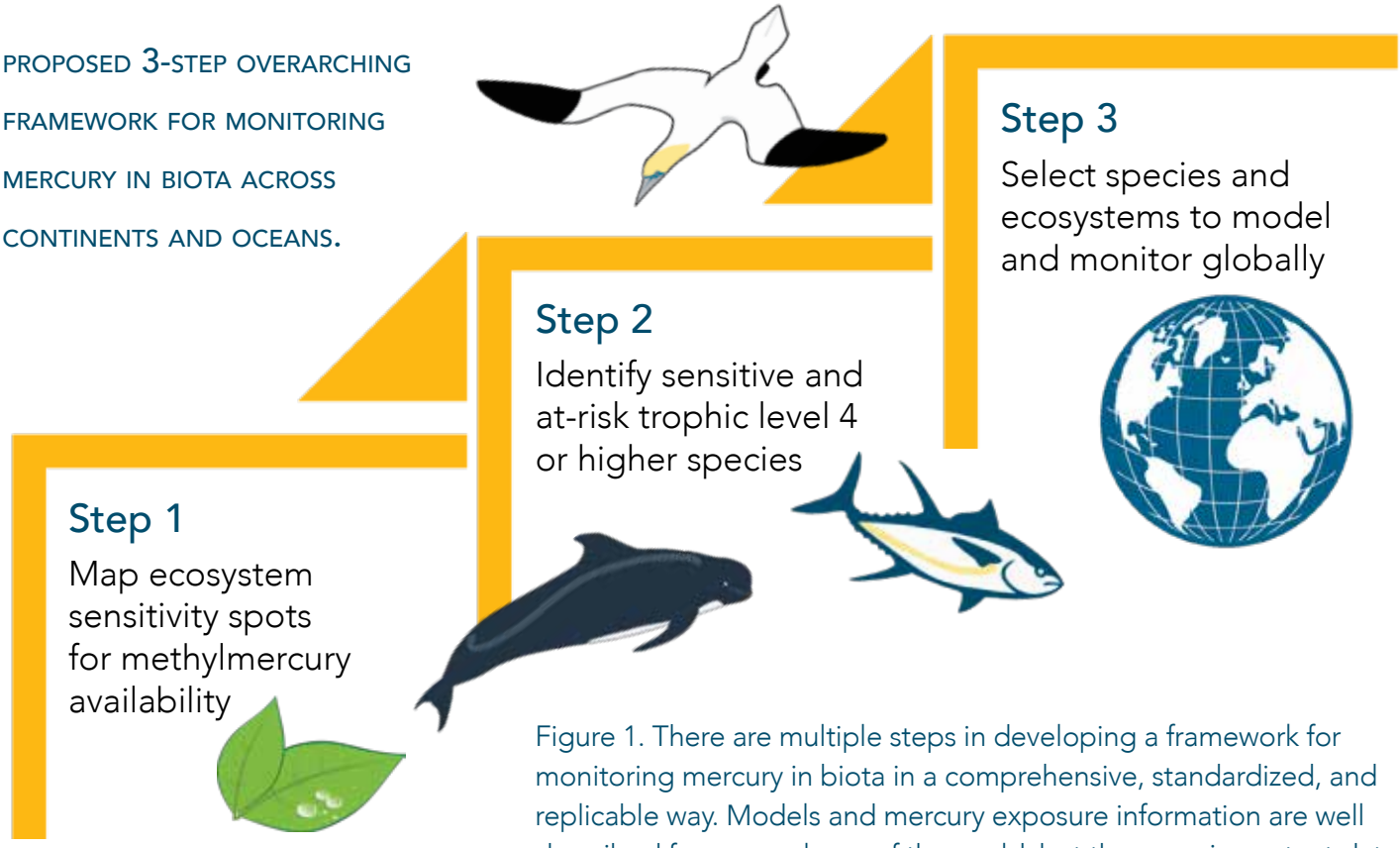


Figure 1. There are multiple steps in developing a framework for monitoring mercury in biota in a comprehensive, standardized, and replicable way. Models and mercury exposure information are well described for many places of the world, but there are important data gaps that still need to be defined, prioritized and filled.

or harmful to fish, wildlife and humans. Because mercury methylation greatly varies according to many environmental factors, identifying ecosystem sensitivity spots is critical for attaining resource efficiencies—i.e., low cost, high reward information in a timely way (Figure 1).

To best track global and regional biotic mercury exposure over time and space, we need to synthesize existing information with new data in a structured and strategic way. Global models will be critical for understanding current needs and prioritizing future patterns.

The dual approach presented here suggests conducting biotic mercury monitoring across continents and ocean basins using representative bioindicators. This information can then confidently provide information for decision makers to assess the effectiveness of the Minamata Convention on Mercury at both regional and global spatial levels at temporal scales of interest (Figure 1).

Ecosystem sensitivity to mercury

The extent to which mercury is methylated and made available in the environment is complex and can be influenced by many factors. Specific ecological conditions can facilitate the production and bioavailability of methylmercury. For example, bacteria often produce more methylmercury under moderate amounts of sulphate, low oxygen conditions, and low pH habitats; these conditions are especially prevalent in wetland ecosystems.

Identifying appropriate bioindicators

The complexity of mercury cycling makes it challenging to predict exposure levels in upper trophic level fish and wildlife from environmental mercury concentrations alone. Therefore, identifying appropriate bioindicators based on their relationship with sensitive ecosystems is a critical first step in assessing risk to ecological and human health.Trophic level 4 or higher biota are best and include focal species such as tuna and billfish.

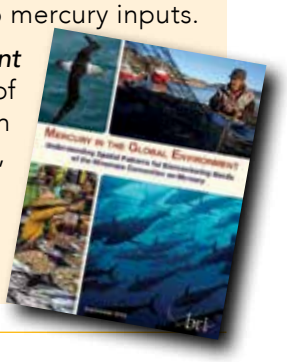
Global Biotic Mercury Synthesis Database

Biodiversity Research Institute (BRI) has compiled mercury data from peer-reviewed published literature into a single database, the Global Biotic Mercury Synthesis (GBMS).

Data from the GBMS database can be used to understand spatial and temporal patterns of mercury concentrations in biota (Figure 2). This information can also help establish baseline concentrations for focal taxa and identify ecosystems most at risk to mercury inputs.

BRI's report ***Mercury in the Global Environment*** presents data on mercury concentrations in biota of concern in Article 19 of the Minamata Convention on Mercury (i.e., marine and freshwater fish, sea turtles, birds and marine mammals), which are extracted from the GBMS database.

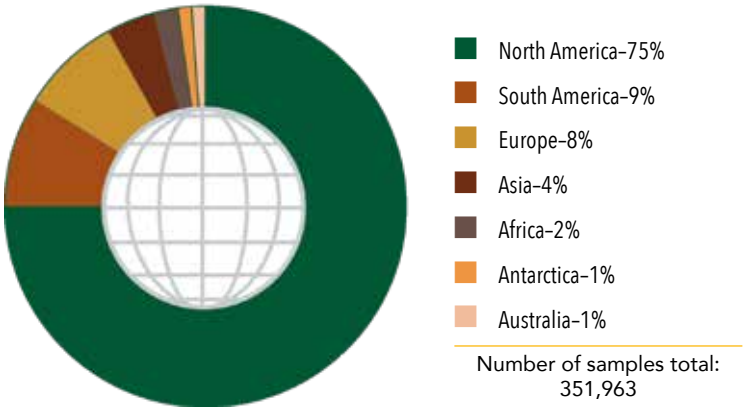
To download, go to: **www.briloon.org/hgpubs**



Continental Samples

Summary of published mercury concentrations in focal taxa across continents as summarized by the GBMS database.

(a)



Oceanic Samples

Summary of published mercury concentrations in focal taxa across major ocean basins as summarized by the GBMS database.

(b)

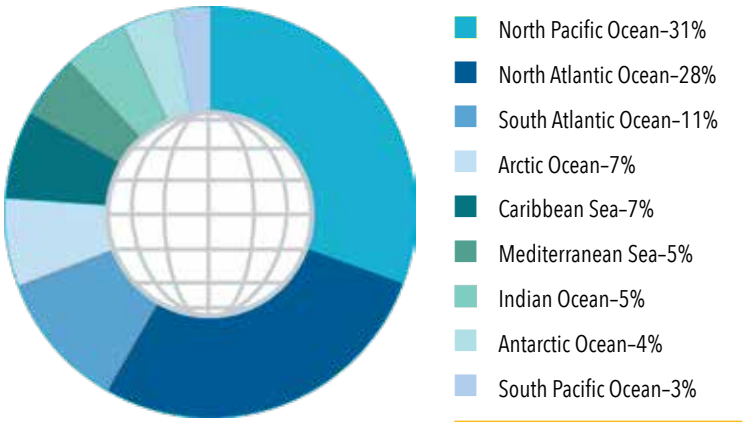


Figure 2. Number of biotic mercury concentrations for (a) continental areas and (b) oceanic areas.

Monitoring Mercury in Biota across the Globe

Approximate Existing Coverage of Mercury Data

The level of existing Hg data varies globally. A suggested approach for monitoring Hg globally could use stepwise frameworks and would vary in the need for field sampling by continents (Figure 3) and oceans (Figure 4). Potential monitoring locations can be based on ecosystem sensitivity, location of major Hg sources, e.g., artisanal small-scale gold mining (ASGM), and human/ecological health concerns.

This map depicts an exercise to identify potential sampling locations by continent (shown by colored dots) and by ocean basin (shown by colored fish icons) when existing coverage is less than 50%.

Existing Coverage

- < 10%
- < 20%
- < 10%
- < 20%
- < 50%
- > 80%
- < 50%
- > 80%

North America:
> 80% existing coverage–
10 sites still to be selected

PROPOSED 3-STEP OVERARCHING FRAMEWORK FOR MONITORING MERCURY IN BIOTA ACROSS **OCEANS**

Step 1

a. Identify distinctions among ocean basins of interest
b. Collect FAO commercial fisheries data

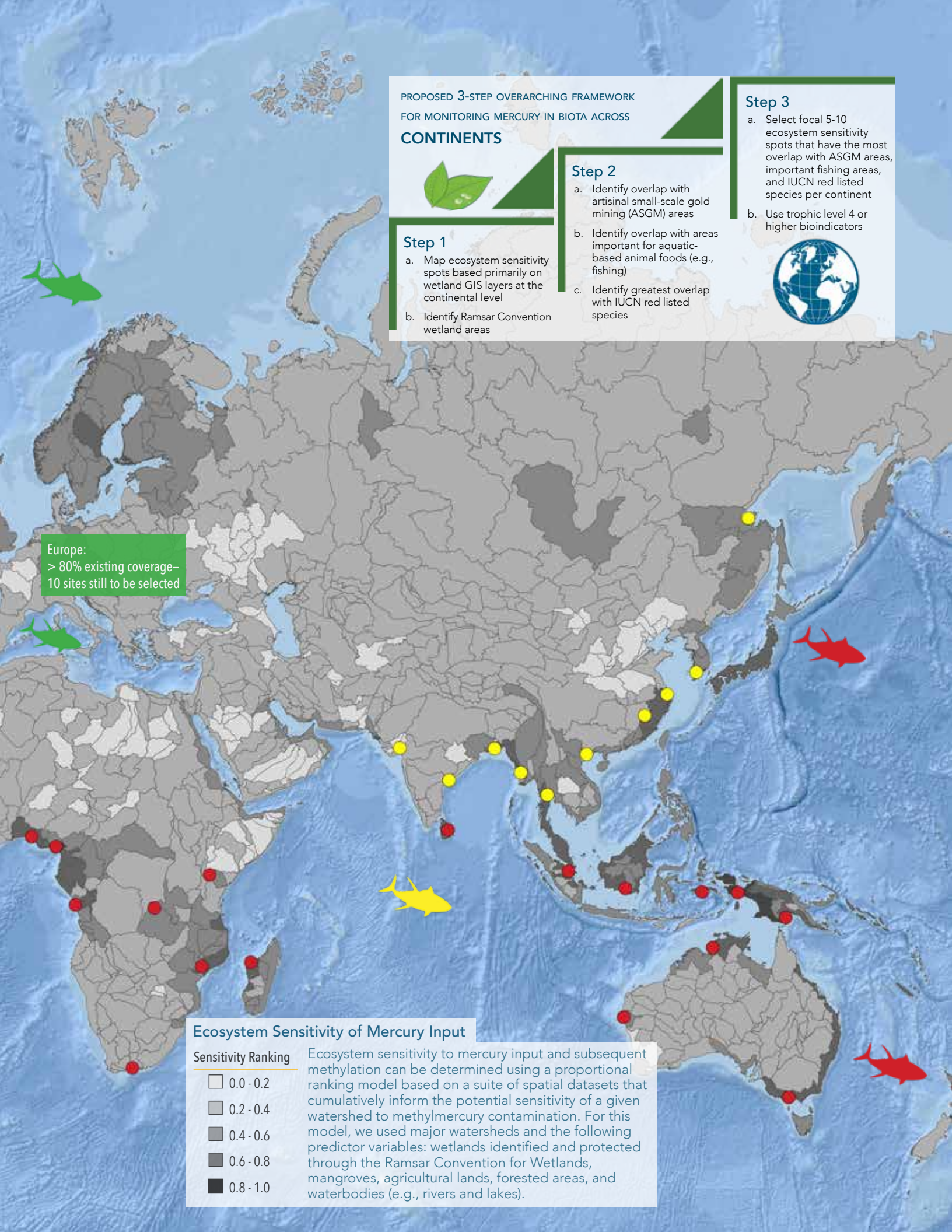
Step 2

a. Identify tuna and billfish trophic level 4 or higher species of greatest commercial and recreational concern by ocean basin
b. Identify tuna, billfish and other species that reflect temporal trends and spatial gradients

Step 3

a. Select focal trophic level 4 or higher species per ocean basin
b. Conduct a power analyses based on the species/groups selected and their known mercury concentrations within that ocean basin to determine sample size

0 1,000 2,000 km


PROPOSED 3-STEP OVERARCHING FRAMEWORK
FOR MONITORING MERCURY IN BIOTA ACROSS
CONTINENTS
Step 1
a. Map ecosystem sensitivity spots based primarily on wetland GIS layers at the continental level
b. Identify Ramsar Convention wetland areas
Step 2
a. Identify overlap with artisinal small-scale gold mining (ASGM) areas
b. Identify overlap with areas important for aquatic-based animal foods (e.g., fishing)
c. Identify greatest overlap with IUCN red listed species
Step 3
a. Select focal 5-10 ecosystem sensitivity spots that have the most overlap with ASGM areas, important fishing areas, and IUCN red listed species per continent
b. Use trophic level 4 or higher bioindicators
Europe:
> 80% existing coverage–
10 sites still to be selected
Ecosystem Sensitivity of Mercury Input
Sensitivity Ranking
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
Ecosystem sensitivity to mercury input and subsequent methylation can be determined using a proportional ranking model based on a suite of spatial datasets that cumulatively inform the potential sensitivity of a given watershed to methylmercury contamination. For this model, we used major watersheds and the following predictor variables: wetlands identified and protected through the Ramsar Convention for Wetlands, mangroves, agricultural lands, forested areas, and waterbodies (e.g., rivers and lakes).

Proposed Biomonitoring Frameworks

Two overarching biotic mercury monitoring approaches differ for continents and oceans.

Continental framework

To choose locations for global mercury monitoring requires multiple defined steps.

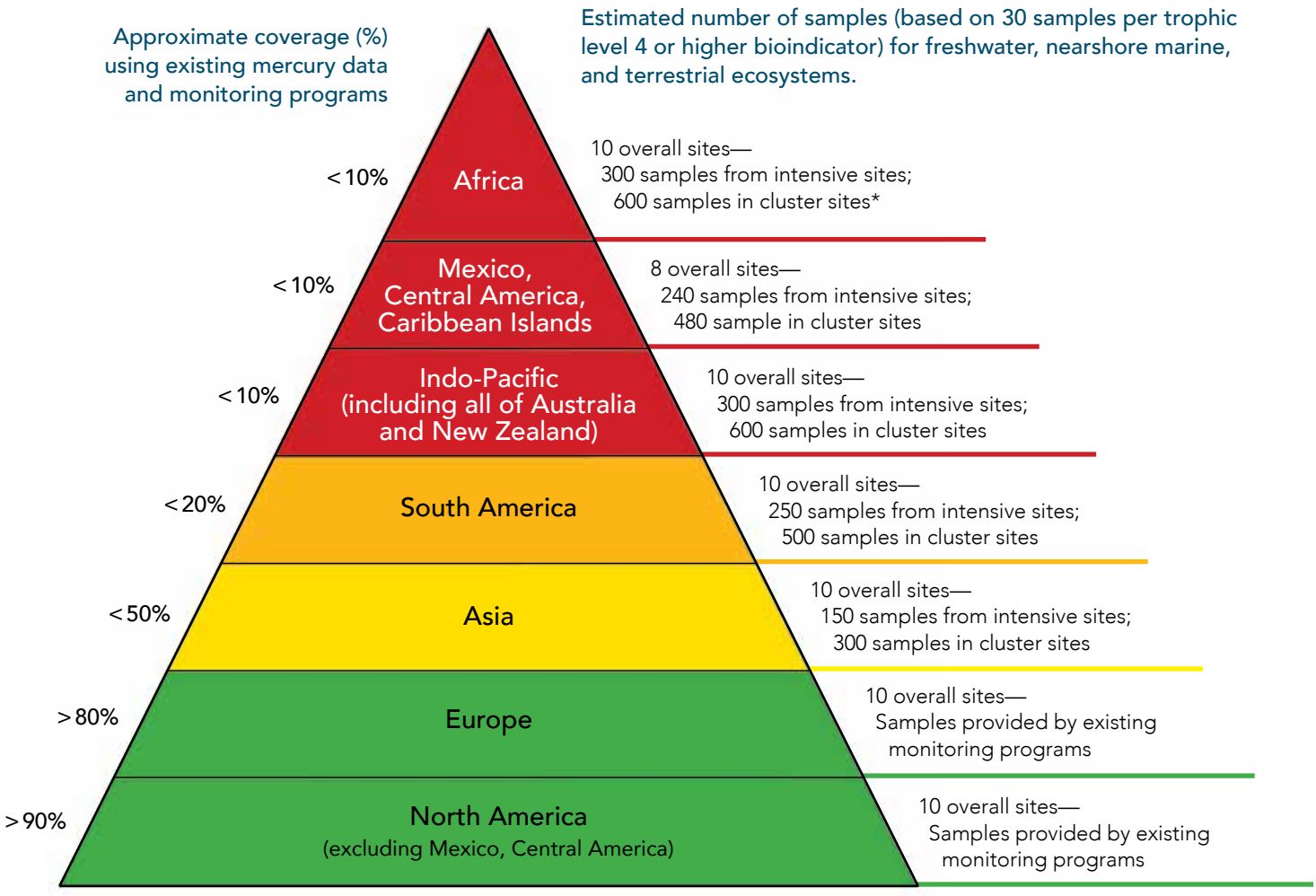
Step 1: Understand the complexities of a landscape and its ability to methylate mercury and make it available in the food web. Mercury methylation is highest in wetlands—and, potentially greatest in estuarine wetlands such as mangroves. Forested areas are also an important factor for higher methylation rates, while agricultural areas tend to dampen methylation rates.

Step 2: Identification and potential overlap with ecosystem sensitivity areas of three important elements that will help prioritize areas of greatest concern for protecting human health and the environment: (1) the mapping of artisanal small-scale gold mining (ASGM) sites—the top mercury source in the world; (2) ecosystem sensitivity areas that overlap with locations important for harvesting animals for human consumption—generally fish, but can include turtles, crocodiles, birds, and mammals; and (3) the need and ability to protect ecosystems and species at greatest risk.

Step 3: The selection of 5-10 areas in each continent quantitatively defined as areas that are most sensitive to the methylation of mercury released or deposited.

CONTINENTAL Sampling Framework for Integrated Mercury Monitoring

Figure 3. Sampling strategy for trophic level 4 or higher biota for the Continental Sampling Framework. Listed are the number of intensive sites (with a sample size of 30 at each site); each which should include another three cluster sites (with a sample size of 20 at each site) to account for local variability.



* See Technical Information Report for full explanation of intensive sites and cluster sites.

Oceanic framework

Due to wide variations in the cycling and movement of mercury throughout the world's oceans, the approach for monitoring mercury in oceanic areas greatly differs from the continental approach.

Step 1: Define distinctions among the ocean basin limits (and the number of ocean basins of interest), likely related to how the UN's Food and Agriculture Organization (FAO) defines commercial fishing areas.

Step 2: Determine species to monitor. Based on GBMS data, the species of highest mercury concern related to human consumption are tuna and billfish (e.g., swordfish, sailfish, and marlin species). The mercury concentrations in tuna vary greatly by species due to growth rates, size, age, trophic level, and ocean basin.

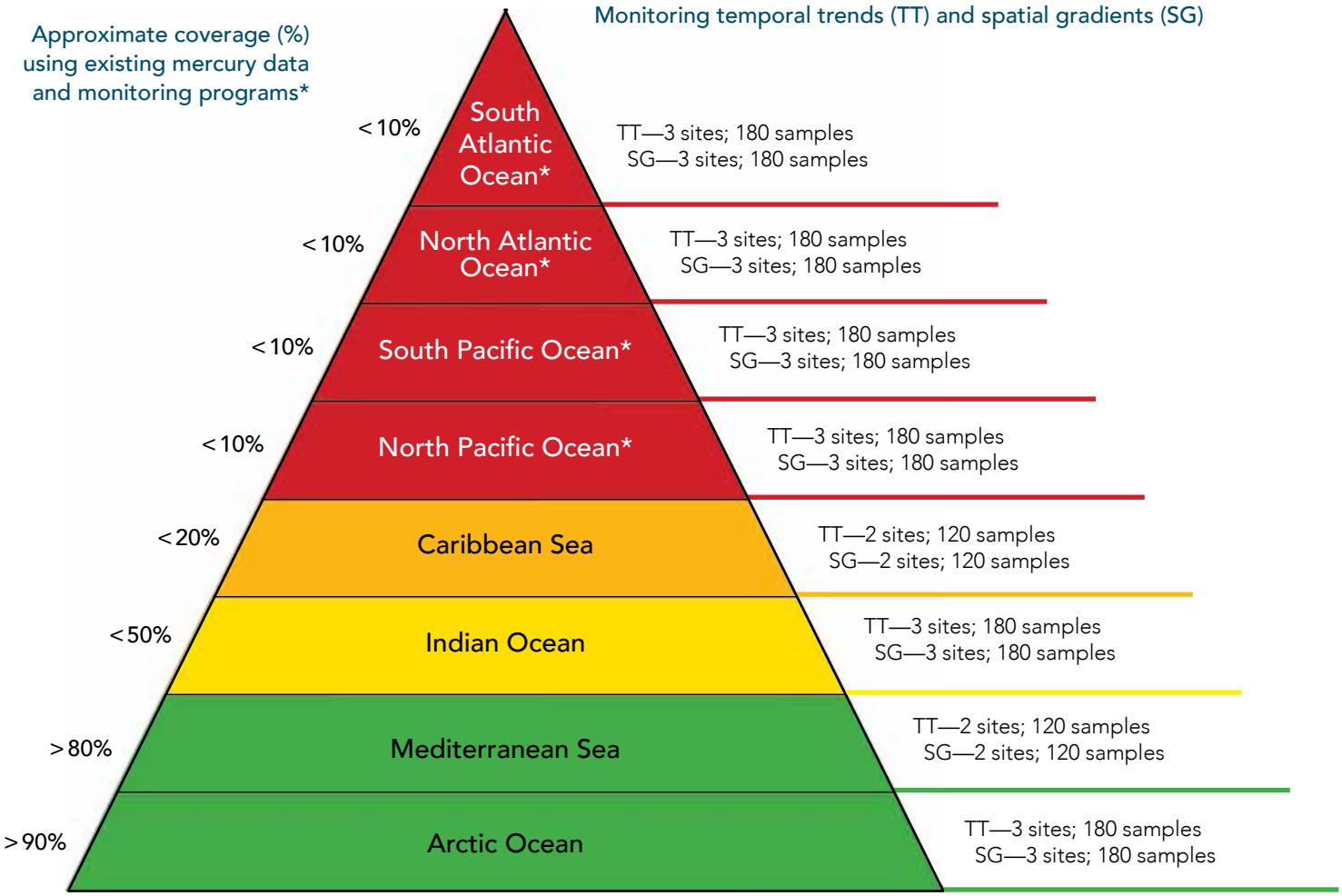
Step 3: Determine spatial gradients through similar species that have global ranges. For example, bluefin tuna (representing three sibling species) are found in the Atlantic, Indian, and Pacific Oceans, and the Mediterranean and Caribbean Seas.

Bluefin tuna tend to have some of the highest mercury concentrations, which can be compared across the world's temperate and tropical oceans. Billfish, in particular swordfish, are also relevant for comparisons across the world's oceans.

To best track mercury concentrations in trophic level 4 fish in the Arctic Ocean, Atlantic cod are the best species for regional comparisons.

OCEANIC Sampling Framework for Integrated Mercury Monitoring

Figure 4. Sampling strategy for trophic level 4 or greater biota for the Oceanic Sampling Framework. Listed are the number of sites (with an initial sample size of 30 fish at each site) for both objectives of monitoring temporal trends and spatial gradients of mercury.



* For Atlantic and Pacific Oceans: 100% coverage for sampling is considered to be already in place based on existing commercial fleets.

Modeling Capabilities

The compilation of existing biotic mercury data is an important approach to understand broad spatial gradients and temporal patterns. Models based on existing data and scientific findings are useful for extending observations in space and time (Figure 5).

Recent global modeling efforts show 49 percent of global Hg^{II} deposition occurs over the tropical oceans. The equatorial Pacific region is an essential commercial harvesting location for many large pelagic species such as tuna that are responsible for a large fraction of human exposure to methylmercury. Thus, linking elevated mercury deposition to methylmercury formation in the ocean and associated biological exposures is an important goal of ongoing research

Similarly, understanding the relationship between enhanced deposition of mercury in India and China, and other regions of intense coal use in Europe and the U.S., and biological concentrations in inland food webs is essential for linking changes in benefits from future emissions reductions to human and ecological exposures.

In freshwater ecosystems, a global meta-analysis suggests that mercury biomagnification through food webs is highest in cold and low productivity systems, however large contaminated sites (e.g., ASGM areas) are likely important drivers of variability in tropical freshwater biota concentrations.

One recent effort to characterize global aquatic mercury releases to inland ecosystems is therefore especially important for understanding the spatial distribution of these locations. Our understanding of how mercury released from ASGM and associated conversion to methylmercury, exposures, and impacts on human and ecological health is poor—and is now one of the more important data gaps to fill.

Established associated patterns of ASGM-derived mercury and other sources over time and space are critical to understand for developing biomonitoring activities in a time-efficient and cost-effective manner.

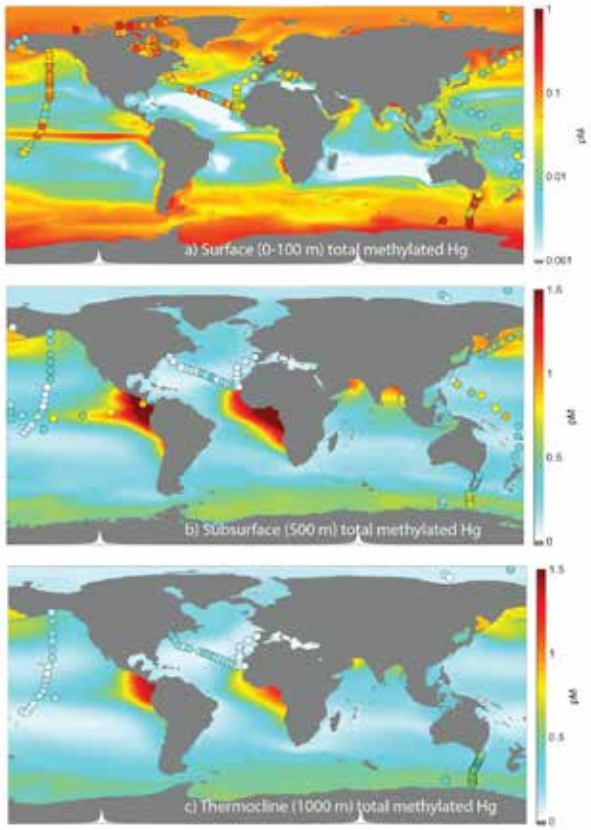


Figure 5. Example of simulated methylmercury concentrations in seawater. *Source: Evers and Sunderland 2019 (see Technical Information Report*)*

Technical Information Report on Mercury Monitoring in Biota

*Download a copy (with a complete list of scientific references) at:

www.unenvironment.org/node/26343

or **www.briloon.org/hgpubs**

This Technical Information Report is a proposal for monitoring mercury in biota for the ad hoc technical expert group for effectiveness evaluation. For more information on the work of this technical expert group, visit:

www.mercuryconvention.org/Meetings/Intersessionalwork/Effectivenessevaluation/tabid/8091/language/en-US/Default.aspx

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