Mercury in the Global Environment:

Impacts to BIODIVERSITY?

Mercury Special Issue | Ecotoxicology 2024

About this Publication

To inform policy efforts and advance public awareness, an international group of scientists collaborated on producing 18 peer-reviewed papers that describe the impacts of mercury on the enviroment and key biota—information vital for evaluating the effectiveness of the Minamata Convention on Mercury. These papers, published in two parts, are collected in a Special Issue of ***Ecotoxicology*** entitled ***Assessing Global Environmental Mercury Exposure in Biota and Potential Impacts on Biodiversity***. This publication, ***Mercury in the Global Environment: Impacts to Biodiversity?,*** highlights the major findings of those studies and collaborative efforts.

Journal numbering system within this publication

Study No. 1 — Reference to each study published in Volume 32, Issue 8 is identified throughout this booklet with this green icon.

Study No. 1 — Reference to each study published in Volume 33, Issues 4-5 is identified throughout this booklet with this rust icon.

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About Biodiversity Research Institute

Biodiversity Research Institute (BRI), headquartered in Portland, Maine, is a nonprofit ecological research group whose 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.

Through its Center for Mercury Studies, BRI oversees several ongoing national and international mercury monitoring networks and database summary efforts for the United Nations Environment Programme and other UN agencies. BRI's executive director David Evers is the co-lead for the Fate and Transport Global Mercury Partnership Group of the Minamata Convention on Mercury and a member of its Open-ended Science Group (OESG).

Acknowledgments

We gratefully acknowledge Terry Keating, Ph.D., senior scientist at the U.S. Environmental Protection Agency (USEPA), and Simon Wilson, Ph.D., Secretariat of the Arctic Monitoring and Assessment Programme (AMAP) for their generous contributions to this publication.

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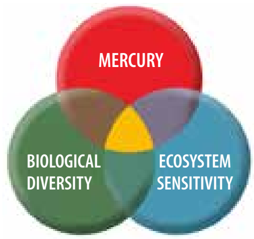
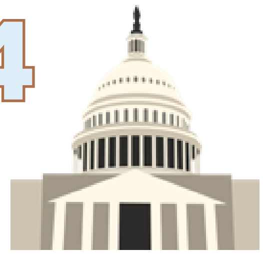
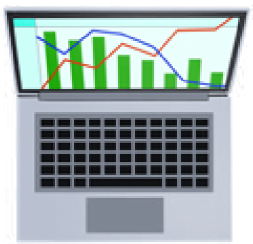
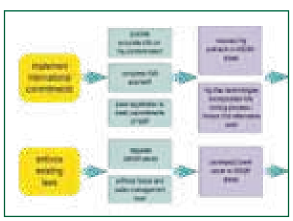


MERCURY
BIOLOGICAL DIVERSITY
ECOSYSTEM SENSITIVITY







WATERBIRDS
Ecotoxicology

CONNECTIONS

Biodiversity—more than just the number of species that exist—encompasses the rich diversity of ecosystems, the diversity within and between species, and the interactions that occur between species within ecosystems.

Recognizing the Connections

A plethora of scientific studies are revealing and confirming the interconnectedness and complexities of the variety of life on Earth. The loss of biodiversity threatens our food supplies, opportunities for recreation and tourism, and sources of wood, medicines, and energy. It also interferes with essential ecological functions. The underlying causes of biodiversity loss are often complex and stem from many interrelated factors such as habitat loss, development, overfishing, invasive species, industrial activities, and pollution.

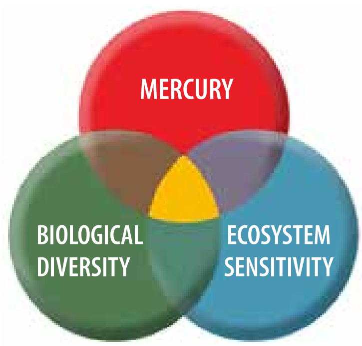


Figure 1. This diagram shows the interconnectedness of ecosystem sensitivity, mercury exposure, and biological diversity. The nexus of these three factors is of greatest concern where mercury may be playing a role in biodiversity loss.

Mercury Contamination: A Global Analysis

Understanding the biotic response to methylmercury availability in the environment for all biomes and key biota is vital for evaluating the effectiveness of the Minamata Convention on Mercury and enhancing its contribution to broader environmental goals, including biodiversity conservation.

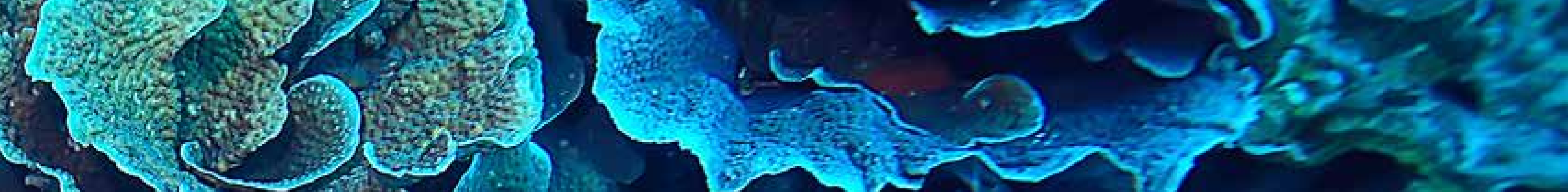
A comprehensive global analysis of spatiotemporal patterns of mercury exposure and effect to biota requires obtaining and synthesizing critical information from known as well as remote and/or poorly documented areas.

As part of this investigative synthesis, an international group of scientists collaborated on producing nearly 20 papers that document environmental mercury loads geographically by major biomes (Arctic, Temperate, and Tropical) and their associated freshwater and marine waters, as well as for major taxa (elasmobranch and teleost fish, reptiles, birds, and mammals).

These papers are published as a Special Issue of Ecotoxicology as a collection. The papers focus on: (1) mercury concentrations in biota around the world; (2) relationships of mercury with biological diversity; (3) mapping ecosystem sensitivity and mercury inputs to understand cumulative threat; and (4) evaluating integrated policy impact pathways for artisanal small-scale gold mining.

Major Findings

- The availability of methylmercury is of concern globally - for every continent and across all oceans and for many lakes and rivers.
- Based on over 2,000 references, mercury body burdens are elevated across all major groups of biota—for fish, reptiles, birds, and mammals.
- Many species of higher trophic level fish and wildlife are exposed to methylmercury concentrations that are of concern by reducing reproductive success and output.
- A meta-analysis demonstrates that over half of tuna, billfish and shark species and over half of the fish, seabird and marine mammal species are adversely impacted by environmental methylmercury loads.
- Because of the large number of individuals, populations, species, and families of biota adversely impacted by methylmercury, biological diversity is likely significantly negatively impacted.
- Models are now available to identify locations in the world where the most sensitive ecosystems overlap with important biodiversity areas. Within those overlap zones, species of greatest concern that are at the highest trophic levels can be identified.
- Spatial analyses of ecosystem sensitivity and of high trophic level species that are regularly consumed by humans can also now be used to conveyed globally to indigenous communities.
- BRI's Global Biotic Mercury Synthesis (GBMS) dataset provides an important standardized and comprehensive platform for understanding mercury concentrations at spatial and temporal scales that are important for biomonitoring interests of Parties and the Minamata Convention (see pages 8-9).



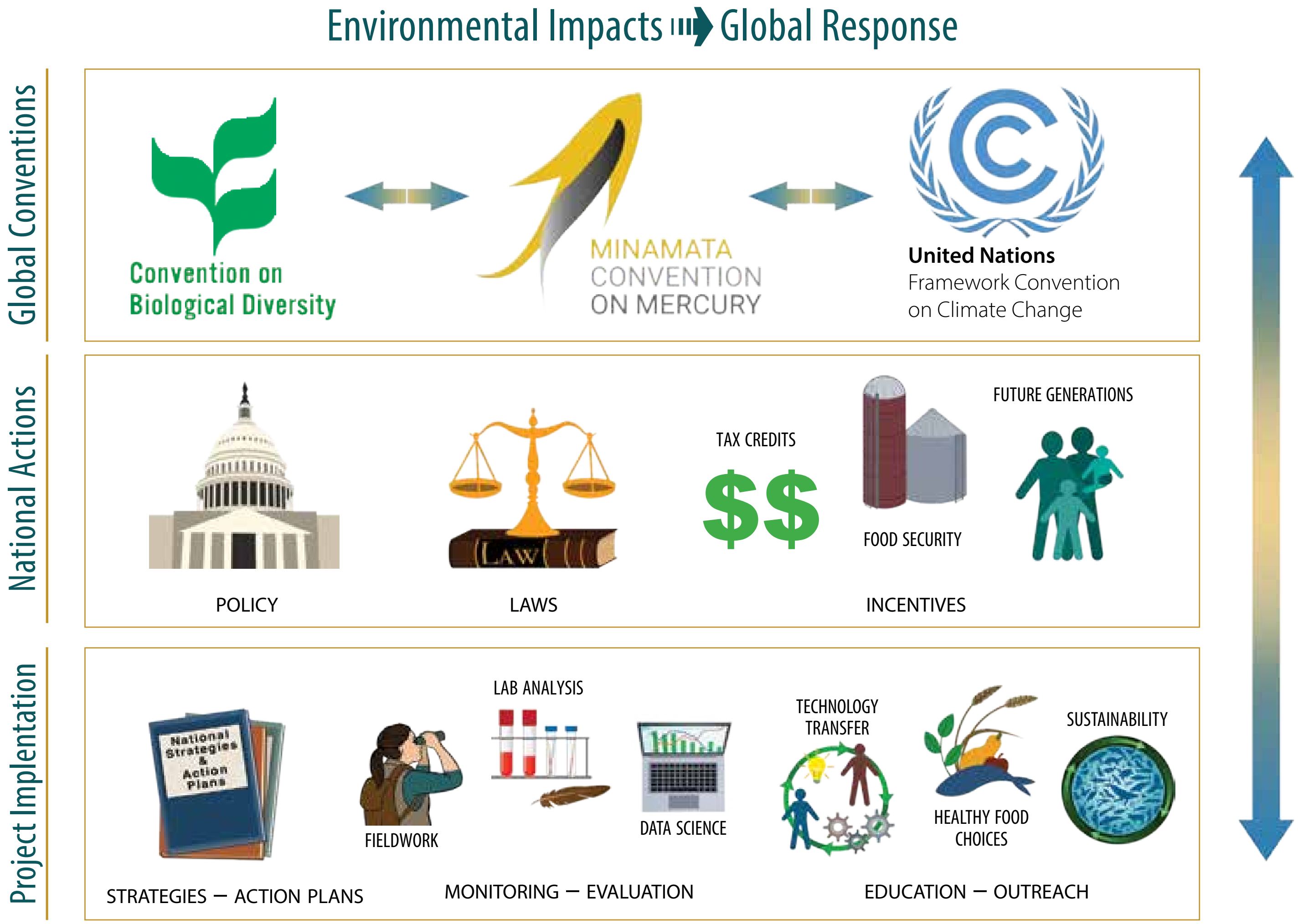


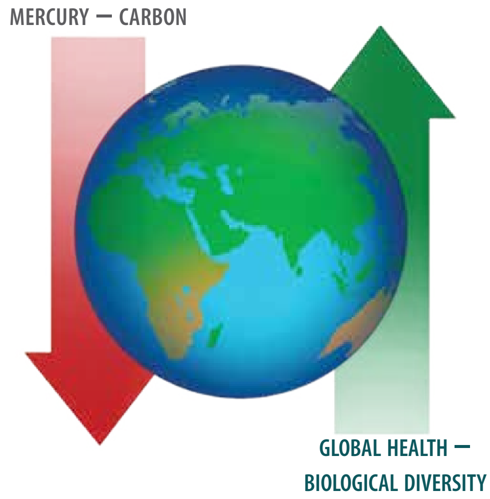
Figure 2. This diagram shows how a coordinated multilevel effort can help mitigate environmental threats.

A Global Response to Global Crises

Levels of mercury and carbon—both naturally occurring elements—are being released and remobilized by human activities at increasing rates. As a result, these levels far exceed their natural states of circulation, creating impacts that result in harm or damage to human and ecological health.

Each of these crises has been met by three global conventions: the Convention on Biological Diversity (CBD), the Minamata Convention on Mercury, and the Framework Convention on Climate Change. A clear challenge is to better coordinate these global efforts to have greater impact addressing these threats to people and nature.

These conventions share the commitment of the Parties to organize national level actions and associated incentives to support related national and international policies and regulations. In support of these efforts, the Global Environment Facility (GEF) manages and allocates funds to advance action plans, monitor activities, and raise awareness.



If the Conventions are successful, global levels of redistributed mercury will decline, carbon emissions will decline, and more carbon emissions will be sequestered. If the reduction of these two direct threats to biodiversity is enough, the hope and goal is that global health will be enhanced and avert the biodiversity crisis.

Use of Mercury Data, Monitoring Needs for the Minamata Convention and Relationships with the Global Biodiversity Framework

In the quest to conserve life on earth, many global environmental conventions have been initiated. As the threat of climate change continues to increase, a noticeable gap has emerged—the integration of these global conventions to achieve more than any single convention can on its own.

The Need to Integrate Information

The Minamata Convention on Mercury made a clear decision at COP-4 in March 2022 to work collaboratively with the Convention for Biological Diversity. The development of the Global Biodiversity Framework and the identification of Target 7 to reduce the threat of pollution creates a distinct area of overlap between the two conventions.

A major question remains—how to make this happen?

One major step towards integration can and must be the effective and efficient sharing of information to improve impact and policy effectiveness assessments. For example, the United Nation Environment Programme (UNEP) World Environment Situation Room maintains information on biodiversity and threats.

Global Mercury Inventories

UNEP has also been working with BRI to develop a database of mercury inventory toolkits and to create a mercury dashboard (Figure 3) to capture the latest information on the sources of mercury contamination in countries. This information is generated via Minamata Initial Assessments (MIAs) as part of each country's commitment to participating in the Minamata Convention. The dashboard aggregates national mercury inventories developed using UNEP's Toolkit for the identifications and quantification of mercury releases.

These comprehensive inventories are core activities for developing countries and countries with economies in transition to understand and identify the sources of mercury emissions and releases within their borders. The dashboard allows users to interactivity explore emerging patterns in mercury inputs and releases by region and sector and follow the pathways of the mercury cycle using a full life-cycle approach.

Effectiveness Evaluation

In order to assess the effectiveness of the global conventions, and the countries that participate in these conventions, a necessary next step is to develop better ways to integrate information on biodiversity, threats to biodiversity, and efforts to reduce these threats. In response toward the long-term need for evaluating the Convention's effectiveness in reducing global environmental mercury loads, the Minamata Convention is working with Parties and other stakeholders through an Open-ended Science Group (OESG) forum. These efforts help to pave the way for improved information sharing and knowledge flow.

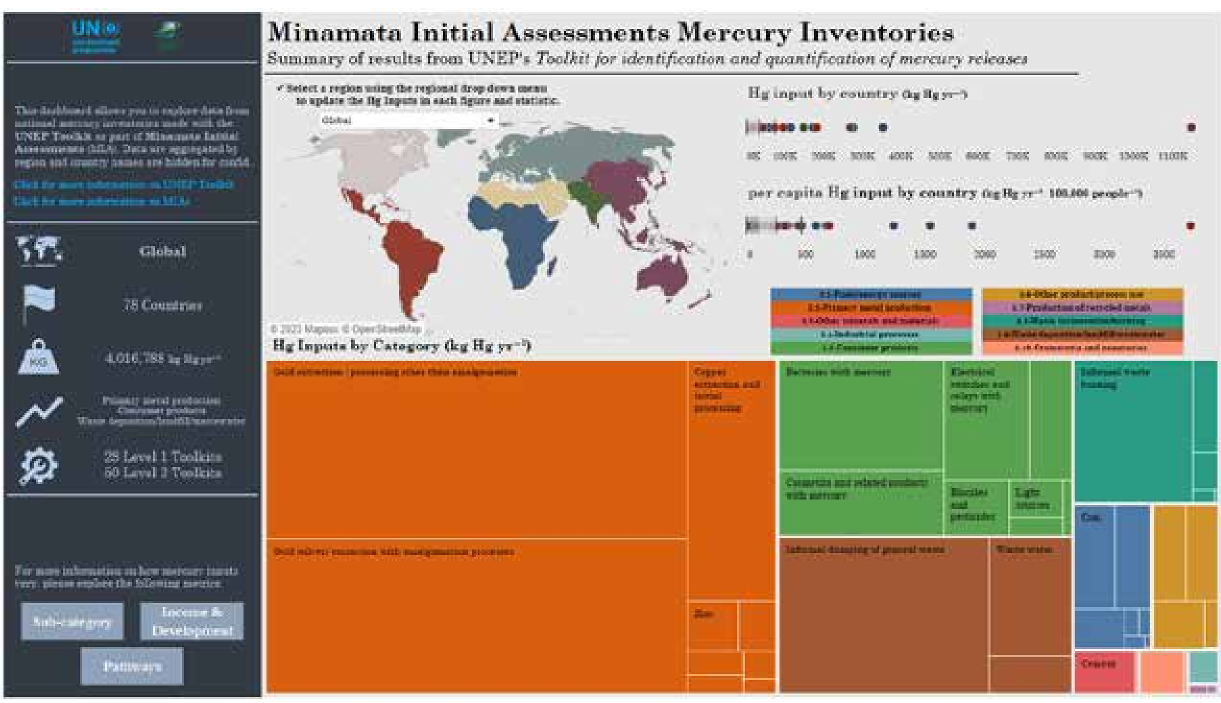


Figure 3. UNEP dashboard with recent information on mercury contamination generated by Minamata Initial Assessments undertaken by the Minamata Convention.

Open-ended Science Group for Effectiveness Evaluation

In accordance with Article 22, the Secretariat of the Minamata Convention has initiated an Open-ended Science Group (OESG) to support an evaluation of the Convention's effectiveness in meeting its objectives. Comprised of up to one representative from each Party as well as technical experts, this group will contribute, analyze, and synthesize data, both published and unpublished, pertaining to mercury emissions and releases and monitoring in air, wildlife, people, and other matrices. BRI is developing protocols to standardize and harmonize data originating from various sources so that the information is presented in a clear and accessible format.

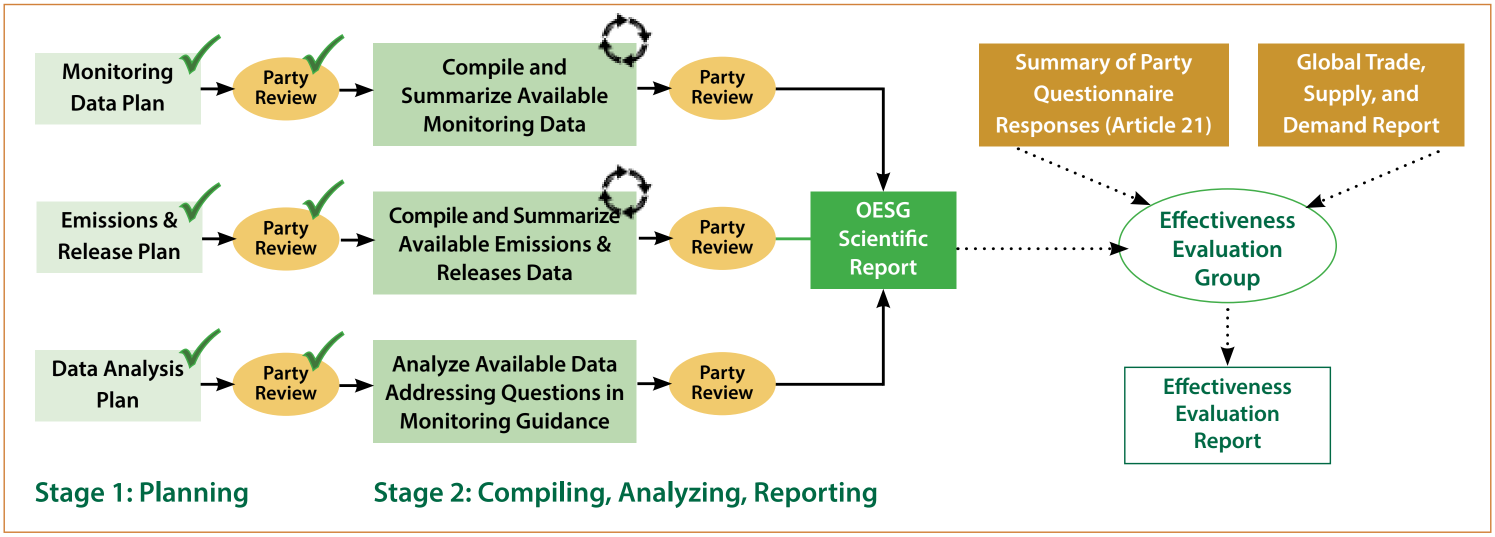
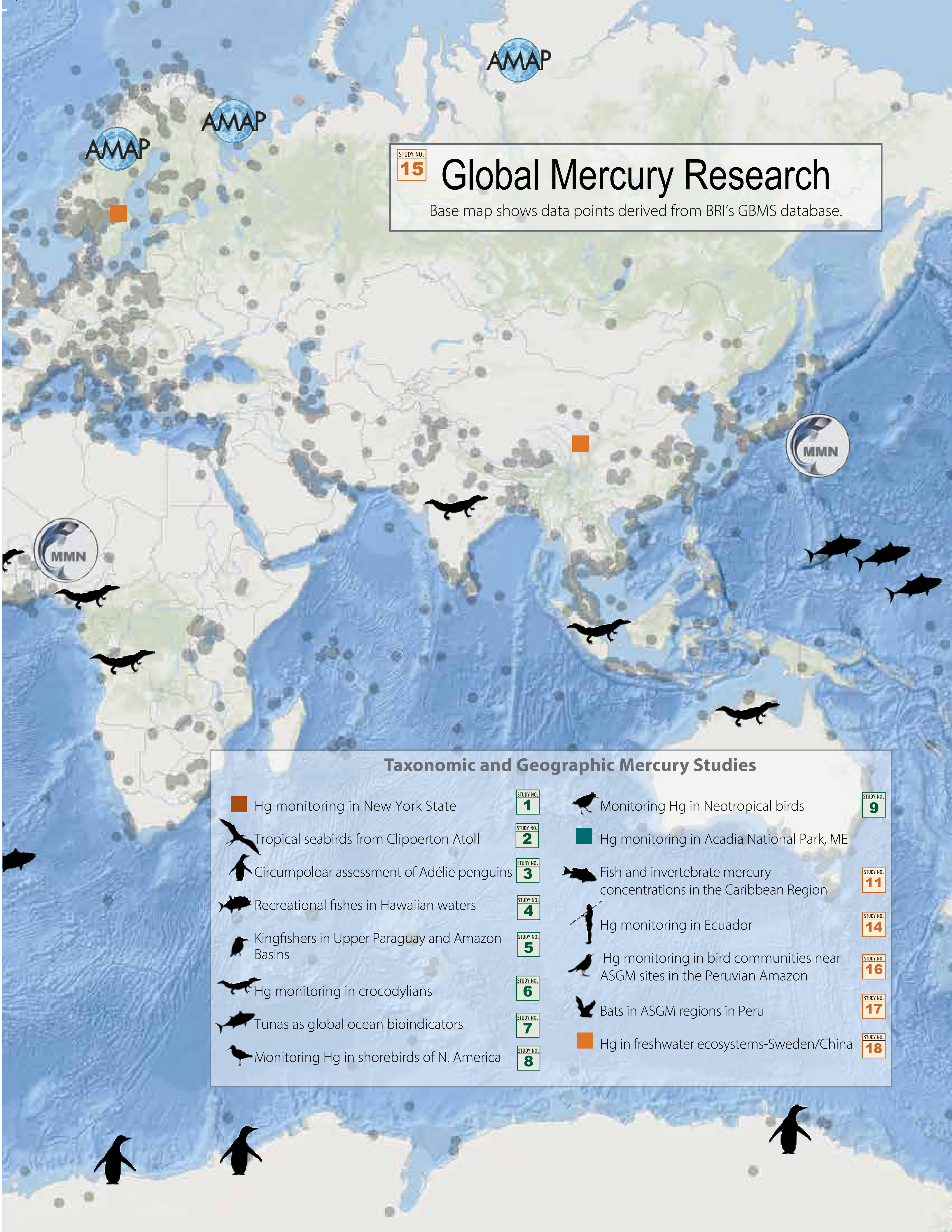


Figure 4. This material was presented at a public forum of UNEP's Global Mercury Partnership. Author Terry Keating, Senior Scientist at the U.S. Environmental Protection Agency.

Table 1. Information outputs for six themes identified by the Open-ended Science Group for the Fourth Conference of Parties of the Minamata Convention.

Themes	Information Outputs
Current levels	Current levels of mercury emissions and releases and current levels of mercury observed in air, biota, humans and other media
Temporal trends	• Changes over the timeline of the Minamata Convention in the levels of mercury emissions and releases and mercury observed in air, biota, humans and other media • Specific mitigation measures that have contributed to changes in emissions and releases • Expected changes in the levels of mercury emissions and releases and mercury observed in air, biota, humans and other media
Spatial patterns	Geographic variation at the global scale of current mercury levels and temporal trends
Source or process attribution	• Changes over the timeline of the Minamata Convention in the fractional contribution of contemporary anthropogenic emissions and releases to current mercury levels observed in air, biota, humans and other media • Geographic variation at the global scale of contribution levels and their trends • Contribution of drivers other than changes in emissions and releases to the trend in observed mercury levels
Health and environmental impacts	Changes over the timeline of the Minamata Convention between current observed levels of mercury in air, biota, humans and other media in relation to: (1) the levels established in health guidelines; and (2) observed and expected impacts on humans, other living organisms and biodiversity based on recent research and knowledge
Process understanding	Consistency in the observed levels, temporal trends and spatial patterns of mercury emissions and releases and mercury levels in air, biota, humans and other media in relation to estimates from current mechanistic models


AMAP
AMAP
AMAP
MMN
Mercury Monitoring Networks
Laboratory networks for mercury and other contaminant analyses in regional hubs throughout the world provide vital data for the assessment of risk, to humans and wildlife, in these environments.
MMN
Regional Hubs
• Caribbean Region
• Central Africa
• Asia/Pacific
AMAP
Arctic Monitoring Assessment Programme
N
0 1,500 3,000 km
0 750 1,500 mi



STUDY NO. 15
Global Mercury Research
Base map shows data points derived from BRI's GBMS database.
AMAP
AMAP
AMAP
MMN
MMN
Taxonomic and Geographic Mercury Studies
Hg monitoring in New York State STUDY NO. 1
Tropical seabirds from Clipperton Atoll STUDY NO. 2
Circumpoloar assessment of Adélie penguins STUDY NO. 3
Recreational fishes in Hawaiian waters STUDY NO. 4
Kingfishers in Upper Paraguay and Amazon Basins STUDY NO. 5
Hg monitoring in crocodylians STUDY NO. 6
Tunas as global ocean bioindicators STUDY NO. 7
Monitoring Hg in shorebirds of N. America STUDY NO. 8
Monitoring Hg in Neotropical birds STUDY NO. 9
Hg monitoring in Acadia National Park, ME
Fish and invertebrate mercury concentrations in the Caribbean Region STUDY NO. 11
Hg monitoring in Ecuador STUDY NO. 14
Hg monitoring in bird communities near ASGM sites in the Peruvian Amazon STUDY NO. 16
Bats in ASGM regions in Peru STUDY NO. 17
Hg in freshwater ecosystems-Sweden/China STUDY NO. 18

Study No. 15

Global Mercury Concentrations in Biota: Their Use as a Basis for a Global Biomonitoring Framework

David C. Evers, J.T. Ackerman, S. Akerblom, D. Bally, N. Basu, K. Bishop, N. Bodin, H.F. Veitberg Braaten, M. Burton, P. Bustamante, C. Chen, J. Chételat, L. Christian, R. Dietz, P. Drevnick, C. Eagles-Smith, L.E. Fernandez, N.Hammerschlag, M. Harmelin-Vivien, A. Harte, E. Kruemmel, J. Lailson-Brito, G. Medina, C.A. Barrios Rodriguez, I. Stenhouse, E. Sunderland, A. Takeuchi, T. Tear, C. Vega, S. Wilson, P. Wu

An important provision of the Minamata Convention is to monitor and evaluate the effectiveness of the adopted measures and their implementation. Here, we describe currently available biotic mercury data on a global scale. Data from the primary peer-reviewed literature were compiled in the GBMS database.

These data provide a foundation for establishing a biomonitoring framework needed to track mercury concentrations in biota worldwide. Based on the GBMS database, mercury levels are presented at relevant geographic scales for continents and oceanic basins.

Temporal trend data for mercury in biota are generally limited. Ecologically sensitive sites (where conditions promote the potential for mercury methylation and bioavailability) have been mapped globally and regionally and could help establish effective and efficient biomonitoring programs (see Tear et al. In Press; page 10). The relationship of these ecologically sensitive sites with areas of documented biodiversity importance can be assessed for impacts to high trophic level species (see Etui et al. 2024; page 12).

>1,700 Number of peer-reviewed scientific publications

>588,000 Number of individuals sampled

>4,100 Unique sampling locations

139 Number of countries where sampling took place

Major findings

- Mercury contamination is ubiquitous in global marine and freshwater ecosystems.
- Mercury concentrations in fish, sea turtles, birds, 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.
- 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.
- GBMS dataset provides a standardized and comprehensive platform for understanding mercury concentrations that can aid Parties to the Minamata Convention during the ratification and implementation process.

Table 2. Percentage of species, genera, or families that include individuals with muscle tissue Hg concentrations exceeding the U.S. EPA–FDA human health threshold of 0.46 µg/g, ww ("choices to avoid"). Percentages are based on data presented within this paper.

Taxa Group of Interest to Human Health*	Taxonomic Unit	Sample Size	Percent >Threshold
Tuna (commercial)	Species	(n=9)	67%
Billfish	Species	(n=7)	71%
Sharks	Genera	(n=24)	88%
Marine fish–Mediterranean Sea	Families	(n=36)	67%
Marine fish–Caribbean Sea	Families	(n=39)	64%
Freshwater fish–African	Families	(n=16)	19%
Freshwater fish–South America	Families	(n=36)	47%
Freshwater, estuarine, marine fish–Australia	Families	(n=18)	38%
Freshwater fish–Asia	Families	(n=31)	39%
Freshwater fish–North America/Europe	Families	(n=25)	48%
Seabirds–Arctic and Subarctic	Species	(n=20)	30%
Marine mammals–toothed whales	Species	(n=38)	100%

* Taxa identified by the Minamata Convention: fish, sea turtles, birds, and marine mammals.

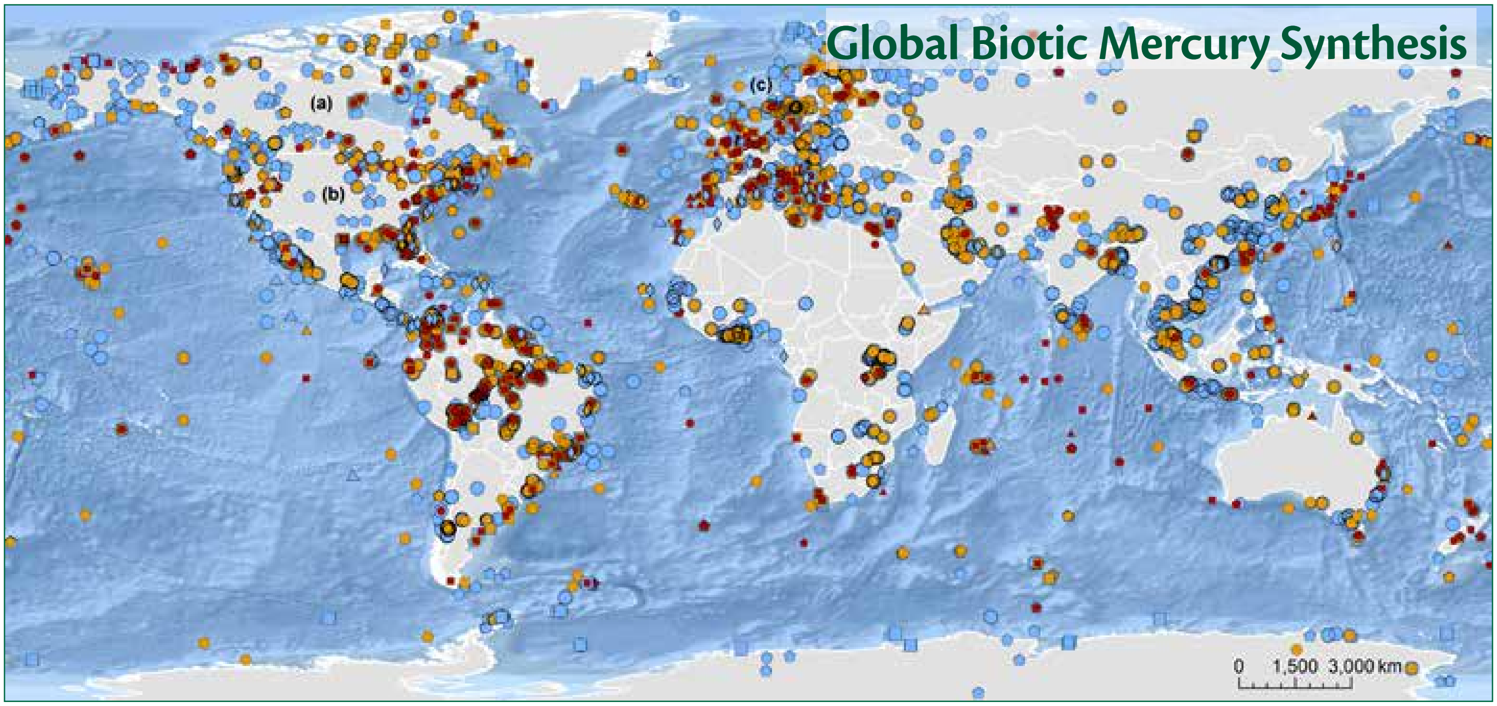


Figure 5. Data presented emphasize the global distribution of marine and freshwater fish, sea turtles, seabirds and other avian species that forage in coastal areas, and marine mammals. Mercury risk categories shown are for human health dietary purposes, except for birds, which reflect reproductive harm. Letters indicate additional available fish Hg samples that are not mapped but represent large datasets.

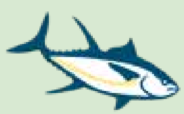
Table 3. The sampling density (# samples per area for each region) of available biotic Hg data summarized by priority taxonomic group identified by the Minamata Convention. Note that the color used reflects a "stop light" pattern, with warmer colors (red and yellow) signaling a problem with very low and low sampling densities, and cooler colors (green and blue) representing more desirable levels (high and very high) of sampling intensity.

	Sampling Regions	Fish	Sea Turtles	Birds	Marine Mammals
Continents	Africa	Red	N/A	Red	Red
	Antarctica	Red	N/A	Red	Red
	Asia	Red	N/A	Red	Green
	Australia	Red	N/A	Red	Red
	Europe	Green	N/A	Grey	Green
	North America	Green	N/A	Blue	Red
	South America	Grey	N/A	Red	Grey
Ocean Basins	Antarctic	Red	N/A	Grey	Grey
	Arctic	Orange	N/A	Green	Blue
	Gulf of Mexico-Caribbean	Blue	Blue	Grey	Green
	Indian	Orange	Orange	Red	Red
	Mediterranean	Blue	Blue	Blue	Blue
	North Atlantic	Green	Green	Grey	Grey
	North Pacific	Grey	Grey	Green	Grey
	South Atlantic	Grey	Grey	Orange	Orange
	South Pacific	Orange	Red	Red	Red

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

Step 1

Map ecosystem sensitivity spots for methylmercury availability.

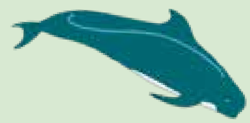


Step 2

Identify sensitive and at-risk trophic level 4 or higher species.

Step 3

Select species and ecosystems to model and monitor globally.



Sampling Intensity	
Very High	Blue
High	Green
Medium	Grey
Low	Orange
Very Low	Red

Chart Key

Global averages are used to categorize relative sampling intensity.

Developing a Global Threat Assessment Based on Ecosystem Sensitivity and Risk Mapping

Tim Tear, Mark Burton, David Evers, and Allison Aldous

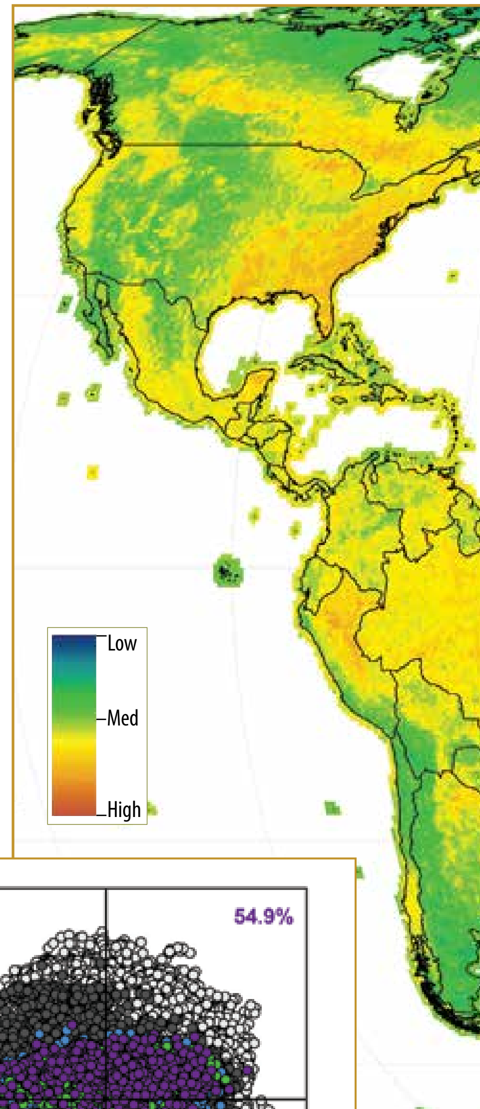
Mercury Threat Assessment

We propose that combining the sensitivity of ecosystems to mercury methylation with the risk of anthropogenic mercury contamination produces a credible estimate of the overall threat of mercury impacts to people and nature. Based on a well-established threat assessment methodology we applied a simple 1:1 relationship—i.e., ecosystem sensitivity and risk are each weighted the same when they are combined together to produce an overall threat rating.

Relationship to the Biodiversity Crisis

We compared biodiversity priorities identified for Africa and found that over half (54.9%) of global priority areas are highly threatened (i.e., high in risk and sensitivity rating) and that only a very small percentage (3.9%) would be considered at low threat (Figure 8). In addition, two-thirds (67.5%) are considered as highly sensitive (> 0.5) to mercury methylation where only small amounts of mercury can have large impacts. Similarly, global biodiversity priorities in Africa have significantly higher threat values than both terrestrial and freshwater continental priority areas (Figure 8). In addition, continental priority areas have significantly higher threat values than non-priority areas. In other areas of the globe, areas with high threat values correlate with negative impacts to people and to nature.

It is our intent that over time, and with additional information from the field on mercury levels in nature and people, that these maps will gradually improve to better reflect the relationships between mercury levels and its ultimate impacts around the world.



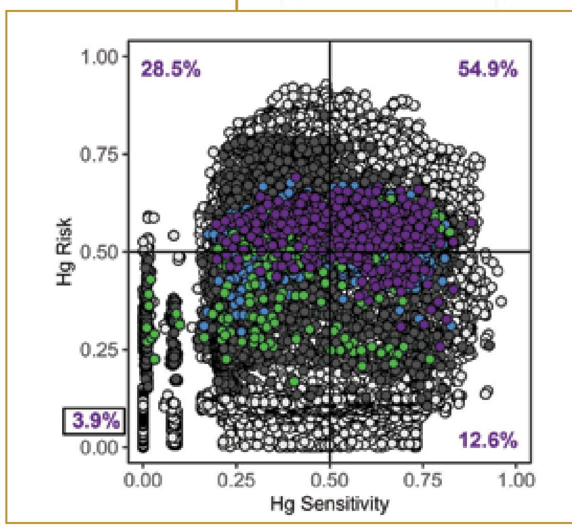


Figure 8. "Fingerprint" graph of the distribution of mapping cells (circles) on the global mercury threat map in relation to biodiversity priorities. All areas not in Africa (light grey) are compared with all areas in Africa that are not biodiversity priorities (light grey). Biodiversity priorities in Africa are shown by the colored circles that represent terrestrial (green) and freshwater (blue) continental priorities, as well as global priorities (purple) based on Tear et al. 2014.

GIS Layer Selection

By combining spatial information on the distribution of habitats and species with the extent and severity of mercury contamination, it is possible to measure the ecosystem response and risk exposure to methylmercury availability (Figure 7).

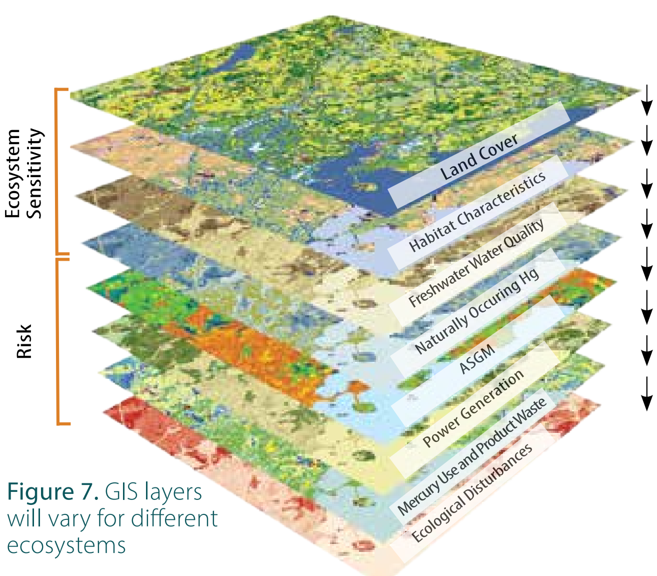


Figure 7. GIS layers will vary for different ecosystems

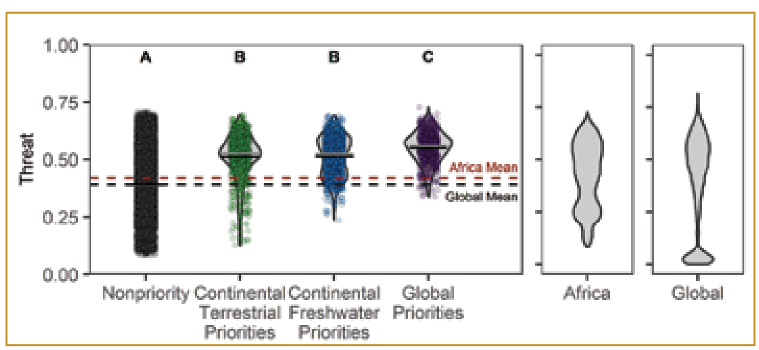


Figure 9. Box plot analysis of Africa biodiversity priorities in relation to mercury threat. Global priorities (identified as the overlap of continental terrestrial and freshwater priority areas based on Tear et al. 2014). Different letters denote statistically significant differences.

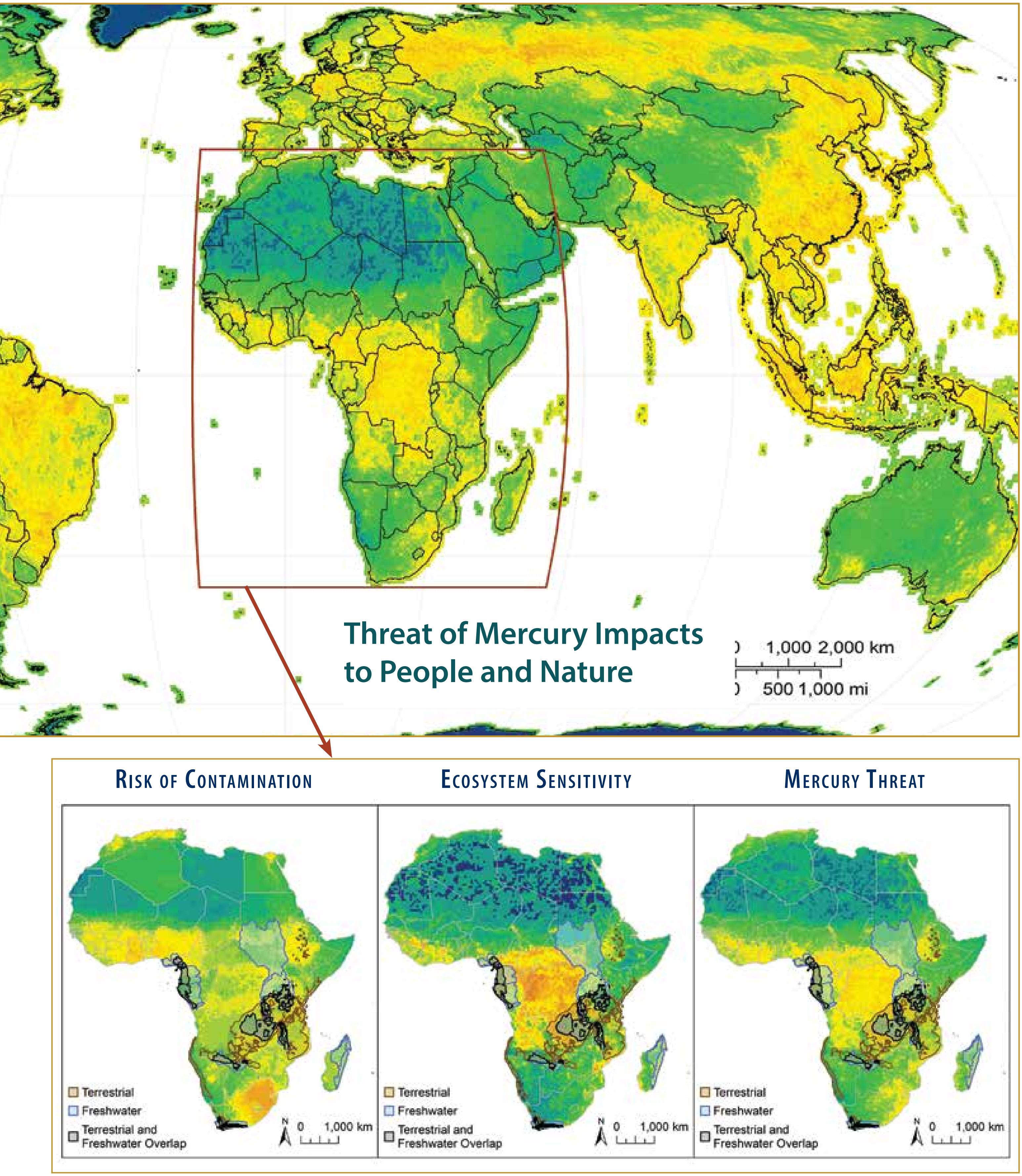


Figure 9. Illustration of how the risk of anthropogenic mercury contamination (left) is added to the sensitivity of ecosystems to mercury methylation (center) to create a map depicting the overall threat of mercury impacts to nature and people (right). Continental biodiversity priorities for terrestrial (brown) and freshwater (blue) ecosystems overlap to create global biodiversity priority areas (grey) following Tear et al. 2014.

STUDY NO. 13

Biodiversity Impacts from Artisanal and Small-scale Gold Mining Activities

Imelda Dossou Etui, Malgorzata Alicja Stylo, Kenneth Davis, David C. Evers, I. Slaveykova Vera, C. Wood, and Mark Burton

Artisanal and small-scale gold mining (ASGM) is the single largest anthropogenic source of mercury. Reducing mercury use within this sector requires a multidisciplinary approach to address technical, social, economic, and ecological issues. A majority of the literature reviewed—including 27 National Action Plans (NAPs)—cite chemical pollution as one of the main consequences of ASGM, leading to environmental contamination of air, soils, and water, which according to the CBD is one of the main drivers of biodiversity loss.

80	**15 Million**	**4-5 Million**	**38**
Number of countries where ASGM occurs, found mostly in tropical regions.	People rely on ASGM for their livelihood, mostly in rural areas.	Women are included in the total number who rely on ASGM.	Percent of global anthropogenic mercury emissions from ASGM.

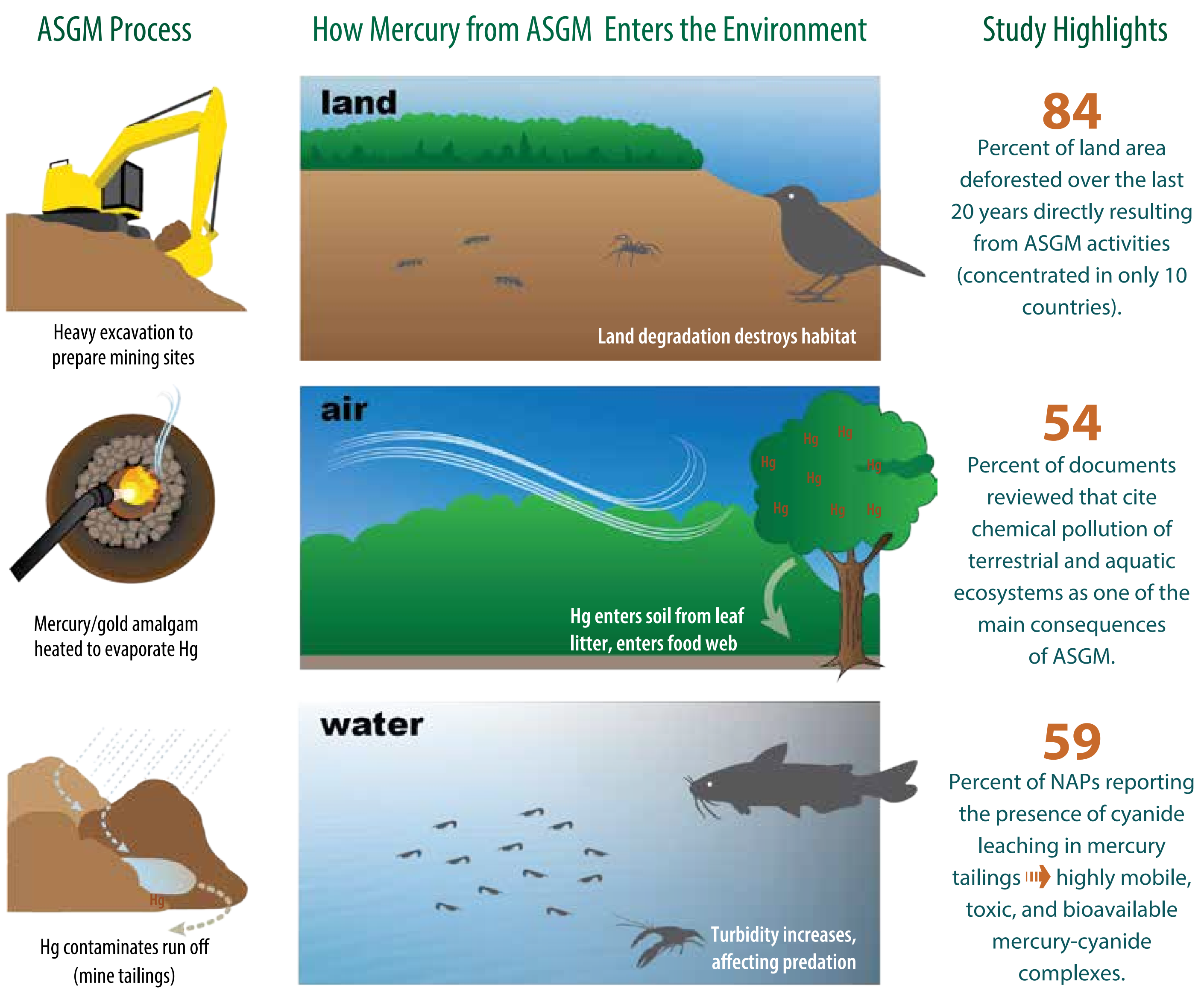
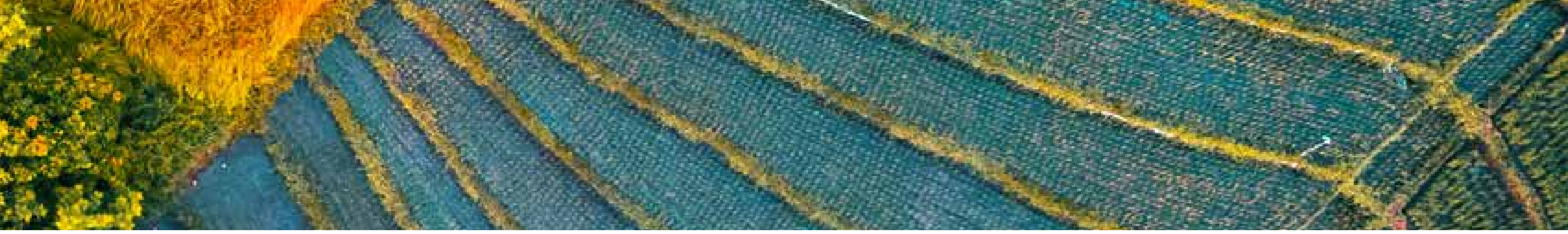


Figure 10. Impacts of ASGM. The data in this literature review support the need to reduce the use of mercury in the ASGM process.



STUDY NO. 10

The Global Challenge of Reducing Mercury Contamination from Artisanal and Small-scale Gold Mining: Evaluating Solutions Using Generic Theories of Change

Allison R. Aldous, Tim Tear, and Luis E. Fernandez

Mercury contamination from ASGM is a global conservation and human rights challenge in many parts of the world, negatively impacting both nature and the people closely reliant on intact ecosystems for nutrition, livelihoods, and culture. This type of mining occurs primarily in tropical areas, including biodiverse regions such as the Amazon Basin, Indonesia, and the Congo Basin, which receive high levels of mercury deposition.

Mercury use in ASGM is a multifaceted problem that presents practitioners with several complex challenges. Despite the substantial efforts that have been channeled into the ASGM sector, there remains a conspicuous absence of explicitly defined strategies in the published literature focusing on mercury risk reduction in the context of ASGM, and associated studies that document the effective implementation of these interventions that result in the actual reduction in mercury contamination.

There are many possible interventions, all with significant complexity and cost. Therefore, we recommend taking an established systematic approach to articulate the current situation and construct theories of change for different possible interventions for any government or organization trying to solve this problem in a particular place. We support this approach by creating ***a generic theory of change*** to help projects around the world take on this challenge.

We identified three integrated policy impact pathways:

1. Governments develop new laws and policies to support international agreements, such as the Minamata Convention, to reduce mercury use.
2. Governments more effectively enforce and incentivize compliance with existing national laws and regulations on mercury use.
3. Indigenous and other civil society groups hold governments accountable for developing and enforcing laws and policies to reduce mercury releases.

83
Percent of South America's mercury emissions originate from ASGM activity.

71
Percent of mercury emissions in the Amazon related to ASGM.

400
Metric tons of gold produced annually on a global scale from the ASGM sector.

15-20
Percent of the global gold supply is attributed to ASGM.

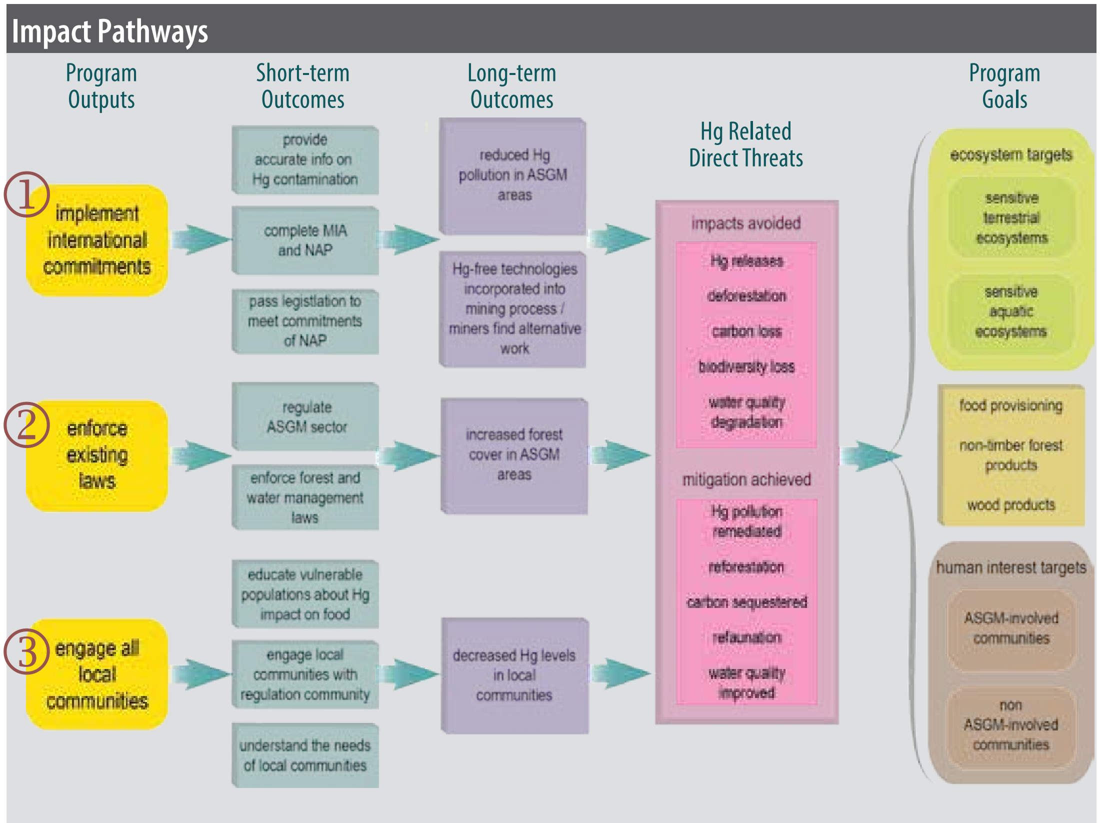


Figure 11. Generic Theory of Change.

A RICH DIVERSITY

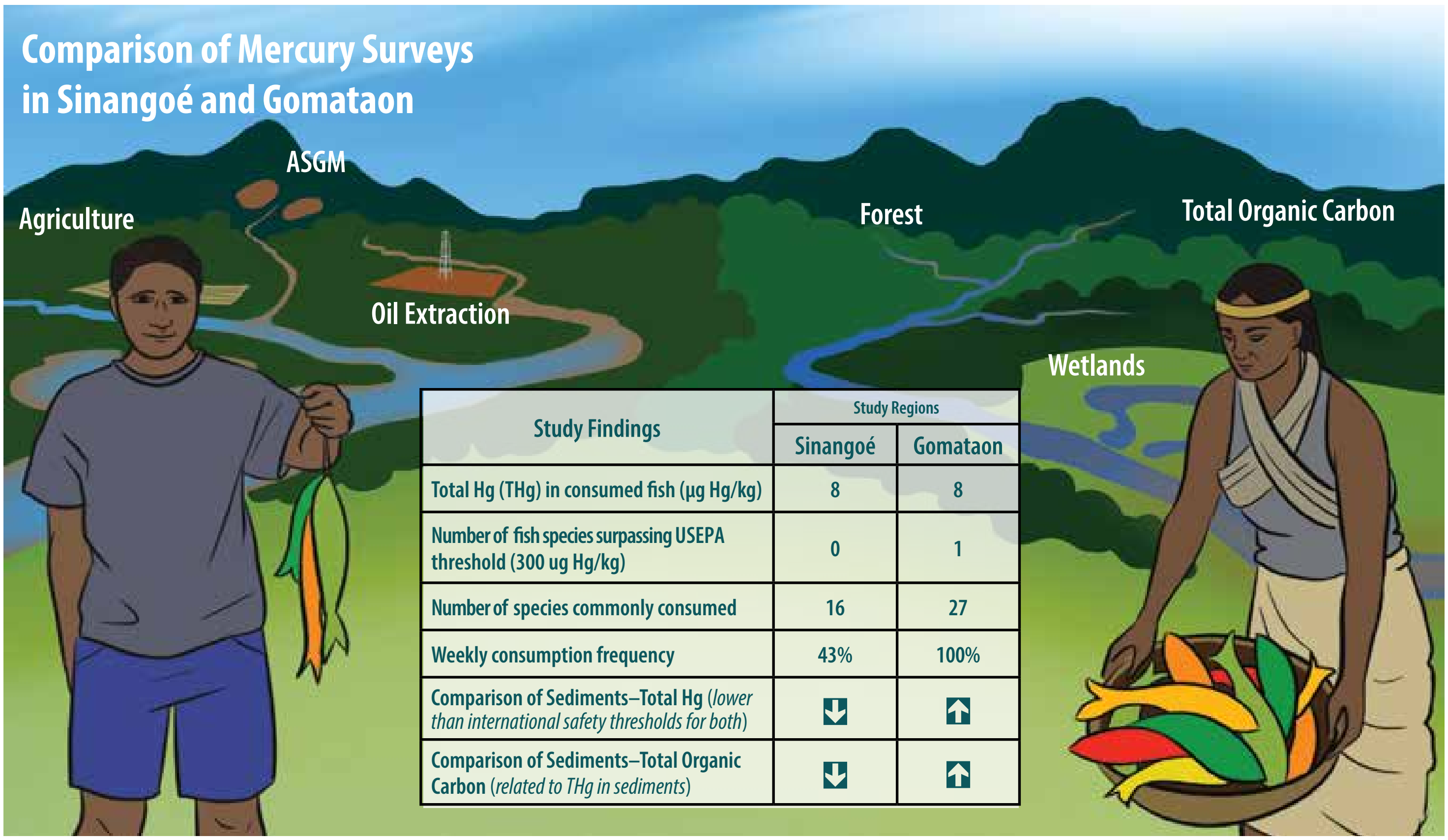
STUDY NO. 14

Mercury Levels in Fish and Sediments from Two Indigenous Communities in the Piedmont Ecuadorian Amazon

Daniel Escobar-Camacho , Karla Barragán, Daniela Rosero-López, Melany Ruiz-Urigüen, Natalia Carpintero-Salvador, José R. Daza, Allison Aldous, Silvia Benitez, Timothy Tear, and Andrea C. Encalada

Understanding mercury mobilization pathways and concentrations are key to assessing risks to biodiversity and indigenous communities. The goal of this research was to investigate the level of total mercury present in water, sediments, and fish to better understand the level of risk and mercury pathways in indigenous communities and their lands in the Ecuadorian Amazon.

Preliminary surveys of two Ecuadorian communities—Sinangoé and Gomataon—shows that while some species of fish are contaminated, others are not, providing options for people to make healthy dietary choices. Further analysis will be done using mercury isotopes to improve our understanding of where the mercury originates.



Study Findings	Study Regions: Sinangoé	Study Regions: Gomataon
Total Hg (THg) in consumed fish (μg Hg/kg)	8	8
Number of fish species surpassing USEPA threshold (300 ug Hg/kg)	0	1
Number of species commonly consumed	16	27
Weekly consumption frequency	43%	100%
Comparison of Sediments–Total Hg (*lower than international safety thresholds for both*)	↓	↑
Comparison of Sediments–Total Organic Carbon (*related to THg in sediments*)	↓	↑

Mercury and methylmercury concentration in the feathers of two species of Kingfishers in the Upper Paraguay Basin and Amazon Basin

Thaysa Costa Hurtado, Gerlane de Medeiros Costa, Giovani Spínola de Carvalho, Bruno Ramos Brum, and Áurea Regina Alves Ignácio

The bioaccumulation of mercury to methylmercury is a significant environmental concern, especially in food chain dynamics. In this study, researchers investigated the levels of mercury in wing feathers of two waterfowl species, the ringed kingfisher (*Megaceryle torquata*) and the Amazon kingfisher (*Chloroceryle amazona*).

Study Findings

- The primary feathers of M. torquata exhibited the highest total mercury concentrations, serving as a good indicator of mercury levels.
- Feathers play a significant role in the methylmercury excretion process, as observed from 95% methylmercury in primary feathers and 80% in secondary feathers.
- It's important to pay attention to these birds as their opportunistic feeding behavior and sustained mercury concentrations in feathers make them valuable tools for monitoring mercury contamination.

STUDY NO. 4

Elevated Mercury Exposure in Bird Communities Inhabiting ASGM Landscapes of the Southeastern Peruvian Amazon

Jessica N. Pisconte, C.M. Vega, M. Pillaca, E. Quispe, C. S. Sevillano-Rivers, C.J. Sayers, V. Tejeda, C. Ascorra, M.R. Silman, and L.E. Fernandez

In this region of the Southern Peruvian Amazon, ASGM activities have created landscapes marred by deforestation and postmining water bodies (mining ponds) with notable methylation potential. While data on mercury contamination in terrestrial wildlife remains limited, this study measured mercury exposure in several terrestrial bird species found near water bodies, including mining ponds associated to ASGM areas and oxbow lakes.

STUDY NO. 16

Study Findings

- Total mercury concentrations were two times higher in sites affected by ASGM than in control sites.
- Some species of piscivorous and insectivorous birds reported the highest mercury concentrations ever reported.
- Foraging preferences and ASGM presence influence mercury exposure and bioaccumulation.
- Increased emissions of inorganic mercury and mining ponds from ASGM may influence mercury exposure in birds in the Southern Peruvian Amazon.

Investigating the Diet Source Influence on Freshwater Fish Mercury Bioaccumulation and Fatty Acids: Experiences from Swedish Lakes and Chinese Reservoirs

Pianpian Wu, Haiyu Yan, Martin J. Kainz, Brian Braunfierun, Ann-Kristen Bergström, Min Jing, Kevin Bishop

Dietary nutrients such as polyunsaturated fatty acids (PUFA) are key in transferring contaminants like mercury to consumers at other levels of the food web. This study evaluates the role of diet sources for mercury bioaccumulation and PUFA retention in fish across lake food webs in Swedish lakes and Chinese reservoirs.

Study Findings

- Chinese fish contained significantly less total mercury compared to Swedish fishes, with 50% of total mercury in Chinese fishes being methylmercury, and Swedish fishes having nearly 100% of total mercury as methylmercury.
- Fatty acid enrichment of linoleic acids was more prevalent in Chinese fishes, regardless of size.
- In reservoirs, where fish had low mercury concentrations, the food chain lengths were longer and more enriched in essential fatty acids than in the Swedish lakes.

STUDY NO. 18

Distribution and Trends of Mercury in Aquatic and Terrestrial Biota of New York, USA: A Synthesis of 50 Years of Research and Monitoring

Evan M. Adams, J.E. Gulka, Y. Yang, M.E.H. Burton, D.A. Burns, V. Buxton, L. Cleckner, C.R. DeSorbo, C.T. Driscoll, D.C. Evers, N. Fisher, O. Lane, H. Mao, K. Riva-Murray, G. Millard, N.R. Razavi, W. Richter, A.K. Sauer, and N. Schoch

Mercury exposure is high in the northeastern United States due to concentrated anthropogenic emissions sources. In this study, researchers used data from more than 37,000 samples to quantify spatial and temporal trends of mercury exposure in New York state over the past 50 years.

STUDY NO. 1

Study Findings

- The Adirondack Mountains and Long Island areas had the greatest number of aquatic and terrestrial species with elevated mercury concentrations.
- Elevated mercury concentrations were associated with open water, forests, and rural, developed habitats for aquatic species, and open water and forested habitats for terrestrial species.
- Most temporal trends were stable, but there are significant declines in mercury exposure over time in some long-sampled fish species.
- Land cover is a significant factor driving areas with elevated mercury levels, specifically in areas of forests, water, and rural habitat types.

Monitoring Mercury in Times of Changing Sources: A Case Study of Acadia National Park*

Mark E. Burton, C. Chen, D. Buck, C.R. DeSorbo, C. Eagles-Smith, D.C. Evers, C.F. Pritz, W. Gawley, A. Jackson, A. Miller-Rushing, K. Morris, S.J. Nelson, T.H. Tear, B. Wheeler, J. Willacker, and D. Yates

Acadia National Park (ANP) is one of the few locations in the United States where comprehensive assessments of spatial and temporal data exist. Mercury data were synthesized to examine the spatial and temporal patterns of mercury in abiotic (atmosphere, throughfall, litterfall, soils, stream water, and lake sediment) and biotic (birds, mammals, terrestrial and aquatic invertebrates, and fish) matrices of aquatic and terrestrial ecosystems.

The synthesis provides evidence that ANP exhibits decoupled trends in mercury deposition and mercury concentrations in some biotic species. Despite the relatively intensive research conducted to date, there are still significant data gaps and confounding variables that make synthesizing and interpreting mercury patterns in ANP challenging. These challenges point to the need to develop a robust, reliable, standardized and comprehensive monitoring plan that will allow for synthetic, integrated analyses.

**To be published in a later issue of Ecotoxicology*

STUDY NO. 7

Are Tunas Relevant Bioindicators of Mercury Concentrations in the Global Ocean?

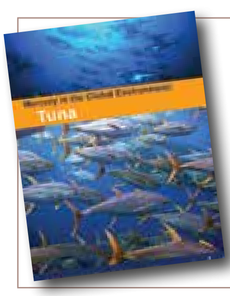
Anaïs Médieu and Anne Lorrain

Humans are exposed to methylmercury mainly by consuming fish. Tunas are considered sentinels of mercury exposure in the ocean. Researchers conducted a literature review of mercury concentrations in tropical tunas (bigeye, yellowfin, and skipjack) and albacore, the four most exploited tunas worldwide.

Study Findings

- Strong spatial patterns of tuna mercury concentrations were shown, mainly explained by fish size, and methylmercury bioavailability in marine food web, suggesting that tunas reflect spatial trends of mercury exposure in their ecosystem.
- The few mercury long-term trends in tunas were contrasted and sometimes disconnected to estimated regional changes in atmospheric emissions and deposition, highlighting potential confounding effects of legacy mercury, and complex reactions governing the fate of mercury in the ocean.
- Inter-species differences of tuna mercury concentrations associated to their distinct ecology suggest that tropical tunas and albacore could be used complementary to assess the vertical and horizontal variability of methylmercury in the ocean.

50 YEARS
Lifespan of some tuna species, allowing for high bioaccumulation of mercury.



For more information, download *Mercury in the Global Environment: Tuna*

briwildlife.org/hgcenter

Figure 12. Overall, this review elevates tunas as relevant bioindicators for the Minamata Convention, and calls for large-scale and continuous mercury monitoring.

5.7 MILLION
Number of tonnes of commercial tuna catch for 2019[1]

$40+ BILLION
Total worth of the global commercial tuna fishing industry.[2]

Mercury Accumulation and Biomarkers of Exposure in Two Popular Recreational fishes in Hawaiian Waters

Stephanie Shaw Holbert, Colleen E. Bryan, Keith E. Korsmeyer, and Brenda A. Jensen

Mercury contaminants in recreational fish species can cause a number of negative health effects in fish and higher-level trophic species. In this study, researchers examined the mercury exposure of recreational nearshore fish species, the bluefin trevally, giant trevally, sharp jaw bonefish, and round jaw bonefish, around the Hawaiian Islands.

Study Findings

- Round jaw bonefish and giant trevally had mercury bioaccumulation in their tissues, similar to previous studies.
- Mean muscle total mercury in round jaw bonefish exceeded World Health Organization and USEPA fish tissue criteria for human consumption.
- The relationship between THg in muscle tissue and internal fish organs in this study matched the relationship observed in several other fish species.

STUDY NO. 4

[1]FAO. 2022. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461en

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Circumpolar Assessment of Mercury Contamination: The Adélie Penguin as a Bioindicator of Antarctic Marine Ecosystems

STUDY NO. 3

Fanny Cusset, Paco Bustamante

In this first circumpolar assessment of mercury contamination across Antarctic marine food webs, authors focused on the Adélie penguin (*Pygoscelis adeliae*) as a bioindicator species to examine regional variation across 24 colonies.

Study Findings

- Adélie penguins are good bioindicators of mercury contamination in Antarctic marine ecosystems.
- Feather mercury concentrations were measured in 24 breeding colonies (adults and chicks).
- The highest mercury concentrations were found in Ross Sea.
- Both trophic ecology and colony location drove feather mercury concentrations.

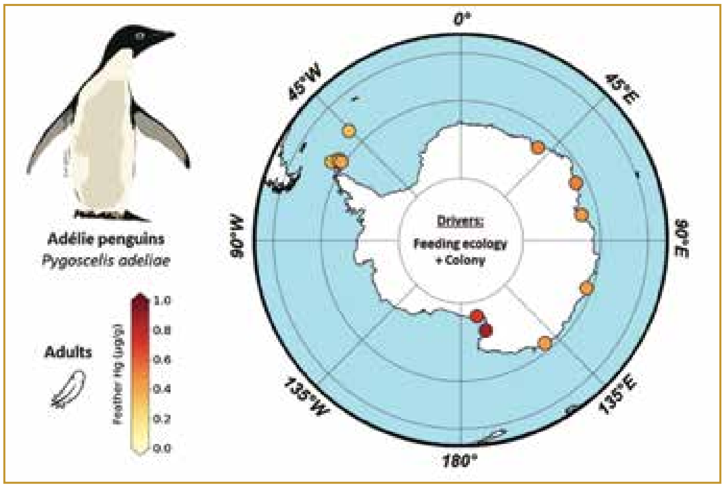

Figure 13. Mercury disperses worldwide mainly through atmospheric currents and deposits even in the most remote oceanic regions, such as polar oceans. This graphic shows mercury concentrations at each of the study sites. Above: *Graphical abstract published with paper.*

Monitoring the effectiveness of the Minamata Convention on Mercury in the tropics using Crocodylians

Jérémy Lemaire

To monitor environmental mercury contamination, studies have evaluated the use of living organisms; however, reptiles are among the least documented vertebrates. In this review researchers evaluate the use of crocodylians for mercury contamination biomonitoring in tropical ecosystems.

Study Findings

- Of the 28 crocodylid species, only 10 have been evaluated regarding mercury contamination.
- Major challenges when using this taxon for mercury monitoring are inconsistencies in the applied methodology (e.g., wet versus dry weight, tissues used, quantification method).
- Due to their life history traits, crocodylians are particularly relevant for monitoring mercury contamination in regions where ASGM activities occur.
- Given their ecological and socio-economic importance, crocodylians are at great risk of mercury contamination and are excellent bioindicators to evaluate the effectiveness of the Minamata Convention.

STUDY NO. 6

Mercury Contamination in the Tropical Seabird Community from Clipperton Atoll, Eastern Pacific Ocean

Paco Bustamante, Thibault Le Verge, Charles-André Bost, Maud Vault-Favrou, Mattheiu Le Corre, Henri Weimerskirch, Yves Cherel

While mercury contamination is well studied in the open ocean, there are few studies that look at the bioaccumulation in tropical predators. This study looks at six tropical seabird species and uses blood and feathers to determine the short and long-term mercury contamination levels in these nesting communities.

Study Findings

- Most seabirds sampled at Clipperton Island had little or no exposure to mercury toxicity, with 30% in the **no risk** category and 70% in the **low risk** category.
- There was a relatively small intraspecific variation in blood and feather concentrations depending on different factors such as species, trophic ecology, sex, and age.
- Among species, Great Frigatebirds had the highest mercury concentrations in blood and feathers, with Brown Noddies and Sooty Terns having the lowest concentrations.

STUDY NO. 2

Mercury in Neotropical Birds: A Synthesis and Prospectus on 15 Years of Exposure Data

Chris Sayers, D.C. Evers, V. Ruiz-Gutierrez, E. Adams, C.M. Vega, J. Pisconte, K. Regan, O.P. Lane, A.A. Ash, R. Cal, S. Reneau, W. Martínez, G. Welch, K. Hartwell, M. Teul, D. Tzul, W. Arendt, M. Tórrez, M. Watsa, G. Erkenswick, C.E. Moore, J. Gerson, V. Sánchez, R. Pérez Purizaca, H. Yurek, M. Burton, P.L. Shrum, F.F. Fogarty, M.R. Charette, A.E. Martínez, E.S. Bernhardt, T.H. Tear, and L.E. Fernandez.

STUDY NO. 9

Environmental mercury contamination of the global tropics outpaces our understanding of its consequences for biodiversity. Due to their global distribution and sensitivity to pollution, birds provide a unique opportunity to assess how mercury emissions from rapidly expanding industries impact biodiversity, and more broadly, global health.

Here, we present summarize the largest database on Neotropical bird mercury concentrations, which establish exposure baselines for 309 bird species in eight countries across Central America, South America, and the West Indies.

Study Findings

- Birds provide a valuable opportunity as bio-indicators to understand how increasing mercury pollution throughout the global tropics impacts wildlife, ecosystem, and human health.
- We detected the highest mercury concentrations in carnivorous bird species, aquatic habitats, and gold mining sites.
- Bird mercury concentrations were over four times higher at sites impacted by ASGM activities.
- We showcase among the highest published mercury concentrations for songbirds (Passeriformes) in the world.
- Madre de Dios, Peru, central Belize, and Ayapel, Colombia are biological mercury hotspots, but widespread sampling is necessary throughout the Neotropics.
- Inclusive collaboration will excel the field of tropical ecotoxicology by improving the efficiency and comparability of future monitoring efforts.

The Tropical Research for Avian Conservation and Ecotoxicology (TRACE) Initiative exemplifies inclusive, equitable, and international data sharing.

www.briwildlife.org/trace/

TRACE

2,316

Neotropical bird mercury concentrations in our database (the largest in the world).

322

Bird species for which we established exposure baselines.

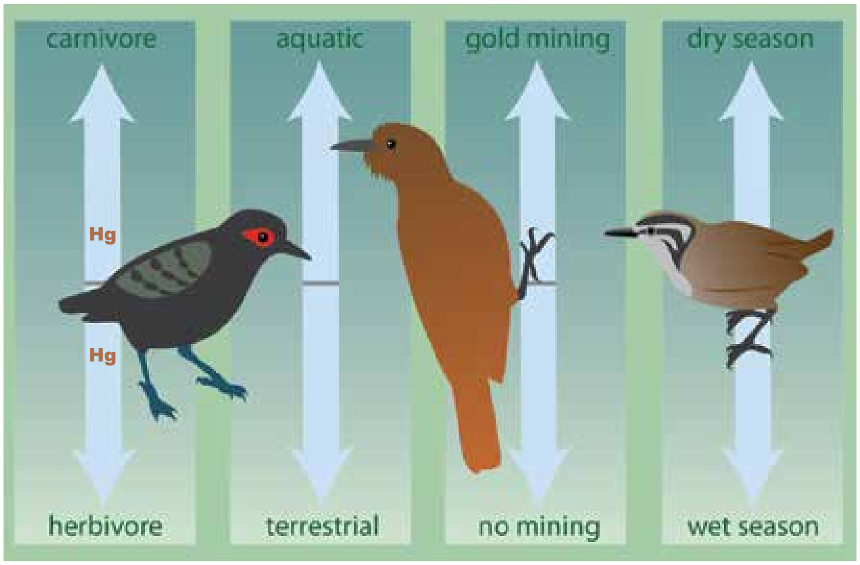

Figure 12: This study found patterns of avian Hg in the tropics that broadly align with those in temperate regions: consistent bioaccumulation and high spatio-temporal variation.

Mercury Bioaccumulation in Bats in Madre de Dios, Peru: Implications for Mercury Bioindicators for Tropical Ecosystems Impacted by ASGM

Alejandro Portillo, Claudia M, Vega, Jose Luis Mena, Emilio Bonifaz, Cesar Ascorra, Miles R. Silman, Luis E. Fernandez

STUDY NO. 17

Artisanal small-scale gold mining in Peru can emit mercury and endanger human and wildlife health. In this study, researchers use bats as bioindicators for mercury pollution in sites that have been impacted by ASGM.

Study Findings

- Insectivorous and piscivorous bats from ASGM sites had elevated mercury levels that surpassed the mercury small mammal threshold (10 mg/kg).
- These findings confirm that mercury emissions from AGSM are entering local food webs and exposing wildlife species at higher trophic levels to higher levels of mercury than areas not affected by mining.
- The frugivorous and insectivorous bat genera of Artibeus, Carollia, Phyllostomus consistently showed increased mercury levels in AGSM sites relative to controls, indicating potential use as bioindicators.

An Evaluation of Fish and Invertebrate Mercury Concentrations in the Caribbean Region

STUDY NO. 11

Linroy Christian, M.E. Burton, A. Mohammed, W. Nelson, T. Ali Shah, H.G. Yurek, D.C. Evers

Aquatic foods are an important source of protein and are culturally and economically important in the Caribbean Region. Consumption of seafood is the predominant source of human exposure to mercury, so understanding geospatial and taxonomical patterns and individual variation in mercury concentrations has important implications for biota and human health.

Study Findings

- >1,600 samples from 107 species of fish and aquatic invertebrates collected between 2005 and 2023 from 11 countries or territories
- 55% of samples were below the 0.23 µg/g ww guideline from the US FDA/USEPA (2022) for 2 or 3 weekly servings
- 26% exceeding the 0.46 µg/g ww guideline as a choice to avoid and consistent with adverse effects on human health from continual consumption, particularly for sensitive populations
- There was a significant positive relationship between mercury concentration and both length and trophic level.
- Some countries and fish families were found to have higher mercury concentrations

The data analyzed supports the need for further research with finer resolution geospatial data to better understand patterns and mechanisms in mercury concentrations and allow for better informed decision making on the consumption of fish and invertebrates from the wider Caribbean Region.

Factors Influencing Mercury Exposure in Arctic-breeding Shorebirds

Marie Perkins, I.J. Stenhouse, R.B. Lanctot, S. Brown, J. Bêty, M. Boldenow, J. Cunningham, W. English, R. Gates, G. Gilchrist, M. Giroux, K. Grond, B. Hill, E. Kwon, J. Lamarre, D.B. Lank, N. Lecomte, D. Pavlik, J. Rausch, K. Regan, M. Robards, S. T. Saalfeld, F. Smith, P. A. Smith, B. Wilkinson, P. Woodard, N. Basu

This study investigated factors influencing mercury exposure in Arctic-breeding shorebirds by utilizing a large-scale collaborative network to simultaneously collect nearly 2,500 blood and feather samples from 12 shorebird species breeding at nine sites across the North American Arctic during 2012 and 2013.

STUDY NO. 8

Study Findings

- Most Arctic-breeding shorebirds had blood and feather mercury concentrations at levels where no adverse effects of exposure were predicted, though some individuals had mercury levels that would be considered of concern.
- Arctic-breeding shorebirds are at low risk of adverse effects of mercury exposure, but differences among species indicated that some species were at greater risk of adverse effects than others.
- Blood mercury concentrations, reflective of breeding habitat, were influenced by foraging habitat, sex, body mass, and capture day.
- Feather mercury concentrations, reflective of nonbreeding habitat, were influenced by species and sex, with males generally having higher mercury concentrations than females.
- Many factors influence blood and feather mercury concentrations, therefore, care should be taken when using birds as bioindicators of mercury risk within a system.

Mercury and methylmercury concentration in *Megaceryle torquata* and *Chloroceryle amazona* feathers in the Upper Paraguay Basin and Amazon Basin

STUDY NO. 5

Thaysa Costa Hurtado

The focus of this research is on mercury movement into riparian food webs and how this is modulated by habitat characteristics in a river system. Researchers characterize differences in mercury exposure in aquatic invertebrates and riparian songbirds across the Willamette River system in western Oregon, starting at a mercury-contaminated Superfund site in the headwaters and including a reservoir known to methylate mercury.

Study Findings

- Methylmercury concentrations in aquatic invertebrates varied spatially among habitat categories and invertebrate orders.
- Total mercury in songbird blood also varied among habitat categories and bird species. The highest mercury concentrations occurred near the mercury mine, but mercury did not decline linearly with distance from the source of contamination.
- Findings suggest that mercury risk to riparian songbirds can extend beyond point-source contaminated areas, highlighting the importance of assessing exposure in surrounding habitats, such as reservoirs and wetlands where methylmercury production may be elevated.

ARCTIC MODEL

The Minamata Convention and the Arctic Council

A decade ago, the adoption of the Minamata Convention on Mercury marked a breakthrough in the international effort to address mercury pollution. Under Article 22 of the Convention, Parties shall, beginning no later than 2023, evaluate the effectiveness of the Convention. Work is underway to establish arrangements for the effectiveness evaluation that includes a provision for "comparable monitoring data on the presence and movement of mercury and mercury compounds in the environment as well as trends in levels of mercury and mercury compounds observed in biotic media and vulnerable populations."

The Arctic Council

In 1991, the Arctic countries adopted the Arctic Environmental Strategy and established the Arctic Monitoring and Assessment Programme, a framework for circumpolar collaboration on monitoring and assessment of environmental contaminants.

In 1996, AMAP became a working group of the Arctic Council, which is made up of the eight Arctic States: Canada; the Kingdom of Denmark; Finland; Iceland; Norway; the Russian Federation; Sweden; and the United States, as well as six Indigenous organizations as Permanent Participants. All member states, with the exception of the Russian Federation, are Parties to the Minamata Convention. National jurisdictions and international law govern the lands surrounding the Arctic Ocean and its waters. The northern provinces and territories of the Arctic States are home to more than four million people; approximately 10 percent of the total population is indigenous, whose health and well being is a priority for the Arctic Council's agenda.

The region covered by AMAP includes both High Arctic and Subarctic regions. The AMAP area also includes northern seas that extend as far south as 51.1o N (Hudson Bay, Canada; Figure 13).

Tackling mercury pollution is also a priority for AMAP's sister group Arctic Contaminants Action Program which encouraging national actions to reduce emissions and releases of pollutants. Where relevant to its assessment activities, AMAP's work extends beyond the Arctic to address global connections associated with long-range transport of contaminants, and global climate linkages.

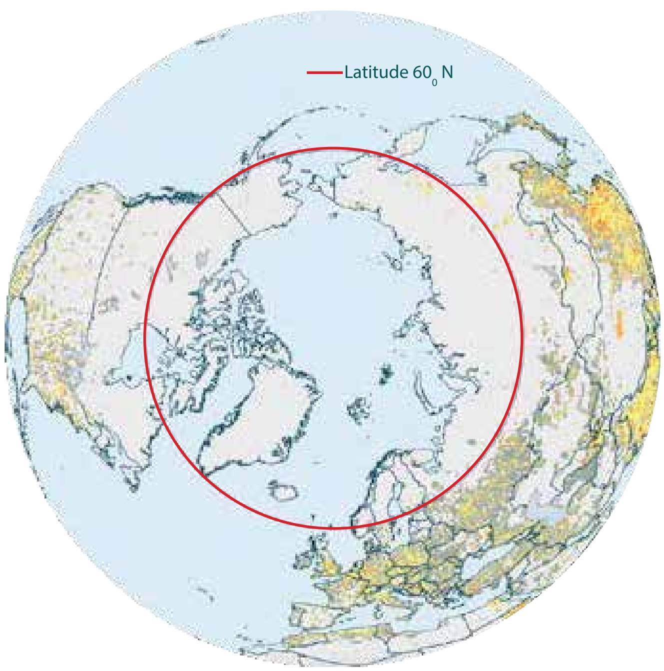

Figure 13. Global mercury emissions showing proximity of emissions in major source regions to the Arctic.

Data Source: *2021 AMAP Assessment of Mercury in the Arctic*

AMAP: A Model for Effectiveness Evaluation

The monitoring and assessment work of AMAP, which is underpinned by national monitoring programs, has been recognized as one of the best examples of a regional mercury monitoring system that can help assess the effectiveness of the Minamata Convention.

The potential cumulative and combined effects of persistent organic pollutants and mercury carried into the Arctic from different parts of the world via long-range atmospheric transport as well as by ocean currents and rivers may be detrimental for some Arctic human populations, especially some Indigenous people.

AMAP has also identified some wildlife, including polar bears, killer whales, and birds as being at high risk of negative health effects or even population level impacts.

AMAP's series of scientific reports and related communication publications detail the status of the Arctic with respect to climate and pollution issues. These documents include recommendations for actions that are addressed to the Arctic Council as well as governments around the world, and to international processes such as the Minamata Convention.

The *2021 AMAP Assessment of Mercury in the Arctic*, the most recent published to date, highlights science-based recommendations for future monitoring of mercury pollution in the Arctic and addresses impacts of climate change on mercury transport and fate.

For more information, visit: www.amap.no

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