GLOBAL MERCURY THREAT ASSESSMENT
Ecosystem Sensitivity and Risk Mapping

A TWO-PRONGED APPROACH

Mercury emissions, deposition, and releases into the environment explain only part of the spatial story of mercury pollution. Ecosystem sensitivity and food web relationships help further define the actual risks to human and ecosystem health.

Elemental mercury (Hg) is converted to a more toxic organic form of mercury through the process of methylation, which occurs with the help of bacteria found primarily in wet areas. Large variations in methylmercury (MeHg) concentrations may occur in different parts of the food web depending on the sensitivity of the ecosystem to mercury input.

Where methylmercury availability is elevated, fish and wildlife may exhibit harmful mercury concentrations and represent the places that will require the most attention by countries and global monitoring programs.

The combination of these two factors—the risk of mercury contamination from multiple sources and ecosystem sensitivity to mercury methylation—represents a new approach to conducting a global mercury threat assessment (GMTA).

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Developing a Global Mercury Threat Assessment

Mercury can pose a significant threat to freshwater ecosystems. Increased availability due to human disturbances and the management of natural resources (e.g., dams and reservoir management) may exacerbate mercury's availability to enter food webs. Much of the contamination of people and natural resources in the terrestrial environment is derived from mercury cycling through nearby freshwater ecosystems (UNEP 2019).

A New Mapping Approach

Due to the complexities of the methylation process that converts inorganic mercury into its more toxic, bioavailable organic form methylmercury, the amount of total mercury in any given location is only part of the story of ecosystem impact.

For example, small amounts of mercury introduced into ecosystems that are highly sensitive to mercury methylation may pose great risks to organisms. Similarly, large amounts of mercury introduced into ecosystems that have little or no sensitivity to mercury methylation will have limited impacts to the environment.

To assess the potential threat of mercury to biota, biodiversity, ecosystem services, and people, we purposely combine maps of ecosystem sensitivity with maps of mercury contamination risk. Mercury contamination comes from multiple sources. Notably, mercury emissions from the artisanal and small-scale gold mining (ASGM) sector account for almost 38 percent of total global mercury emissions, the most of any single emissions sector (Spiegel and Veiga, 2006).

Mercury emissions and releases from ASGM activities in Indonesia are among the highest in the world, and are that country's dominant source of mercury emissions (Boese-O'Reilly, et al. 2017). ASGM-related emissions and releases have a significant impact on Indonesians working in or living near these mining activities, with especially high levels of mercury intoxication symptoms in Indonesian gold miners (UNEP 2019; Steckling, et al. 2017).

Ecosystem Sensitivity

At a landscape level, mercury is converted to methylmercury through complex processes by sulphur- and iron-reducing bacteria (Podar, et al. 2015). The suite of environmental characteristics and conditions that optimize methylation by these bacteria are potentially predictive of mercury cycling into waters, and its subsequent rate of conversion to methylmercury and bioaccumulation up through the food web (Evers, et al., 2007; Shanley and Bishop, 2012; Hsu-Kim, et al., 2013; Hsu-Kim, et al., 2018). We combined multiple environmental characteristics to produce a global map of areas likely to be disproportionately sensitive to mercury contamination (Figure 1).

Mercury Sensitivity Factors

Four primary factors used to assess ecosystem sensitivity include:

1. Land cover types and their relative sensitivity to mercury methylation;
2. Habitat characteristics associated with mercury methylation;
3. Freshwater water quality indicators linked to the methylation process; and
4. Areas of high amounts of naturally occurring mercury.

Specific indicators for each were based on availability of high-quality data with global coverage.

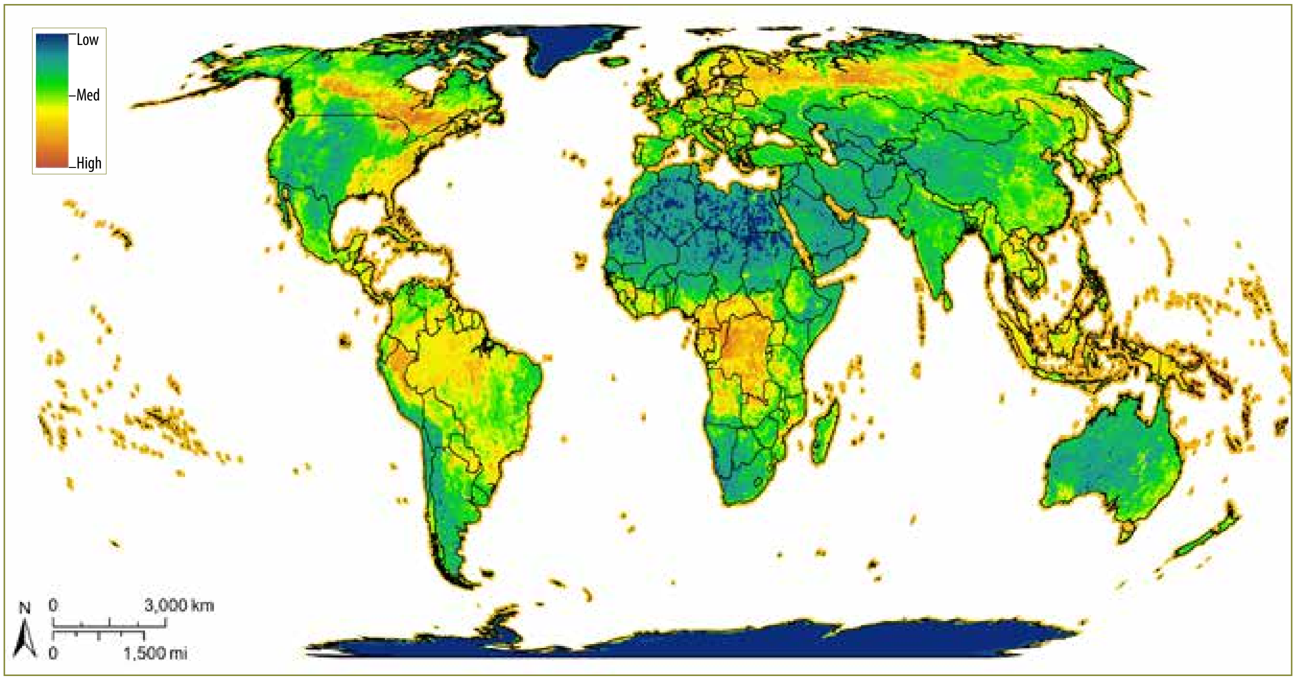


Figure 1. Ecosystem sensitivity to mercury methylation.

Mercury Contamination Risk

Similar to natural variability in ecosystem sensitivity to mercury methylation, contamination from human-induced mercury inputs are not uniform across a landscape, influencing the amount of mercury that has the potential to enter ecosystems and the food web and cause adverse effects. The risk of mercury contamination from anthropogenic sources comes in many forms at a range of spatial and temporal scales.

A significant amount of research has been devoted to understanding and estimating the amount of mercury that has been volatilized into the air, and then deposited as it returns to the earth's surface. Mercury can travel long distances—in some cases it has circled the globe twice before being deposited—further complicating mercury's distribution and availability. The most recent models of mercury deposition, assembled for the ***Global Mercury Assessment*** (GMA) were used in this analysis (UNEP 2019).

The GMA presents the most recent and credible estimates of mercury contributions from the four major sources of mercury contamination: ASGM; power generation; industrial sources; and intentional use and product waste. However, mercury contamination does not solely come from the global distribution patterns of mercury deposition.

There is growing evidence that human-induced ecological disturbances play an increasingly large role in the remobilization of mercury from both recent mercury releases and deposition, as well as sources of legacy (historically deposited) mercury. In this new mapping approach (Figure 2), we introduce several known human-influenced disturbance processes associated with the remobilization of mercury for which global data are available, such as deforestation, sediment loading, fire, and hydrologic alterations.

Mercury Contamination Factors

Four primary factors used to assess mercury contamination risk include:

1. ASGM activities;
2. Power generation;
3. Mercury use and product waste; and
4. Human-influenced ecological disturbances.

Specific indicators for each were based on availability of high-quality data with global coverage.

Mercury emissions from the artisanal and small-scale gold mining (ASGM) sector contribute the most from any sector, accounting for almost 38% of total global mercury emissions.

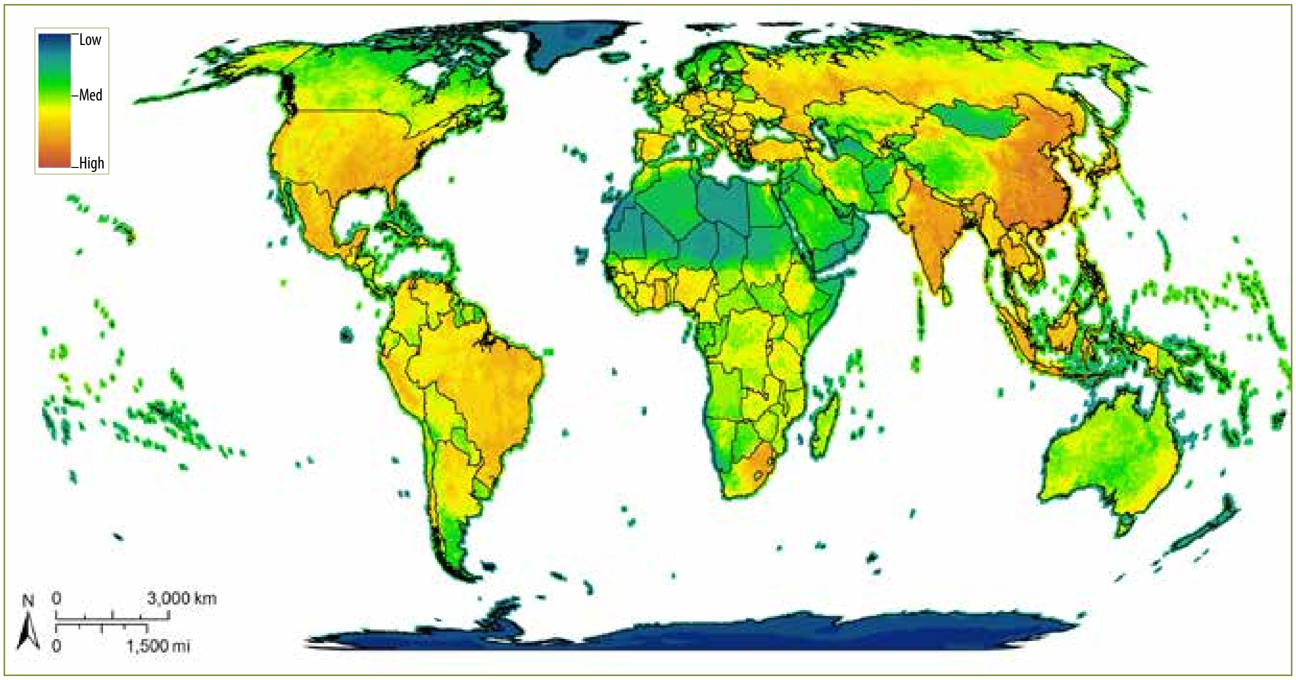


Figure 2. Risk from mercury contamination.

Mapping the Mercury Threat to Nature and People –

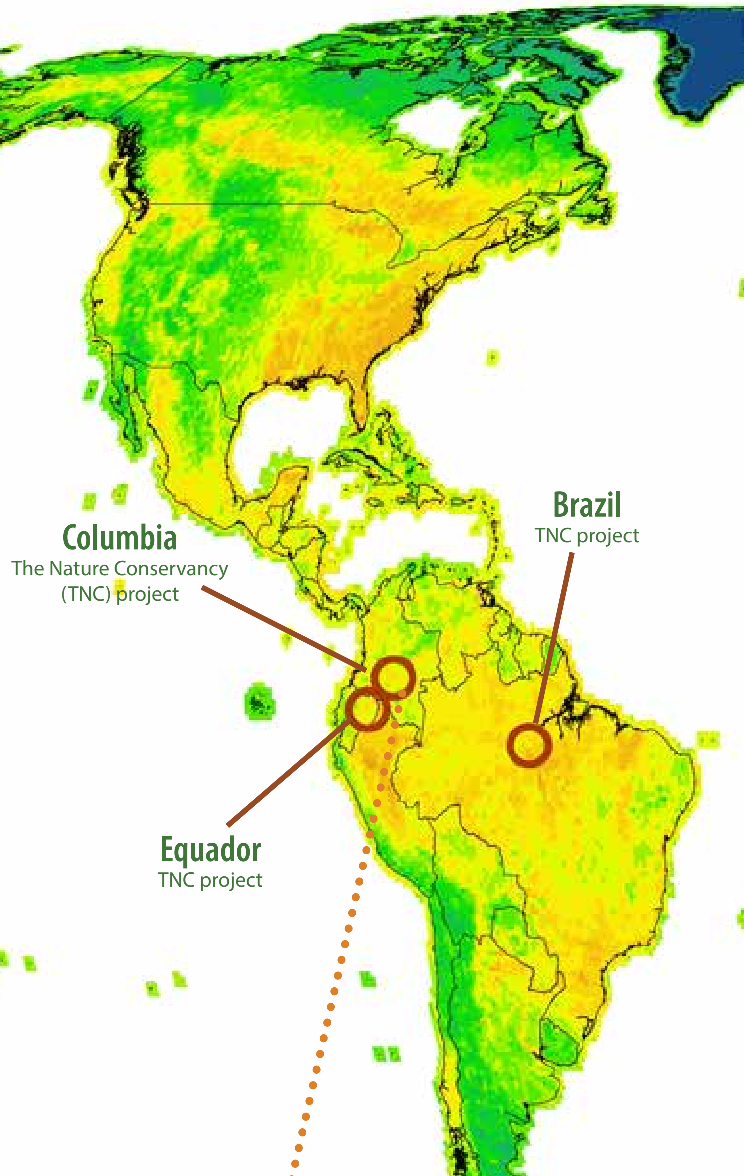
Combined Mercury Threat Assessment

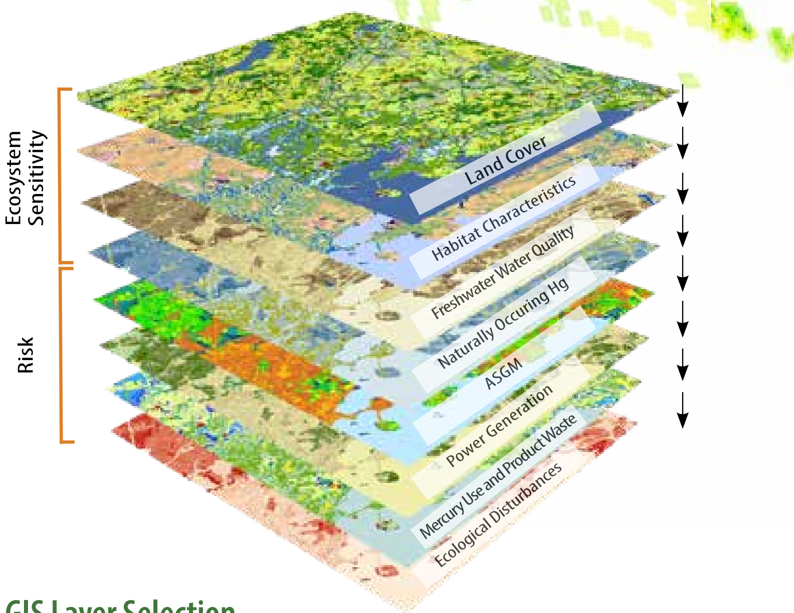
It is the combination of ecosystem sensitivity and risk of multiple mercury inputs that defines the overall threat of mercury contamination. Based on a well-established threat assessment methodology (Vörösmarty et al. 2010) we applied a simple 1:1 relationship—i.e., ecosystem sensitivity and risk are each weighted the same when they are combined together to assess overall threat ranking. The relative weights of other mapping inputs were primarily weighted equally based on expert input. It is our intent that over time, and with additional information from the field, that the relative weights of mapping input factors may be altered to better reflect reality.

Assessing Impacts to People and Nature

Humans are exposed to mercury primarily through diet; methylmercury is the predominant form of mercury found in fish (Sunderland, 2007). Exposure is known to cause adverse health effects particularly in young children and developing fetuses (Basu, et al. 2018).

Elevated mercury levels in fish can cause fish to suffer behavioral changes and reduced reproductive success. Mercury exposure can subsequently have adverse effects through the twin processes of biomagnification and bioaccumulation on the behavior and reproductive success of those that eat fish, including people, other mammals, and fish-eating birds.

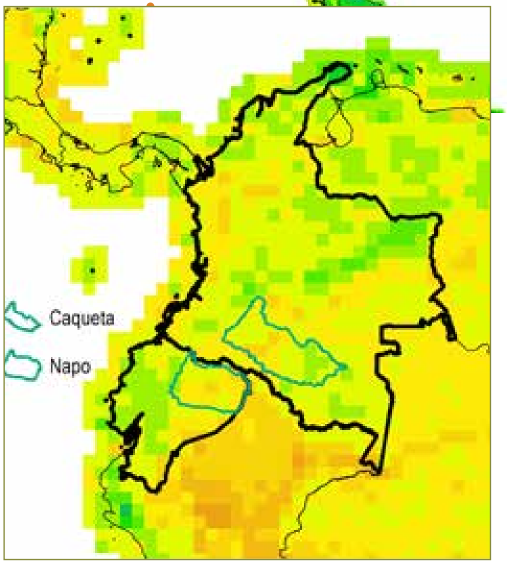




GIS Layer Selection

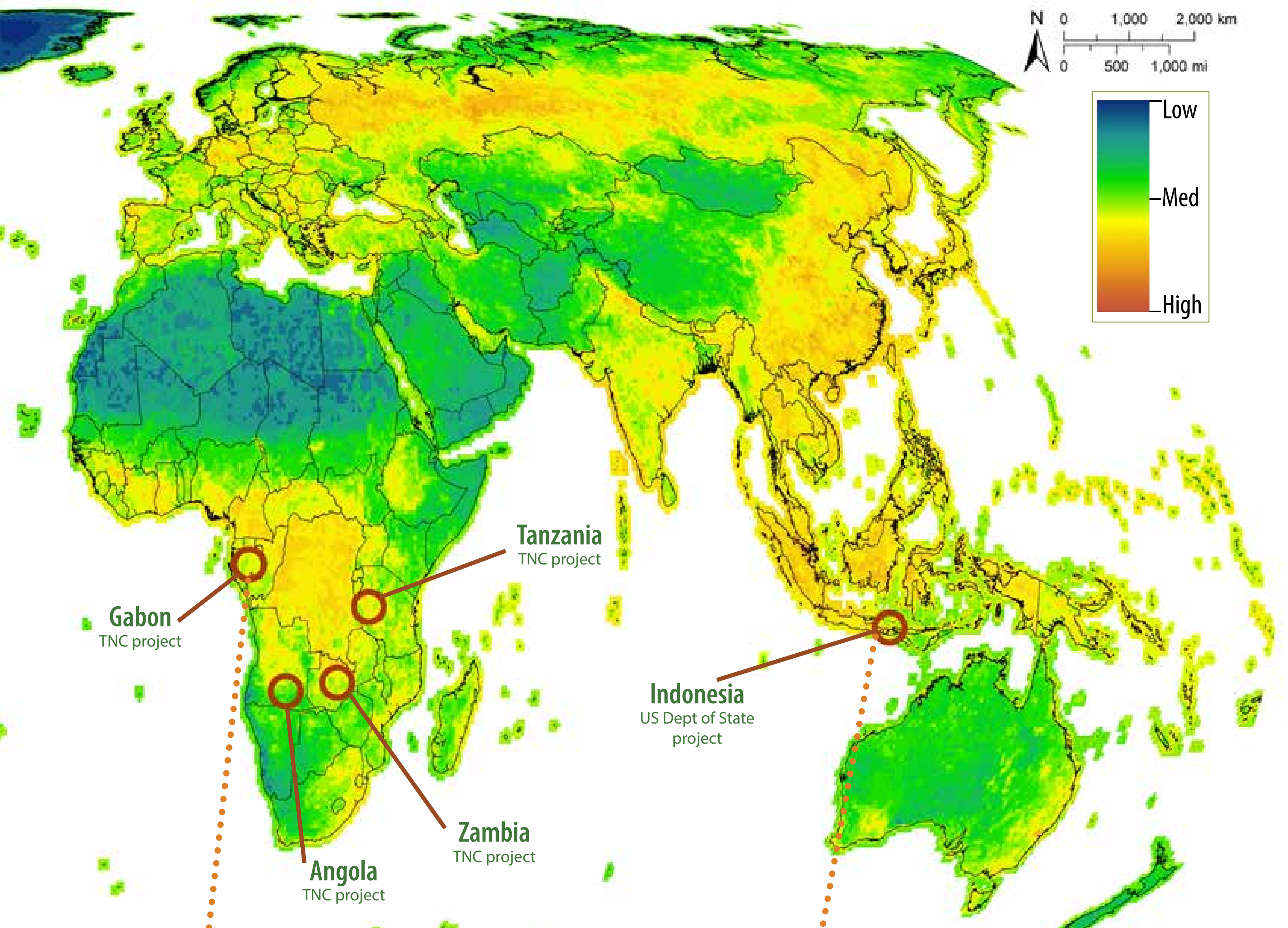
By combining spatial information on the distribution of habitats and species with the extent and severity of mercury contamination, it is possible to measure the ecosystem response and risk exposure to methylmercury availability (see Brazil Case Study, page 6).

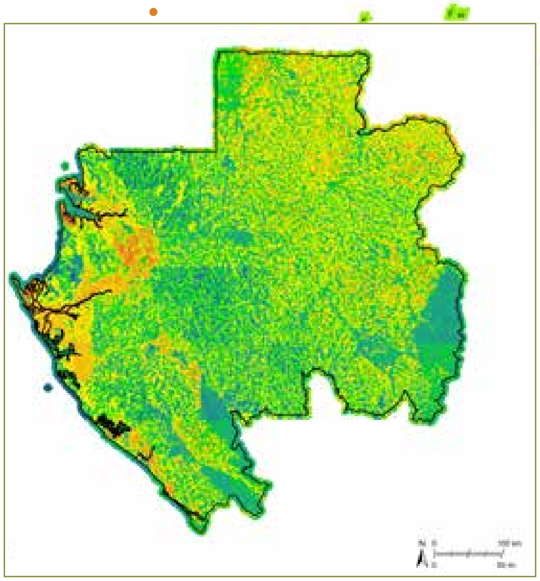
These data can be mapped to specific locations to better inform natural resource managers, regulators, and other decision makers to help prioritize resources to best protect human and ecosystem health.



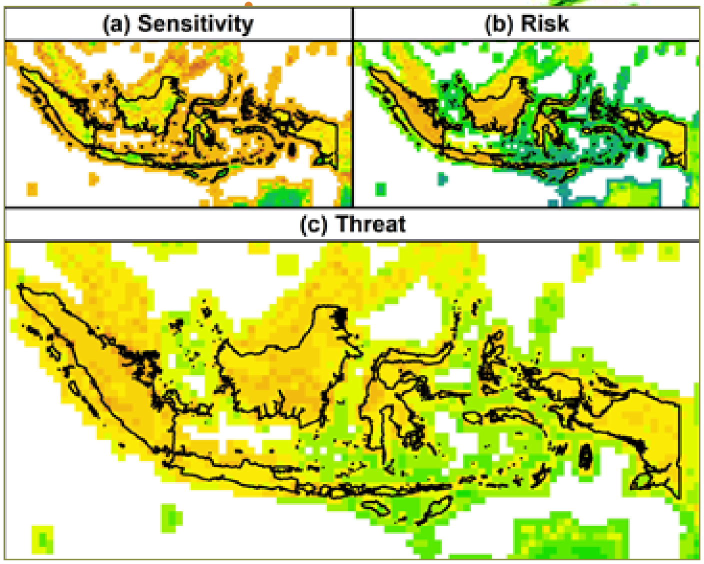
Enlargement of **Colombia and Ecuador Mercury Threat** map with Caquetá and Napo Watersheds highlighted to show landscape-scale variability.

A Global Assessment





Regional map of **Ecosystem Sensitivity in Gabon** illustrating additional detail possible from a Regional Mercury Threat Assessment (RMTA) vs. the GMTA.



Enlargement of Indonesia to illustrate how higher mercury risk in Indonesia has a greater influence than lower ecosystem sensitivity scores on the overall threat assessment.

CASE STUDY
BRAZIL

Analysis of fish found in Brazil in comparison to the rest of the Amazon basin (BRI 2021) revealed very similar patterns—similar fish species are much more impacted by mercury than others—likely the result of high sample sizes in Brazil for many fish families in relation to the rest of the Amazon basin (Figure 4).

Mercury in Fish and Human Health Risks

Many fish families have mean total mercury levels in the danger zone for human consumption. Published studies show that mercury contamination levels in people from the Tapajós region are far above all human health safety thresholds (Figure 5).

There was a significant difference observed in mercury concentrations between sexes in the Tapajós. There was no significant difference observed in mercury concentrations between age classes in the Tapajós. These results suggest that, while men who are miners are more highly contaminated, all people are being negatively impacted by ASGM activity.

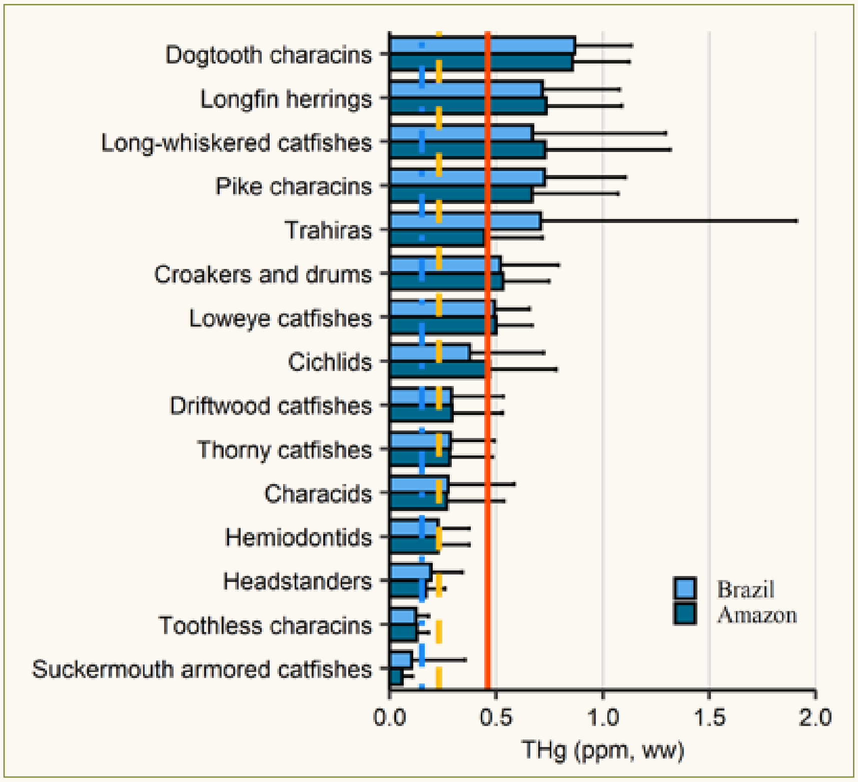


Figure 4. Fish mercury levels (by family) in Brazil in comparison to the Amazon Basin. Fish mercury levels derived from published values in BRI's Global Biota Mercury Synthesis (GBMS) database. Vertical, colored lines refer to screening threshold for human consumption (sidebar).

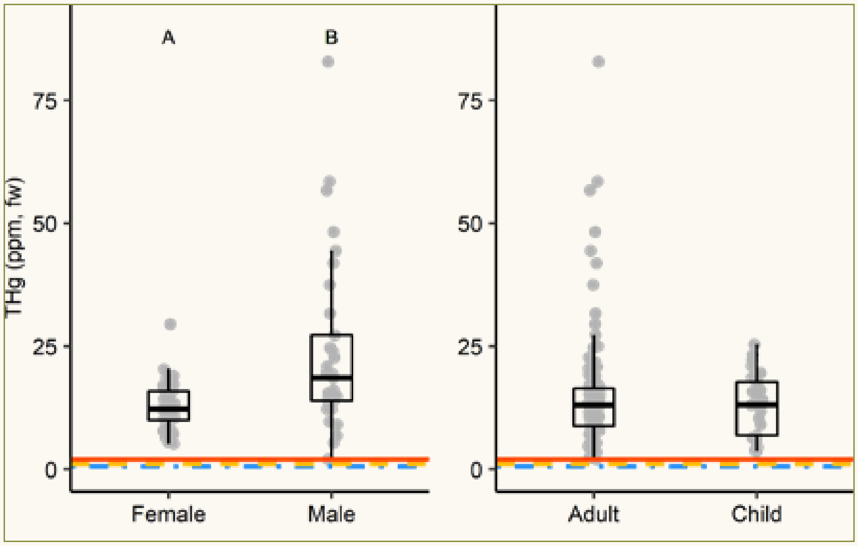


Figure 5. Distribution of mean hair total mercury in published literature for the Tapajós River Basin. Colored lines refer to screening thresholds (sidebar). All levels were well above safety thresholds.

Screening Thresholds

Screening thresholds for total mercury (THg) wet weight (ww) concentrations in fish and the potential impacts to people, fish, and birds that eat fish. Thresholds are illustrated graphically by colored lines:

Fish for human consumption (muscle)

- 0–0.15 ppm – Best Dietary Choices (below blue dotted line)
- 0.15–0.23 ppm – Good Dietary Choices (between blue and yellow dotted lines)
- 0.23–0.46 ppm – Not as Good Dietary Choices (between yellow dotted line and red solid line)
- > 0.46 – Choices to Avoid (above red solid line)
- > 1.0 – Choices to Avoid (above red solid line)

Fish (whole body)

- > 0.04 ppm – effects to reproductive success[1]
- > 0.30 ppm – reduced reproductive success[2]
- ≤ 0.1 ppm – No effect[3]

Fish for avian piscivores (whole body)

- 0.1–0.18 ppm – adverse effects on behavior of avian piscivores (~between blue and yellow dotted lines)
- 0.18–0.4 ppm– Significant reproductive impairment (~between yellow dotted line and red solid line)
- > 0.4 ppm – Reproductive failure (~above red solid line)

Human hair[4]

- ≤ 0.58 ppm – safe levels
- 0.58 - 1 ppm – reference dose
- 1.0 - 2.0 ppm – moderate
- ≤ 2 ppm – elevated

Threshold Data Sources: *US Food and Drug Administration; US Environmental Protection Agency; World Health Organizaiton; [1]Depew et al. 2012a; [2]Scheuhammer et al. 2015; [3]Depew et al 2012b; [4]Grandjean and Budtz-Jørgensen 2007, US EPA 1997, Basu et al. 2018*

Global Comparisons of Mercury as a Threat

Using the GMTA estimates of threat, risk, and sensitivity scores for each of the countries, it is possible to compare and contrast these areas to get a better understanding of the challenges they face in reducing mercury (Figure 6).

Mercury Threat Assessment Comparisons

Indonesia has a significantly higher mean threat level than all other seven countries in this assessment. There were significant differences observed in threat scores between focal countries.

Mercury Contamination Risk Assessment

Indonesia is well above all regional, continental, and global mean risk levels—representing very high risks of mercury contamination. However, Colombia has significantly higher mean risk levels, while Indonesia is statistically similar to Brazil at the country level. There were significant differences observed in risk scores between focal countries.

Ecosystem Sensitivity to Mercury Assessment

In marked contrast to the mercury threat and risk of contamination assessments above, ecosystem sensitivity displayed different patterns. Importantly, this is the only case where a continental average (Africa) was below the global average, and Oceania and Pacific Islands were the highest.

Similar to the threat assessment, Indonesia as a country had significantly higher ecosystem sensitivity than all the other countries, suggesting that ecosystem sensitivity drives much of its higher threat ranking. There were significant differences observed in sensitivity scores between focal countries.

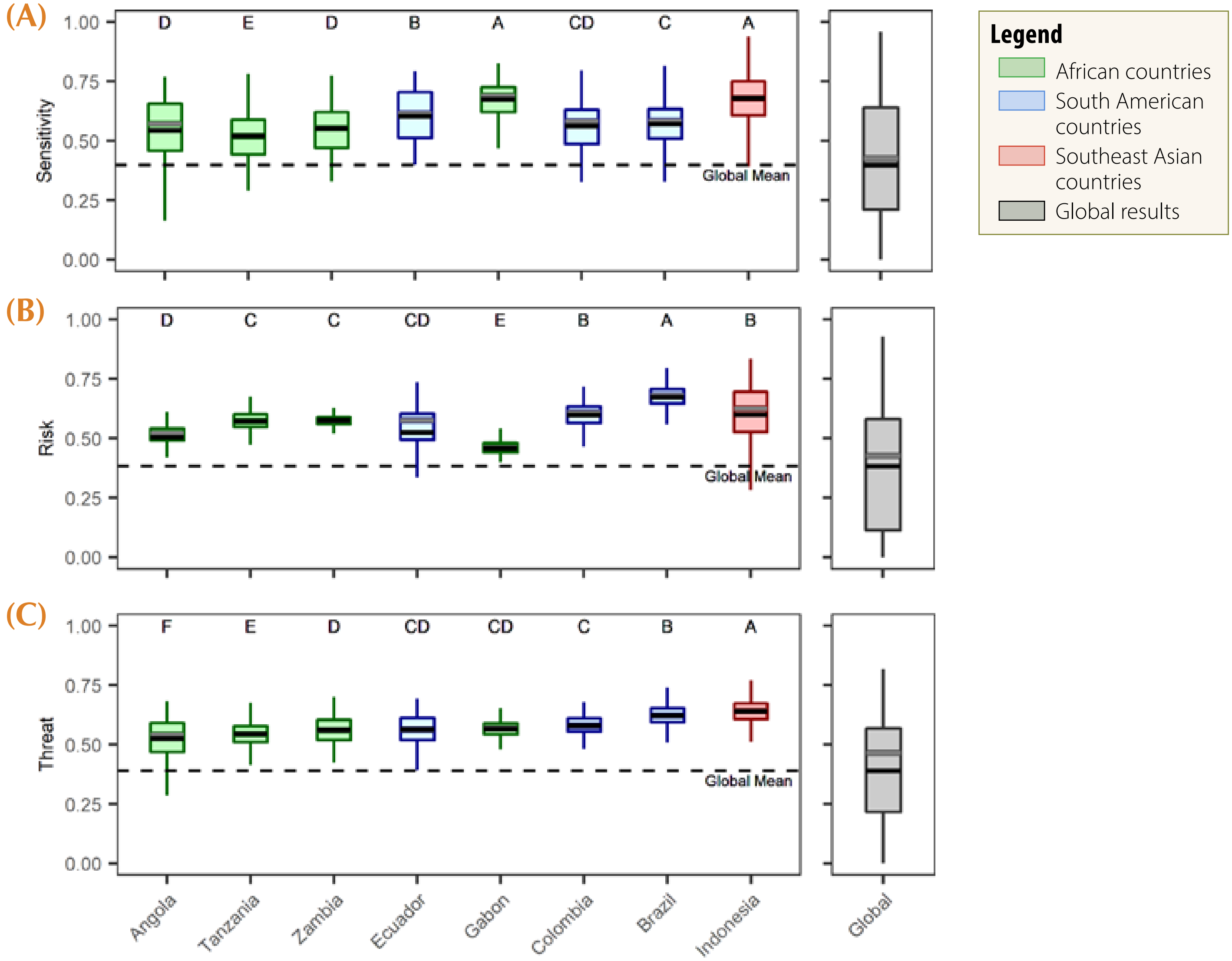


Figure 6. Boxplot and whisker diagrams of threat assessment scores for each country (left), compared to global results (right). Overall threat assessment values (A) are the combination of (B) risk of mercury contamination and (C) ecosystem sensitivity. Median and mean values are depicted by black and gray solid lines, respectively. Horizontal dashed lines indicate applicable continental and global means. Boxplots without letters in common are significantly different according to post-hoc analysis (p<0.05).

Conclusions and Next Steps

We recognize that the GMTA does not translate to evidence of impact in any given location. However, there is an abundance of evidence that supports significant impacts to nature and people in areas where the GMTA identifies high threat levels. For those countries that lack information on the threat of mercury contamination, this global map provides a starting point to assess the mercury threat level.

While ample evidence exists to show that mercury is having negative impacts to freshwater ecosystems and to the people that rely on the freshwater ecosystem services they provide, there is still great uncertainty and wide information gaps about mercury contamination levels, sources, and subsequent impacts in any given location. To help identify and structure effective threat reduction activities, it is necessary to find evidence of impacts, understand the influence of ecosystem sensitivity, and determine the source(s) of contamination in order to reduce the threat of mercury contamination.

Therefore, it is important to continue gathering data to validate/modify the GMTA and its relative factor weighting. In addition, it is critical to revise the GMTA for individual countries by replacing global datasets with more accurate and detailed local information. An example of finer level resolution from a Regional Mercury Threat Assessment (RMTA) is shown for Gabon on page 5 (GMTA insert map of Gabon). The process of developing RMTA for each country will help assess how more accurate spatial data, the relative weighting of GMTA inputs, or other factors directly influence levels of risk, sensitivity, and/or resultant threat levels.

To better assess the effectiveness of interventions designed to reduce the impacts of mercury to nature and people, we strongly encourage the use of maps that depict mercury contamination risks and ecosystem sensitivity to mercury methylation to develop efficient monitoring and evaluation efforts.

References

Basu, N., et al., 2018. A State-of-the-Science Review of Mercury Biomarkers in Human Populations Worldwide between 2000 and 2018. Environ Health Perspect, 126(10): p. 106001.

Bell, L. and Evers, D. 2021. Mercury exposure of women in four Latin American gold mining countries: Elevated mercury levels found among women where mercury is used in gold mining and contaminates the food chain. International Pollutants Elimination Network (IPEN), June 2021.

Boese-O'Reilly, S., et al., Signs and symptoms of mercury-exposed gold miners. Int J Occup Med Environ Health, 2017. 30(2): p. 249-269.

BRI. 2021. Global Biomonitoring Mercury Synthesis (GBMS) database.

Depew, D.C., Basu, N., Burgess, N.M., Campbell, L.M., Evers, D.C., Grasman, K.A. and Scheuhammer, A.M. 2012a. Derivation of screening benchmarks for dietary methylmercury exposure for the common loon (Gavia immer): rationale for use in ecological risk assessment. Environmental Toxicology and Chemistry 31:2399-2407.

Depew, D.C., Basu, N., Burgess, N.M., Campbell, L.M., Devlin, E.W., Drevnick, P.E., Hammerschmidt, C.R., Murphy, C.A., Sandheinrich, M.B. and Wiener, J.G. 2012b. Toxicity of dietary methylmercury to fish: derivation of ecologically meaningful threshold concentrations. Environmental Toxicology Chemistry 31:1536-1547.

Evers, D.C. 2018. The Effects of Methylmercury on Wildlife: A Comprehensive Review and Approach for Interpretation, in: Dellasala, D.A., Goldstein, M.I. (Eds.), Encyclopedia of the Anthropocene. Elsevier, Oxford, pp. 181–194. https://doi.org/10.1016/B978-0-12-809665-9.09985-7

Evers, D.C., Han, Y., Driscoll, C.T., Kamman, N., Goodale, M.W., Lambert, K.F., Holsen, T.M., Chen, C., Clair,T.A., and Butler, T. 2007. Biological Mercury Hotspots in the Northeastern United States and Southeastern Canada, BioScience, Volume 57, Issue 1, January 2007, Pages 29–43, https://doi.org/10.1641/B570107

Grandjean, P. and Budtz-Jørgensen, E., 2007. Total imprecision of exposure biomarkers: implications for calculating exposure limits. American journal of industrial medicine, 50(10): pp.712-719.

Hsu-Kim, H., C.S. Eckley, D. Achá, X. Feng, C.C. Gilmour, S. Jonsson and C.P. Mitchell. 2018. Challenges and opportunities for managing aquatic mercury pollution in altered landscapes. Ambio 47:141-169.

Hsu-Kim, H, KH Kucharzyk, T Zhang, MA Deshusses. 2013. Mechanisms regulating mercury bioavailability for methylating microorganisms in the aquatic environment: a critical review. Environmental Science and Technology 47:2441-2456

Ismawati, Y., Zaki, K., and Septiono, M.A. 2018. Mercury Country Situation Report Indonesia. IPEN and Balifokus. 45 pp.

Podar, M., Gilmour, C.C., Brandt, C.C., Soren, A., Brown, S.D., Crable, B.R., Palumbo, A.V., Somenahall, A.C., and Elias, D.A. 2017. Global prevalence and distribution of genes and microorganisms involved in mercury methylation. Science Advances 1: DOI: 10.1126/sciadv.1500675

Scheuhammer, A., Braune, B., Chan, H.M., Frouin, H., Krey, A., Letcher, R., Loseto, L., Noël, M., Ostertag, S., Ross, P., Wayland, M., 2015. Recent progress on our understanding of the biological effects of mercury in fish and wildlife in the Canadian Arctic. Sci. Total Environ. 509–510:91–103.

Shanley, J. B. and Bishop, K. "CHAPTER 8. Mercury Cycling in Terrestrial Watersheds". Mercury in the Environment: Pattern and Process, edited by Michael S. Bank, Berkeley: University of California Press, 2012, pp. 119-142. https://doi.org/10.1525/9780520951396-012

Spiegel, S. and M.M. Veiga, Global Impacts Of Mercury Supply and Demand In Small-Scale Gold Mining. 2006, GEF UNDP UNIDO: Nairobi.

Steckling, N., et al., Global Burden of Disease of Mercury Used in Artisanal Small-Scale Gold Mining. Ann Glob Health, 2017. 83(2): p. 234-247.

Sunderland, E.M. 2007. Mercury exposure from domestic and imported estuarine and marine fish in the U.S. seafood market. Environmental Health Perspectives. 115(2): 235-242. https://doi.org/10.1289/ehp.9377

UN Environment Programme, 2019. Global Mercury Assessment 2018. UN Environment Programme, Chemicals and Health Branch Geneva, Switzerland

US EPA (1997) Mercury study report to Congress, Volume IV, An assessment of exposure to mercury in the United States. EPA-452/R-97-006

Vörösmarty, C., McIntyre, P., Gessner, M. et al. Global threats to human water security and river biodiversity. Nature 467, 555–561 (2010). https://doi.org/10.1038/nature09440.

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Biodiversity Research Institute
innovative wildlife science

For more information:
Timothy.Tear@briwildlife.org
www.briwildlife.org/mercury

The Nature Conservancy

Credits

Editorial and Production: Deborah McKew

Maps and Graphs: Mark Burton

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