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Modern science of a legacy problem: mercury biogeochemical research after the Minamata Convention

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In the summer of 2017 the Minamata Convention on Mercury entered into force, marking a new phase in global efforts to protect human health and the environment from the deleterious effects of mercury pollution. This global treaty, with 91 parties as of April 2018, builds upon decades of scientific research on mercury. This work describes the harmful effects of mercury for human health, delineates the factors that influence the distribution and transformation of mercury compounds in the environment, and recommends potential strategies to reduce the impacts of mercury on people and ecosystems.

As the implementation of this treaty creates new momentum to reduce human and ecological risks of mercury, one may wonder in the face of the tremendous body of scientific work:

What is new about mercury science? What are the ongoing research challenges?

While considerable progress has been made to understand the underlying processes influencing the environmental distribution and exposures of mercury, major uncertainties remain that hinder progress towards effective solutions. This themed issue of *Environmental Science: Processes & Impacts*, representing research presented at the 13th International Conference on Mercury as a Global Pollutant in July 2017 in Providence (USA), exemplifies the forefront of environmental mercury research. These studies address key knowledge gaps that generally fall within three major themes of contemporary environmental mercury science.

A first common theme is the study of mercury compounds in connection with the cycling of other key elements as well as anthropogenic and natural landscape disturbances. For example, the study described by Jensen and coauthors (DOI: [10.1039/c7em00419b](https://doi.org/10.1039/c7em00419b)) illustrates how the transport of Hg in watersheds is closely linked to the transport of organic carbon, particularly under drastic landscape alterations such as wildfires. Likewise, the bioaccumulation of methylated mercury in fish can be driven by local landscape characteristics, such as percent wetlands as described by Kerfoot and coauthors (DOI: [10.1039/c7em00521k](https://doi.org/10.1039/c7em00521k)). These landscape drivers persist even with recent decreases in

atmospheric mercury loadings. As global climate change is expected to lead to impacts on landscapes (*e.g.*, drought, flooding), the biogeochemical cycling of mercury is also expected to change.

The concept of coupled cycles and coupled processes is especially relevant for managed ecosystems, where actions to address a specific water management problem may increase or decrease concerns about mercury pollution. For instance, active ecological restoration of deforested landscapes, as described by Couic and coauthors (DOI: [10.1039/c8em00016f](https://doi.org/10.1039/c8em00016f)), often aims to improve overall soil quality and nutrient cycling, but could also reduce mercury mobility. The application of lime to address acidification problems in surface waters (Millard *et al.*, DOI: [10.1039/c7em00520b](https://doi.org/10.1039/c7em00520b)) could unintentionally increase organic carbon and methylmercury loadings to surface waters; however, the Millard study suggests that the duration of this impact may be limited at their study site in the Adirondacks region of the northeastern United States. Stormwater retention ponds, which are frequently employed in urbanized landscapes, have the potential to be sources of methyl-mercury to adjoining waterbodies; however, Strickman and Mitchell (DOI: [10.1039/c7em00486a](https://doi.org/10.1039/c7em00486a)) show that their impacts on methylmercury production are less than those of natural wetland habitats of similar size.

A second theme in contemporary mercury science is the documentation of mercury pollution in previously unrecognized or sparsely populated locations. For example, the widespread practice of mercury amalgamation during artisanal and small-scale gold mining has been acknowledged as a major source of global atmospheric mercury emissions. This practice has also led to mercury pollution in new locations (mostly in developing nations) with understudied ecological systems with respect to mercury cycling. The end result is the potential for mercury exposure to communities with health vulnerabilities that are not the same as those in more developed nations with well-studied health impacts of mercury exposure. Policies have been implemented to better manage mercury discharges from artisanal mining operations through centralized waste handling policies. However, regulated controls on informal or already illegal practices may have limited effect, as documented by Marshall and coauthors (DOI: [10.1039/c7em00504k](https://doi.org/10.1039/c7em00504k)) in the Puyango-Tumbes basin of Peru and Ecuador.

A third major mercury research theme is the discovery and utilization of new tools and approaches to study mercury biogeochemical processes. This work is leading to exciting discoveries that improve models for assessing mercury bioavailability and exposure risk. In addition, the new methods also help with source attribution of mercury pollution which is critical for targeted and effective remediation strategies. For example, Demers and coauthors (DOI: [10.1039/c7em00538e](https://doi.org/10.1039/c7em00538e)) used stable isotopic signatures for mercury to differentiate between in-stream processes and upland legacy inputs to a headwater stream that is severely impaired due to historical mercury pollution. Similarly, Baptista-Salazar and coauthors (DOI: [10.1039/c7em00443e](https://doi.org/10.1039/c7em00443e)) used mercury isotopic signatures as a way to understand mercury species transformations and sources in a watershed impacted by legacy mining and more recent atmospheric deposition sources. The inclusion of mercury isotope signatures in the Marshall study also helped to determine the impacts of modern artisanal mining activities in the Puyango-Tumbes.

Molecular-based approaches are greatly improving the scientific understanding of mercury processing in the environment. These approaches include biomolecular tools to quantify mercury methylating microorganisms, such as the example provided by Vishnivetskaya and coauthors in rice paddy soils (DOI: [10.1039/c7em00558j](https://doi.org/10.1039/c7em00558j)). We are also improving our knowledge of the chemical mechanisms of mercury transformations, such as the Kanzler *et al* study (DOI: [10.1039/c7em00533d](https://doi.org/10.1039/c7em00533d)), which provides a detailed report of the abiotic decomposition process of methylmercury by sulfide through a combination of experimental and chemical computation methods. Similarly, Mazrui and coauthors studied nanoscale mercury-sulfide interactions with organic matter using experimental tools that have recently evolved with developments in the nanosciences (DOI: [10.1039/c7em00593h](https://doi.org/10.1039/c7em00593h)).

While recent developments in the environmental mercury sciences could ultimately help improve policies, many scientific challenges persist. The risk driver for mercury pollution (*i.e.*, human exposure to methylmercury *via* fish) typically involves processes ranging from molecular scale chemical/biochemical interactions to ecological (organisms-to-organisms) interactions. Thus to inform better management, researchers will need to tackle the challenge of linking mercury processes across temporal and spatial scales, especially in locations with a mixture of legacy and contemporary mercury inputs. Ecosystem management can have a wide range of impacts on mercury cycling, and understanding these processes requires interdisciplinary research approaches. Finally, the environmental cycling of mercury is intimately linked to societal policies and individual human behaviors in complex and substantial ways. As such, future scientific mercury research needs to draw insights from social science disciplines in order to understand the cycling and impacts of mercury pollution.