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# Connecting mercury science to policy: from sources to seafood

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**Abstract:** Mercury (Hg) is a global contaminant whose presence in the biosphere has been increased by human activity, particularly coal burning/energy production, mining, especially artisanal scale gold mining, and other industrial activities. Mercury input to the surface ocean has doubled over the past century leading governments and organizations to take actions to protect humans from the harmful effects of this toxic element. Recently, the UN Environmental Program led 128 countries to negotiate and sign a legally binding agreement, the 2013 Minamata Convention, to control Hg emissions and releases to land and water globally. In an effort to communicate science to this emerging international policy, the Dartmouth Superfund Research Program formed the Coastal and Marine Mercury Ecosystem Research Collaborative (C-MERC) in 2010 that brought together more than 70 scientists and policy experts to analyze and synthesize the science on Hg pollution in the marine environment from Hg sources to MeHg in seafood. The synthesis of the science revealed that the sources and inputs of Hg and their pathways to human exposure are largely determined by ecosystem spatial scales and that these spatial scales determine the organizational level of policies. The paper summarizes the four major findings of the report.

**Keywords:** mercury policy; mercury pollution; minamata treaty; seafood contamination.

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## Introduction

Mercury (Hg) is a global contaminant whose presence in the biosphere has been increased by human activity, particularly coal burning/energy production, mining, especially artisanal scale gold mining, and other industrial activities (1–3). In the US, Hg is the third most important contaminant on the CERCLA Priority List of Hazardous Substances (4). It strongly bioaccumulates in its organic form, methylmercury (MeHg), driving exposure of this potent toxin with neurological, immunological, and cardiovascular effects (5–8). Consumption of MeHg contaminated fish is a serious public health concern and 50 US states have MeHg consumption advisories, including advisories for coastal waters where subpopulations of recreational and subsistence fishermen are at high risk for MeHg exposure. Exposure to Hg through fish consumption is a concern even in relatively pristine environments, as Hg is readily transported through the atmosphere and can be deposited both nearby and far from source areas (1, 9–11). Marine ecosystems are critical environments for Hg contamination because human exposure to MeHg primarily occurs through the consumption of seafood. Approximately 92% of the global fish harvest for human consumption consists of marine fish with the majority coming from the coastal fisheries.

Mercury input to the surface ocean has doubled over the past century leading governments and organizations to take actions to protect humans from the harmful effects of this toxic element. Most of the legacy Hg in the atmosphere and oceans has come from historic industrial development in North America and Europe (12). However, 40% of the current Hg emissions to the atmosphere now originate from East and Southeast Asia largely by coal combustion and artisanal scale gold mining (12). In the US, President Obama signed the Hg and Air Toxics Standard (MATS) in 2011 for controlling atmospheric emissions predominantly from coal fired power plants. Internationally, the UN Environmental Program led 128 countries to negotiate and sign a legally binding agreement, the 2013 Minamata Convention, to control Hg emissions and releases to land and water globally. Regulations on Hg emissions will

undoubtedly decrease new inputs of Hg into aquatic ecosystems, yet legacy Hg as well as continuing atmospheric inputs will still pose risks to human health through bioaccumulation and biomagnification for decades into the future. Rates of change of Hg in food webs may not reflect the same rate of decrease in primary anthropogenic emissions due to local-scale processes, recycling of Hg between the atmosphere and the ocean and terrestrial environments, and the impact of influential variables other than emission or deposition rates (13–19). Understanding linkages between environmental processes and human health is critical to understanding risk and predicting how and to what magnitude both small- and large-scale changes in environment variables will influence human exposure, particularly to vulnerable populations.

## Methods

In 2010, the Dartmouth Superfund Research Program formed the Coastal and Marine Mercury Ecosystem Research Collaborative (C-MERC) that brought together more than 70 scientists and policy experts to analyze and synthesize the current science on Hg pollution in the marine environment from Hg sources to MeHg in seafood. In 2012, C-MERC authors published a series of 11 papers in the peer reviewed journals (*Environmental Health Perspectives* and *Environmental Research*) and produced a synthesis report, “Sources to Seafood: Mercury Pollution in the Marine Environment” (20), based on these papers and the literature in order to inform policies and management actions under consideration at the local, national and international level to limit Hg exposure and safeguard human health.

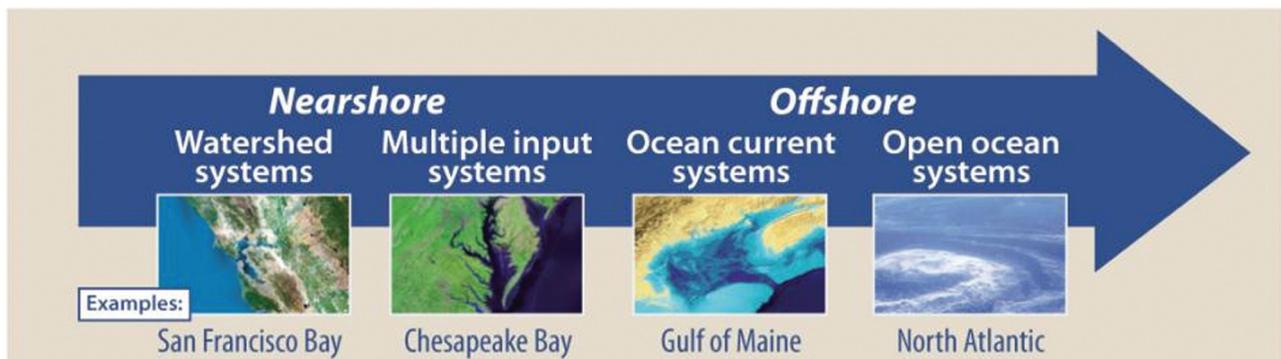
## Findings and conclusion

The synthesis of the science on Hg pollution in marine systems revealed that the sources and inputs of Hg and

their pathways to human exposure are largely determined by ecosystem spatial scales. Those scales ranging from small marine ecosystems to large determine the main sources and endpoints of Hg pollution, and MeHg bioaccumulation. The inorganic Hg inputs to systems ranging from small embayments to the open ocean include river inputs, internal inputs (sediments), ocean currents, and the atmosphere (Figure 1). Human exposure to Hg pollution via MeHg exposure from fish consumption is also determined by ecosystem scale because marine fisheries range from local fisheries in small bays and estuaries to the global open ocean fisheries. The smaller ecosystems are strongly linked to local releases of Hg from watersheds, and the potential for external inputs of MeHg, whereas the larger open oceans mostly receive atmospheric inputs of Hg, and most MeHg is produced in situ. Lastly, the management of Hg sources that ultimately lead to human exposure to MeHg is also determined by ecosystem scale: local scale sources and inputs need to be controlled by local or regional policies, while atmospheric sources and inputs must be managed with national policies and international treaties like the Minamata Convention (Figure 2).

Four major findings emerged from the C-MERC synthesis involving the different pathways between Hg inputs, types of marine ecosystems, and consumers of seafood:

1. Mercury pollution is ubiquitous in the world’s oceans and coastal waters. Therefore, MeHg contaminates most fish and other seafoods that are important sources of protein and nutrition for people worldwide. Despite improvements in some regions, MeHg in commonly consumed marine fish continues to exceed human health guidelines, and Hg pollution is increasing.
2. Mercury pollution enters the marine environment along distinct pathways that are linked to different Hg sources. Atmospheric inputs from global sources of Hg



**Figure 1:** Scales of mercury inputs to marine ecosystems from estuaries to the open ocean. Reproduced from Ref. (20, p. 10).



Figure 2: Scales of mercury policies from the local to the global. Reproduced from Ref. (20, p. 19).

emissions dominate the “open ocean” and “ocean current” (large coastal ocean) systems. Riverine Hg inputs dominate coastal waters that are “watershed systems”. Some coastal waters are “multiple input” systems that reflect both atmospheric and riverine inputs.

3. Many seafood consumers are “general consumers” whose MeHg exposure comes from fish typically harvested from the open oceans that receive high atmospheric inputs from global Hg emission sources. “Local consumers” generally eat seafood from nearby coastal waters that are contaminated by riverine inputs from local, regional, and global sources of Hg.
4. We anticipate that MeHg concentrations in marine fish will decline roughly in proportion to decreases in Hg inputs, though the timing of the response will vary. Specifically, MeHg in open ocean fish will likely begin to decrease within many years to decades after emissions controls because production of MeHg mostly occurs in the upper ocean where most fish feed. In contrast, MeHg in fish from coastal systems contaminated by legacy Hg may take many decades, or even centuries, to fully reflect the declines in inputs, because of the slower rate of burial in coastal sediments and the continued inputs from the watershed.

The Minamata Convention is currently being ratified by signatory countries. To date, 19 of the 128 signatories have ratified the Convention with 50 countries needed for the convention to come into force (21). In the meantime, Hg scientists around the world are continuing to investigate and understand the spatial and temporal patterns of Hg sources, inputs, concentrations in the oceans and its food webs, as well as the extent and degree of human exposure (22). Moreover, the future implementation of the Convention will require effectiveness evaluation and Hg

scientists are working to build a framework for a global monitoring system which will be based on current monitoring programs and will be expanded to include new monitoring sites and additional endpoints. The local to global scale of the Hg pollution problem requires policy solutions at local to international levels for decreasing Hg pollution in the environment.

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