2012

Marine Mercury Fate: From Sources to Seafood Consumers

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Recommended Citation

Chen, Celia Y., Driscoll, Charles T., Lambert, Kathleen F., Mason, Robert P., Rardin, Laurie R., Serrell, Nancy, & Sunderland, Elsie M. (2012). Marine mercury fate: From sources to seafood consumers. Environmental Research, 119(0), 1-2. doi: http://dx.doi.org/10.1016/j.envres.2012.10.001

EDITORIAL: Marine mercury fate: from sources to seafood consumers

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Mercury in the biosphere has markedly increased over the past century leading governments around the world to consider policies that would reduce sources to limit human exposure to this global contaminant. The nine articles in this issue provide a synthesis of the science on the sources, fate, and human exposure to mercury (Hg) in marine systems. These papers along with two papers recently published in *Environmental Health Perspectives* are the products of two workshops convened by the Coastal and Marine Mercury Ecosystem Research Collaborative (C-MERC) sponsored by the Dartmouth Superfund Research Program. In September 2010 and July 2011 we brought together scientists and policy stakeholders to compile and distill information on the inputs, cycling and uptake of Hg in marine ecosystems and the links to fish, wildlife and human exposure to methylmercury (MeHg), the most bioaccumulative form of this global contaminant. The goal of this C-MERC effort was to provide a summary of the current science relevant to public policies being considered at the regional, national and global level, such as the effort of the United Nations Environment Programme to establish the first International Mercury Treaty.

Seven papers in this special issue review the pathways and transformations of Hg and MeHg from sources to seafood consumers in specific marine ecosystems. These include: the Gulf of Maine (Sunderland et al. 2012),;the Gulf of Mexico (Harris et al. 2012a, b); San Francisco Bay (Davis et al. 2012); the Arctic Ocean (Kirk et al. 2012),;Tropical Oceans (Costa et al. 2012); and the global oceans (Mason et al. 2012). The paper by Driscoll et al. (2012) presents a conceptual model of interactions between Hg cycling and nutrient loading in marine ecosystems and the paper by Lambert et al. (2012) provides a review of Hg science on marine ecosystems and implications for policy. The C-MERC papers published in *Environmental Health Perspectives* focused on human health effects of low level methylmercury (MeHg) exposure (Karagas et al. 2012) and on the complexities of providing clear, unified fish consumption advice (Oken et al. 2012).

Coal burning and energy production along with mining and industrial activities have led to increased mercury in the environment (Mason et al. 1994; Driscoll et al. 2007; Selin et al. 2008). Mercury is ranked third on the Agency for Toxic Substances and Disease Registry's priority list of contaminants that pose significant human health threats to the U.S. population (ATSDR 2007). More than 90 percent of Hg exposure in the U.S. comes from consumption of estuarine and marine fish contaminated by MeHg, the most bioavailable form (Sunderland 2007; Chen et al. 2008). This exposure is the result of consuming higher trophic level fish, which generally have higher MeHg concentrations, in combination with more frequently eaten lower trophic level species (e.g., pollock, crabs, shrimp). Due to this widespread human exposure, all 50 U.S. states have established fish consumption advisories for Hg, and most U.S. coastal states on the Atlantic Ocean have statewide coastal advisories (USEPA 2008; Schmeltz et al. 2011). Though most people in the U.S. are exposed to MeHg through consumption of open ocean fish, coastal populations have higher exposure through local/subsistence consumption of regional coastal fisheries.

Ocean systems included in this special issue represent a broad range of management challenges for MeHg contamination due to 1) physical characteristics, 2) dominant Hg sources and MeHg inputs, and 3) different human fish consumption patterns. The relative contribution of different sources of Hg (direct atmospheric inputs, watershed inputs, and exchange at the ocean system boundaries) varies greatly but tends to scale with ocean system size; the larger the water surface area, the more significant are direct atmospheric sources and *in situ* water column production of MeHg, and the less dominant are watershed and coastal point sources.

Offshore Hg concentrations in open ocean fish are determined by direct atmospheric inputs, which are transferred via lateral currents to sites of Hg methylation. As a result, MeHg levels in open ocean fish reflect atmospheric deposition on a global scale (Mason et al. 2012, this issue). Modeling studies and measurements suggest that while Hg in the open oceans and MeHg in ocean fish will decrease immediately in response to decreases in atmospheric emissions it will take many decades for these reductions to be fully realized. These declines will benefit the general population of fish consumers who tend to eat grocery store fish harvested from the open ocean (e.g., canned tuna).

Marine inshore Hg levels are primarily influenced by coastal and watershed inputs (e.g., point source discharges, legacy contamination, and indirect atmospheric inputs). However, there are also substantial differences across coastal regions in their ability to convert inorganic Hg to MeHg. Hg concentrations of fish in coastal waters have been shown to respond in the short term to control of local Hg discharges which are methylated in coastal sediments. Coastal monitoring data suggest that the measurable impacts on fish MeHg concentrations will yield benefits to local fishers who consume recreationally caught fish from adjacent coastal waters (Sunderland et al. 2012, this issue).

Hg fate and bioavailability in marine systems and associated human exposure are also affected by confounding factors such as nutrients and climate change. A conceptual model testing for interactions of nitrogen inputs and Hg bioavailability indicates that increased nutrient concentrations relate to decreased Hg and MeHg in marine organisms (Driscoll et al. 2012, this issue). Climate change will also alter marine ecosystems in ways that will influence Hg fate but these impacts are not yet fully understood. Melting sea ice in the Arctic will alter food webs and mercury biomagnification by forcing animals such as Arctic cod that normally live beneath the ice to feed instead in surface waters where mercury is more available (Kirk et al. 2012, this issue). Changes in ocean temperatures will also alter zones of MeHg production in the open ocean as well as ocean currents that transport Hg between ocean basins. These confounding factors suggest that need for greater attention and resources for mercury monitoring in coastal and marine systems in order to accurately assess the efficacy of national and international policy and associated declines in Hg inputs (Evers et al. 2008; Lambert et al. 2012).

Scientific research on Hg fate, and MeHg production and bioaccumulation has had an important role in informing and motivating policy. However, a number of challenges particular to MeHg fate and transport in marine systems have hindered progress in the policy arena (Lambert et al. 2012). These challenges will benefit from a strong international agreement that addresses: the transboundary nature of Hg including an emphasis on atmospheric emissions; expanded cost benefit analyses that account for the human and ecological health effects of MeHg,;investment in management trials for mitigating the on-going contamination of legacy sources; and a comprehensive and integrated global mercury monitoring network with periodic assessments (Lambert et al. 2012).

Current research indicates that mercury contamination of marine systems has important implications for human health. Fortunately, as policy makers gather to discuss remedies at all scales of government, a large body of mercury research can inform their decision-making. This special issue on mercury in marine ecosystems is the product of a group of scientists and stakeholders who participated in the C-MERC effort to bring science to the policy table.

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