Mercury in Aquatic Ecosystems—

Recent findings from the National Water-Quality Assessment (NAWQA) and Toxic Substances Hydrology Programs (as presented to the NAWQA National Liaison Committee, August 21, 2009)

Selected Highlights:

- Methylmercury—the most toxic form of mercury in the environment and the form most readily taken up by aquatic organisms—is formed in wetlands and other seasonally inundated areas in watersheds, and then transported to streams by runoff.
- Although aquatic ecosystems across the US receive mercury from atmospheric deposition, watershed properties—particularly wetlands, which contribute elevated dissolved organic carbon (DOC)—drive variations in methylmercury concentrations in surface waters.
- The most important influence on mercury levels in fish is the amount of methylmercury that is available for uptake into the food web. Once mercury accumulates in aquatic food webs, its rate of biomagnification (from algae to invertebrates to fish) is similar across diverse environmental settings.
- The highest levels of mercury in game fish across the Nation occur in forested watersheds with high densities of wetlands and DOC, such as the coastal plain streams of the eastern and southeastern US.
- Methylmercury contamination in aquatic ecosystems can be predicted using watershed characteristics (wetland density, and surface water DOC, pH, and sulfate).
- Recently deposited mercury is more efficiently converted to methylmercury and bioaccumulated in aquatic environments than historically deposited mercury.
- Understanding where and how mercury is cycled through water, streambed sediment, and aquatic organisms improves our understanding of where elevated mercury may occur in recreationally important game fish. Findings are critical for decision makers to effectively manage mercury sources and to better anticipate concentrations of mercury and methylmercury in unstudied streams in comparable environmental settings.

Background

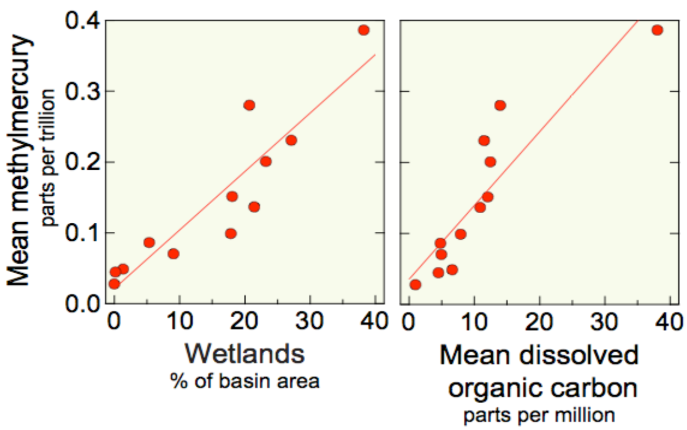
Mercury is a neurotoxin that is present in fish across the globe at levels that threaten human and wildlife health. In the US, 48 of 50 States have fish consumption advisories for mercury (http://www.epa.gov/waterscience/fish/advisories/). Understanding how mercury moves through the environment—where it comes from and how it ends up in commercially and recreationally important fish—is critical to the effective management of mercury sources and to the prediction of how ecosystems (watersheds) respond to changes in mercury loading.

Recently, the U.S. Geological Survey (USGS) investigated the **source, transport, and transformation** of mercury in eight streams across the Nation, addressing the relative importance of each of these processes to the **bioaccumulation** of mercury in game fish. These stream studies cover a large range in environmental and land-use settings—including urban and undeveloped lands, climatic conditions, and atmospheric mercury deposition—over a 3-4 year period. The USGS also investigated **national-scale geographic patterns** and long-term trends in mercury contamination.

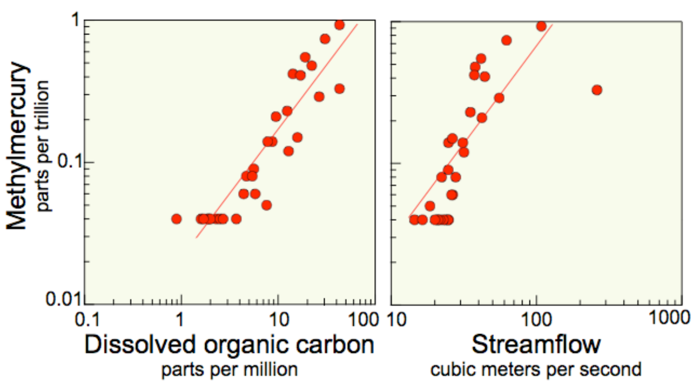
How does mercury get from its source to fish?

Mercury source to streams

Although mercury is a natural element, man's activities have resulted in significant changes in the amount and distribution of this toxic metal in the environment. Inorganic mercury is deposited onto the landscape either directly (industrial discharge, mining) or indirectly (atmospheric deposition of emitted mercury). Once deposited, some of the inorganic mercury is converted to methylmercury (an organic form) in wetlands and other seasonally inundated areas within watersheds; methylmercury is subsequently delivered to streams during runoff events.



Concentrations of methylmercury in streams increase as wetland density in the watersheds and dissolved organic carbon in the streams increase. *(Data represent 12 streams in Oregon, Minnesota, Wisconsin, and Florida that drain watersheds spanning a large range in environmental and land-use settings, including both urban and undeveloped lands.)*



Concentrations of methylmercury in individual streams increase as dissolved organic carbon and streamflow increase. *(Data represent a stream in north Florida, sampled from 2001-2004; relations are typical of sampled streams in Oregon, Wisconsin, and Florida.)*

These processes are demonstrated by strong positive correlations between concentrations of methylmercury in stream water and wetland density, stream water chemistry (specifically high levels of DOC, low pH, and moderate levels of sulfate), and changes in hydrology, such as runoff and increased streamflow. DOC is produced by the breakdown of plants and other organic material in wetlands—it binds strongly to mercury, keeping mercury in the water and enhancing mercury transport from wetlands to streams, where it is available for uptake by aquatic organisms. Concentrations of methylmercury in streambed sediment are not correlated with concentrations in stream water. Methylmercury formed (from inorganic mercury) within streambed sediment is therefore not a significant source of methylmercury to streams.

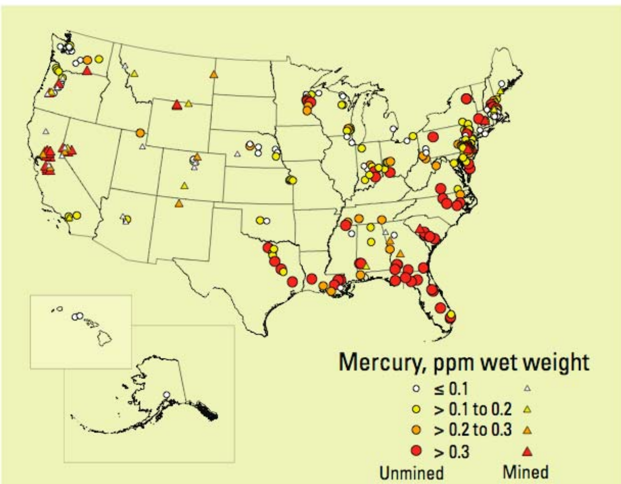
Mercury in stream water to fish

Increasing concentrations of methylmercury in stream water are associated with increasing wetland densities in a watershed and increasing concentrations of DOC in the stream water. Moreover, increasing methylmercury concentrations in stream water result in increasing concentrations of mercury in fish. Once methylmercury is delivered to streams from the watershed, it is taken up by aquatic organisms and is biomagnified with each successive trophic (feeding) level within a food web, from algae to invertebrates to forage fish to larger predatory (game) fish.

Biomagnification rates are similar among streams sampled in Oregon, Wisconsin, and Florida, despite different environmental conditions. Specifically, methylmercury increased by a factor of more than 100,000 times from water to algae and 5-10 times for each successive trophic level—up to top predators, such as largemouth bass and trout. Because mercury accumulates and is biomagnified relatively consistently, even among very diverse streams, the amount of methylmercury in surface water is a stronger predictor of mercury levels in fish than differences in food webs (such as trophic level of top predators).

How does mercury vary geographically?

For 367 streams sampled across the US by the USGS during 1998-2005, the highest concentrations of methylmercury in stream water were detected in the eastern and southeastern States, particularly in forested watersheds with high wetland densities. The geographic distribution of methylmercury concentrations in fish sampled in 291 of these streams is similar to the distribution of methylmercury in stream water. The highest concentrations of mercury also were detected in fish from streams in forested watersheds with high densities of wetlands. These results corroborate previously discussed findings from eight streams studied in Oregon, Wisconsin, and Florida. Overall, the concentrations of mercury in 27% of the fish sampled across the US exceeded the US Environmental Protection Agency human health criterion of 0.3 parts per million (wet weight) for the protection of people who consume average amounts of fish.



Across the Nation, 27% of the fish sampled exceeded the US Environmental Protection Agency human health criterion of 0.3 parts per million (wet weight). Many of the highest concentrations were found in coastal plain streams in the southeastern US and in mined areas in the western US. *(Unmined watersheds are represented by circles; mining-affected watersheds by triangles).*

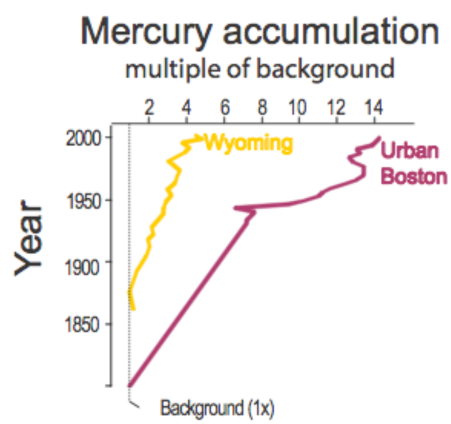
The highest concentrations of mercury in fish occurred in blackwater coastal plain streams in Louisiana, Florida, Georgia, North and South Carolina, areas with both high rates of atmospheric deposition of mercury and high wetland densities. High concentrations of mercury in water and fish also were found in mining-affected streams in western States.

What key factors explain geographic variability in fish mercury concentrations?

Atmospheric deposition of mercury varies by a factor of 5 across the US; however, mercury concentrations in wetlands, surface waters, and fish vary by as much as a factor of 50. This means that while mercury inputs to the environment are an important factor in fish mercury contamination, watershed properties exert a dominant influence on the amount of inorganic mercury that is converted to the methylmercury that ultimately ends up in fish. It also means that across large environmental gradients, the amount of wetlands within a watershed is a key indicator of how sensitive an ecosystem is to mercury inputs. Although many mining-affected areas have relatively low wetland densities, inputs of inorganic mercury to streams in these areas can be significant. In these watersheds, large inputs of inorganic mercury combined with modest methylation capabilities can result in high methylmercury concentrations in water and fish.

Are mercury loads to the environment increasing or decreasing?

Mercury deposition histories recorded in bed sediment samples from remote lakes indicate that mercury accumulation in pristine areas, such as northwestern Alaska, is about 1.5-2 times higher than pre-industrial rates. In remote areas of the continental US, current rates of mercury deposition are 2-4 times background rates, and even greater increases (as much as 14 times background) have been measured near major urban centers in the eastern US.



A lake sediment core from a relatively undeveloped area of Wyoming shows mercury accumulation rates of about 4 times background in recent years, whereas a lake core near the Boston urban area shows rates of about 14 times background rates. *(http://tx.usgs.gov/coring/pubs/)*

A trend analysis of data for 90 streams in a national fish mercury database (http://emmma.usgs.gov/) showed that mercury in fish generally decreased from 1969 to 1987. The trends coincided with a period of large-scale reductions in point-source (industrial and wastewater) discharges to the environment, suggesting that reductions in mercury loading can produce measureable decreases in fish-mercury concentrations.

Most of these data are from the National Contaminants Biomonitoring Program (NCBP), which monitored mercury in fish tissue from rivers, and was discontinued in 1988. Since that time, no national network or program is available to comprehensively assess fish mercury trends in a nationally consistent manner, and track the effectiveness of strategies used to reduce mercury emissions to the environment.

Can we use watershed characteristics to predict mercury in unsampled aquatic ecosystems across the Nation?

Wetland density, pH levels, and concentrations of DOC and sulfate in surface water are all key environmental factors that have direct linkages to processes that control the transformation of inorganic mercury inputs to methylmercury, and each of these factors is known to be correlated with observed levels of methylmercury concentrations in surface waters. As such, USGS scientists are currently working on a national-scale methylmercury prediction map that is supported by a national database of these factors. Such a map will be useful for decision makers, monitoring programs, and resource managers across the Nation.

Will ecosystems respond to decreases in atmospheric emissions of mercury?

Compared to newly deposited mercury, relic mercury pools in the environment are relatively less available to the processes that yield methylmercury. Thus, recent mercury loads are more efficiently converted to methylmercury, and provide a larger portion of the mercury that is incorporated into aquatic food webs and biomagnified. This means that reducing current mercury emissions should decrease the amount of new mercury cycling through aquatic systems, and thus decrease the amount of mercury that ends up in fish.

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