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Mercury and the Ocean

by Rob Mason

When Joane Woodhall, a custodian at UConn, goes to the supermarket or reads the newspaper, like most people, she feels some confusion about whether or not to eat seafood during her pregnancy and which seafood to choose. “All the stories I read in the newspaper make me wonder—should I eat fish?” she asked. She enjoys seafood and knows there are valuable health benefits from eating fish and other seafood dishes, and she doesn’t want to miss out on them for herself or her developing baby boy. Joane did the right thing:

“I asked my doctor what to do about eating seafood, and what to do about mercury in fish” she says. “He told me what seafood is best to eat and how often. My husband helps too—he knows a lot about fish and likes to go fishing, so he makes sure I get the right ones.”

Many people aren’t as informed as Joane, however—there are still people who haven’t heard the consumer health advisories on certain fish that should be avoided, or haven’t heard about the health benefits of seafood, or don’t understand what conditions pertain to consumption.

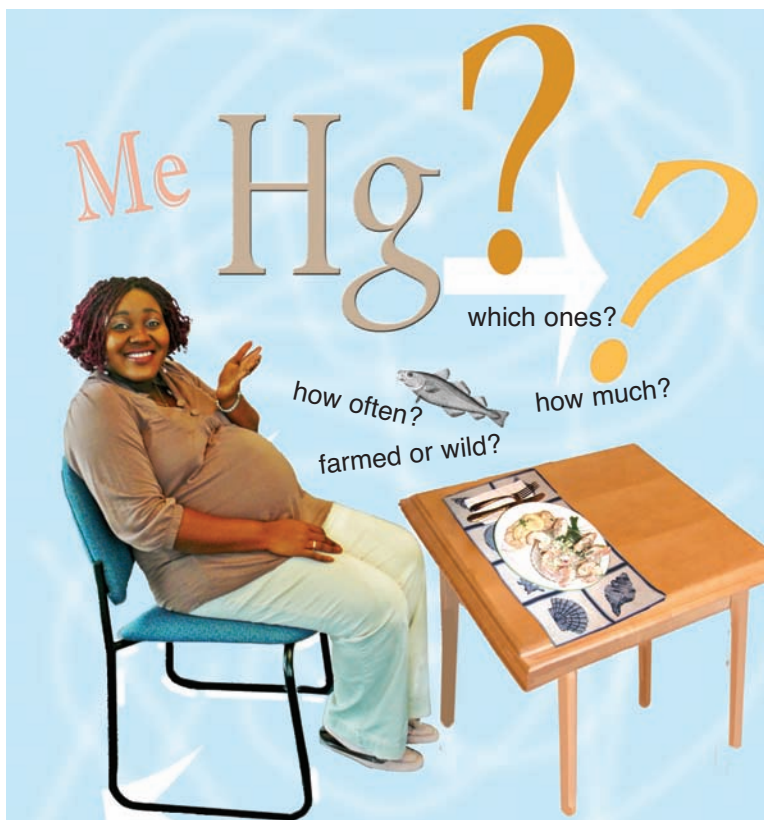
These days, we are continually confronted by questions about food safety that affect our health or could expose us to potentially harmful substances. Mercury is one of the most recognized toxins because of the constant stream of discussions and warnings in the popular press about the contamination of fish and potential impacts on health, such as a recent controversial *New York Times* story about mercury levels in sushi served in New York restaurants.

Baffling or contradictory news reports make it difficult to obtain a well informed perspective. Some confusion results from the fact that mercury is found in many forms, with different toxicities, and in many products. Elemental (liquid) mercury is found in some batteries, thermometers and fluorescent light bulbs.

The other major inorganic form is ionic mercury, which is mercury in a charged state. Ionic mercury is found in the environment mostly in trace amounts, but is also concentrated in some coal, other petroleum products and some minerals and ores. The organic compounds of mercury include methylmercury (MeHg), one of the most toxic forms and the major form of mercury in seafood and other fish. Other organic mercury compounds have been used as antiseptics (e.g. methiolate) and as preservatives in vaccines and other medical products, but have been mostly discontinued.

Overall, MeHg is about a thousand more times toxic than the inorganic forms of mercury. This article therefore focuses on MeHg and provides information on MeHg exposure from marine fish and shellfish, which account for the majority of seafood products consumed by the U.S. population. This discussion represents my personal viewpoint as a marine scientist, informed by my own research and reading of the

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Mercury and Me: Choosing the right seafood in light of concerns about mercury pollution in the ocean can be confusing to consumers, especially to those in the high risk categories, such as pregnant moms-to-be and small children. It's not easy, but we offer some help from a new UConn study.

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scientific and health literature, and from my discussions with other scientists and policy experts at the regional, national and international levels.

We know that eating fish has many health benefits. Fish are high in protein, relatively low in fat and some species are also very high in Omega-3 fatty acids, which are known to have a number of beneficial effects on cardiovascular health. Thus, the primary question that faces the public is: Are the benefits of eating fish worth the risks of being exposed to elevated levels of MeHg and other contaminants?

MeHg is a neurotoxin that is known to cause long-term developmental disorders for children exposed during pregnancy; there are similar reproductive effects for wildlife exposed at elevated levels. It should be noted that some research shows increased risks of heart attacks in adult men with high levels of MeHg exposure. Because these results have not been sufficiently reproduced in other studies, such data are not accounted for in current fish consumption advisories.

For humans, consumption of fish with elevated MeHg is the primary source of exposure, and therefore the U.S. federal government and states and many other countries, have issued advisories that recommend restricted fish consumption. These advisories are often, but not always, aimed at pregnant women, or those that may soon become pregnant, and children because of the potentially deleterious impacts of MeHg on the developing fetus and young child, especially on their neurocognitive development. National standards for “safe” levels of MeHg intake are based on epidemiological studies that have monitored children for up to ten years after their exposure to MeHg during pregnancy.

Most governments rely on the results from three main studies of fish-consuming populations in the Faroe Islands, the Seychelles and in New Zealand. Because the results of these studies show significant variability in responses of individuals to MeHg exposure, resulting “safe” levels of MeHg consumption vary among government agencies. It is standard practice, when deriving public health safety recommendations, to apply a “safety factor” in converting values for the lowest level of observed effect into a consumption advisory for individuals. The U.S. E.P.A. has applied a safety factor of ten, based on the recommendation from a National Academies Panel, in calculating the resulting safe “reference dose” for MeHg. The values vary with an individual’s body weight; for example, for a 130-pound woman, one meal of eight ounces (uncooked) per week of fish with 0.3 parts per million (ppm) MeHg results in a MeHg intake at the reference dose level. The most recent U.S. F.D.A./E.P.A.



UConn Marine Sciences

The author, Rob Mason, samples sediments aboard ship in the Gulf of Mexico. He is measuring how quickly inorganic mercury converts to methylmercury (MeHg).

advisory specifically suggests that pregnant women avoid consuming shark, swordfish, tilefish, and king mackerel, which all are high in MeHg (see chart on next page) and suggests the consumption of two meals a week of species that have moderate levels of MeHg, such as canned tuna. Species that are low in mercury, such as shrimp, salmon, and pollock, and catfish can be consumed in greater quantities.

Standard models that relate the amount of fish consumed to an expected health impact assume that the MeHg is effectively retained within the human body. The half-life (i.e. the time taken for a body’s MeHg burden to be reduced by half) is about 70 days, so, when you cease eating MeHg-containing fish, your body can slowly eliminate it. So, what are our body’s mechanisms for dealing with MeHg? There is evidence that marine mammals and some birds that have an exclusive fish diet can reduce their burden by converting MeHg into a less toxic inorganic mercury form that is either quickly eliminated or bound up in a non-toxic way in association with selenium in their livers. Preliminary research has also suggested that some human populations may have some adaptation and are therefore could be less affected by high levels of MeHg exposure. The potential link between MeHg effects and selenium has also prompted recent studies but few conclusive answers.

Given this background, the question remains: Should one eat fish? In answering this question some complications need to be addressed. As shown in the chart, fish and shellfish can have very different levels of MeHg and these levels can be ten times more or less than the advisory value (0.3 ppm). Freshwater fish tend to have higher

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concentrations for similar species than marine fish. Shellfish (mussels, oysters, shrimp) and open ocean pelagic fish that are not carnivorous (e.g. flounder, haddock) tend to have low MeHg concentrations. Oily fish (sardine, anchovy) and benthic feeders (e.g. catfish) also have relatively low MeHg concentrations (see chart below). Farmed fish appear to have lower concentrations than wild fish, but clearly this depends on the specific fish farming practices, which vary widely globally. Fish from a contaminated location probably have higher MeHg concentrations although there are other factors that can decrease fish accumulation of MeHg.

Unlike organic contaminants which concentrate in fatty tissues, MeHg is associated with protein and therefore has its highest concentration in the filet (muscle tissue). Given these generalities, it is entirely possible to consume fish and shellfish that are low in MeHg and high in Omega-3 fatty acids without substantial risk, if one is careful and knowledgeable about the MeHg levels in the fish and seafood consumed, which is related to their origin.

A partial listing of preferred fish is given in the chart below, and the listing takes into account various factors—MeHg concentration, Omega-3 fatty acid content and other factors. For example, many fish high in MeHg

(e.g. bluefin tuna, swordfish, shark) are over-exploited and/or endangered species and therefore there are both ecological and health reasons for not eating them. The current increased consumption of sushi has lead to a dramatic decrease in ocean bluefin tuna populations and if consumption is to continue at current levels, these fish will need to be farmed in the future, which raises other ecological concerns.

“Based on my analysis, tuna is the most consumed type of fish in the U.S. (a quarter of total fish consumed) with shrimp, pollock, salmon and cod accounting for about 70% of the other seafood” says Elsie Sunderland, a researcher at the E.P.A. This appears to be why tuna is the brunt of most press reports. However, aggregating all tuna into one category is misleading as levels of MeHg in tuna vary by more than a factor of five. Canned tuna - light, which is mostly skipjack and yellowfin, and white (albacore) – is relatively low in MeHg (~0.2 ppm), although albacore, being a larger, older fish when harvested, has higher concentrations. Bluefin tuna, the most desirable fish for sashimi and sushi, can have much higher MeHg levels (above 1 part per million) but usually does not because their harvest size has been reduced by overfishing. Concentration differences reflect the fact that fish MeHg levels increase

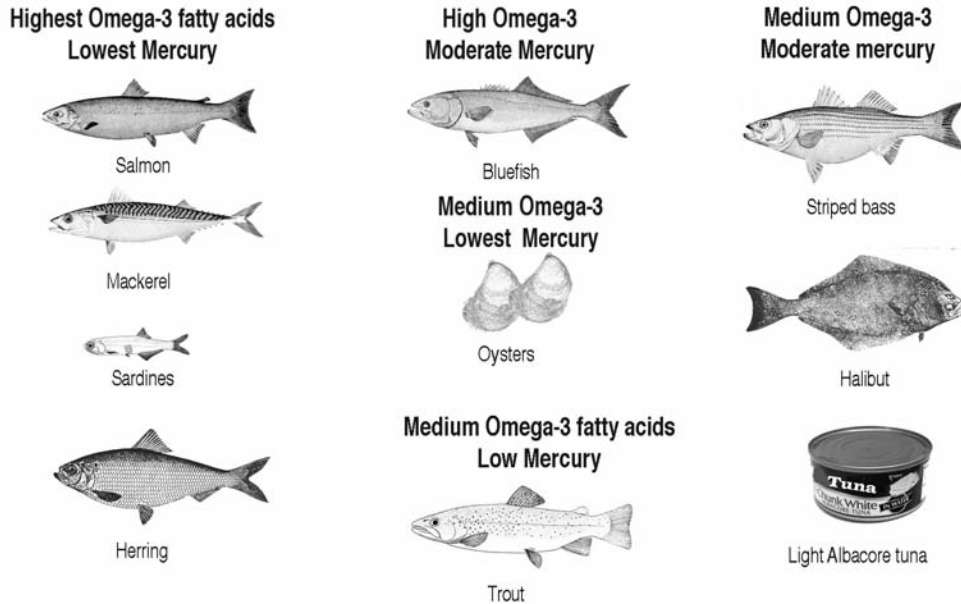
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The chart below, from Rob Mason’s research, shows a vertical scale of mercury levels with a horizontal scale of Omega-3 fatty acids. If you want to minimize mercury levels and maximize Omega-3 fatty acids, match up the boxes.

	High Omega-3’s (>1g per 100 g)	Medium Omega-3’s (0.5-1g per 100 g)	Low Omega-3’s (<0.5 g per 100 g)
Very High (>0.6 ppm MeHg)		Shark, swordfish, tilefish, blackfin tuna	King mackerel
High (0.3-0.6 ppm MeHg)	Bluefin tuna		Grouper, orange roughy, walleye,
Moderate (0.2-0.3 MeHg ppm)	Bluefish	Striped bass, halibut, albacore tuna	American lobster
Low (0.1-0.2 ppm MeHg)		trout	Cod, canned light tuna, black sea bass, king crab, blue crab
Lowest (<0.1 ppm MeHg)	Salmon, mackerel, herring, sardines	Oysters	Clams, squid, scallops, shrimp, haddock, flounder, Pollock, catfish, mahi mahi, perch

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Wrack Lines Top Ten Picks for a Healthy Dinner



Generally, the seafood choices shown above would be wise for diners who want to balance low to medium levels of mercury with medium to high levels of beneficial Omega-3 fatty acids, according to the Mason study results. There are plenty of other good choices for low mercury levels alone, or for high Omega-3 levels alone. These have a good combination.

with age, and depends on what the fish eats. The light tuna usually canned are fast-growing and relatively small when harvested, while bluefin are large fish, typically above 100 pounds, that roam widely and are long-lived.

In addition, we see that fish from different ocean waters have different MeHg concentrations. For example, bluefin and albacore tuna from the Mediterranean Sea have much higher concentrations than those from the North Atlantic, and fish from the Pacific and Southern Hemisphere are lower still. While different species may inhabit different oceans, these differences also reflect two other factors: 1) differences in rate of the historic inputs of mercury into the different oceans from human related activities, and 2) differences in the formation rate of MeHg in these ocean waters. The Mediterranean, for example, has a relatively high MeHg concentration. The research of my group and others are focused on understanding these differences.

Research and model calculations indicate that human activity has increased the amount of mercury in the biosphere by at least a factor of three. The relative increase varies across the U.S.A, and is a function of the

proximity to the anthropogenic sources, which include coal burning facilities, medical and municipal waste incinerators, and other industrial and metal extraction activities.

Levels of mercury in precipitation show that there is a gradient of impact with the eastern U.S.A. being more impacted than the west. This reflects the metrological conditions (the jet stream flows west to east) and the predominance of mercury sources within the midwest and Ohio valley. Thus, the eastern seaboard is receiving mercury emitted to the atmosphere upwind. Emissions of mercury to the atmosphere are in the two inorganic forms—ionic mercury, which is deposited relatively close to its source, within a few hundred miles, and elemental mercury, which travels as a gas globally prior to being deposited, after conversion to ionic mercury, by wet (i.e. in rain, snow, dew) and dry (i.e. in dust, particles and gas) deposition processes. The elemental mercury is converted into ionic mercury in the atmosphere by a variety of chemical processes and the conversion rates of the various processes differ, and thus the “footprint” of any emission source is a function of the composition of the

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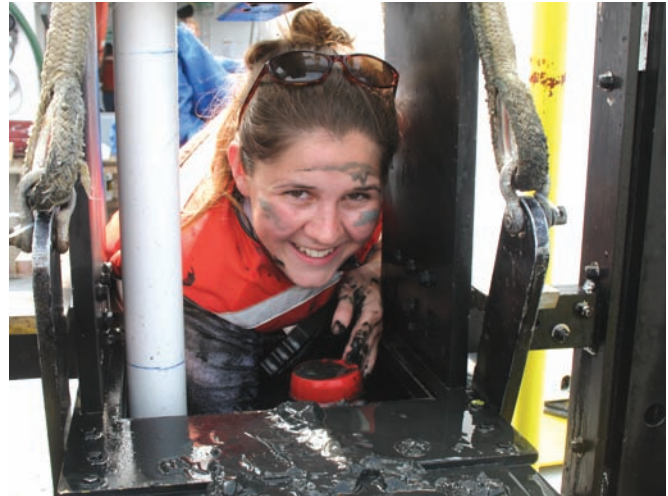
mercury emissions and the physical location of the source. Our current understanding of these atmospheric processes is limited by the lack of data and study, but computer modeling studies allow us to extrapolate from this data to make global assessments.

Overall, freshwaters and estuarine environments are more impacted than coastal waters, and the remote ocean is the least impacted, relatively. For the ocean, most of the mercury is entering from direct atmospheric deposition (precipitation), and not from mercury inputs from rivers and terrestrial sources. It should also be pointed out that ocean waters contained some mercury prior to human disturbance and therefore ocean fish have always likely contained some MeHg.

“Therefore, part of the ongoing debate is what fraction of the MeHg in ocean fish is “natural” and what fraction reflects the anthropogenic signal” says Elsie Sunderland. Estimates of this range widely, from 10% to more than 50% anthropogenic, and this fraction differs for the different ocean basins. Globally, given the history of industrialization, the North Atlantic Ocean and the Mediterranean Sea have been the most impacted but currently, because of the rapid development in China, India and other Asian countries, and the increasing controls over mercury emissions in North America and Europe, it is likely that the Pacific Ocean is where concentrations are currently increasing. This large ocean basin has a complex circulation, and the mixing of surface waters to depth tends to cause a lag in the response time of the ocean to changes in the atmospheric mercury concentration and input. There is a lack of data but our recent analysis suggests there is little evidence that the North Pacific Ocean mercury concentration has changed substantially since pre-industrial times.

Most of the modeling and measurement of Hg movement at the global scale is focused on ionic mercury, but obviously the main health concern is MeHg, and therefore there is a need to focus attention on the conversion process of ionic mercury into MeHg. Most of the mercury entering the ocean from all sources is ionic mercury and therefore most of the MeHg in ocean fish is formed by conversion of ionic mercury to MeHg within the ecosystem. But where and how?

“This is a very important question and a focus of our combined research groups here at Avery Point” says Bill Fitzgerald, a professor in the UConn Department of Marine Sciences who has been working on Hg research for more than 30 years. “We have been focusing our studies on Long Island Sound, while Rob’s group has been working with others in the Chesapeake Bay” adds



UConn Marine Sciences

Terill Hollweg, a UConn Ph.D. student in marine sciences, sub-samples from a box corer aboard ship in Chesapeake Bay. Hollweg is finding evidence that elemental mercury is readily transformed to methylmercury in environments with coastal shelf sediments, such as Long Island Sound, the Hudson River, or Chesapeake Bay.

Fitzgerald.

Most of the conversion of ionic mercury to MeHg is due to the activity of bacteria in low oxygen environments, and for ocean waters these occur either in the sediments, or in waters depleted of oxygen, such as the seasonally hypoxic zone of Long Island Sound, or the “dead zone” in the Gulf of Mexico, or in expansive low oxygen upper ocean waters (100-1000 meters). However, there is not a straightforward relationship between the amount of inorganic mercury present and its conversion to MeHg, as many other factors appear to alter the rate of conversion. Much of the recent study has focused on the coastal zone and there is now clear evidence that estuarine and shelf sediments, such as those of Long Island Sound, the Hudson River, the Chesapeake Bay, and the Bay of Fundy, and even the deeper shelf break sediments and the sediments of the Gulf of Mexico, are locations where ionic mercury is readily transformed to MeHg.

Terill Hollweg, a UConn Ph.D. student in marine sciences, is one of a team studying mercury in my laboratory. Her research focuses on the Chesapeake Bay/shelf mercury study.

“We were amazed to find that the rate of formation of MeHg in the sediments of the shelf, and on the slope, in 600 meters of water, was as high, or higher, than in the Chesapeake Bay itself,” says Terill, “and it’s likely that these environments are important in the ocean MeHg story”. Other potential MeHg production regions include the low oxygen waters mentioned above, the deep ocean sediments. There is also the potential for hydrothermal

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vents to be MeHg sources, but there is insufficient data to implicate the deep ocean sediments as important sources of MeHg to commercially important ocean fish, which mostly inhabit the surface ocean.

One aspect of MeHg movement within the marine environment is how the MeHg is transported from its regions of formation to the locations of bioaccumulation into seafood. The transport of MeHg from sediments to the overlying waters can be estimated and this process is obviously important but there are other vectors for MeHg bioaccumulation into fish. It is not known to what extent MeHg produced in the coastal environment is physically transported by currents to offshore locations to accumulate in ocean fish, or how important the nearshore environment is as a food source for highly mobile open ocean fish species.

Clearly, MeHg can be incorporated from sediments into bottom-dwelling organisms, which can then be consumed by fish, marine mammals and birds. Also, many fish species have life histories that involve migration and time in the nearshore environment, either seasonally or after an extended sojourn in ocean waters. The movement of MeHg in conjunction with such movement of fish (co-called “biotransport” of MeHg) has not been adequately quantified. Again, these are active areas of research and debate, and therefore it is difficult at the current time to make conclusive statements about the primary source of the MeHg in ocean fish.

Understanding the sources would allow for better management of the MeHg in fish problem. While limiting mercury input is the most obvious approach, there could be other strategies to reduce fish MeHg burdens.

Certainly, there are many unanswered questions about how and where MeHg is formed, and how it is transported and subsequently bioaccumulated into fish, and to what extent the levels of MeHg in ocean fish have changed over time. However, while scientists continue to search for these answers, and even given that human

activity has increased the amount of mercury in the biosphere, it is reassuring to know that it is possible to consume seafood high in Omega-3 fatty acids and low in MeHg, and to gain the benefits with little risk.

It behooves us all to ask more questions about the sources of the fish we eat, and to request more oversight from regulators, and more monitoring of the seafood MeHg content. This information would reduce uncertainty and enhance the ability of the consumer to make rational choices about their consumption of seafood. Also, more detailed knowledge allows the consumer to be informed about the impact of their everyday activities, such as how to properly dispose of mercury-containing products and how to help reduce mercury use in everyday life. I eat seafood and ask where it comes from, although many times there is no answer. We should all be more proactive in demanding stricter control and regulation over the seafood and the other foods we eat.



UConn Marine Sciences

About the Author:

Robert Mason (third from left) is a Professor in the University of Connecticut Marine Sciences Department. His lab group at Avery Point, shown above, studies the fate, transport, and transformation of trace metals.

Find Out More! Some online resources:

- Connecticut Department of Health: http://www.ct.gov/dph/lib/dph/environmental_health/eoha/pdf/ificatchit.pdf or go to www.ct.gov/dph and click on “F” for fish advisories.
- EPA website: <http://www.epa.gov/mercury/advisories.htm>
- FDA website: http://www.fda.gov/fdac/features/2004/304_fish.html
- American Heart Association: <http://www.americanheart.org/presenter.jhtml?identifier=3013797>