Mercury Connections

The extent and effects of mercury pollution in northeastern North America

Biodiversity Research Institute

Mercury Connections is a summary of the major findings reported in a series of 21 papers. These papers are published in: Biogeographical patterns of environmental mercury in northeastern North America. 2005. *Ecotoxicology.* Volume 14, numbers 1 and 2. Guest Editors: David C. Evers and Thomas A. Clair.

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To order reports, request illustrations and figures, make a contribution or get additional information, contact:

BioDiversity Research Institute
19 Flaggy Meadow Road, Gorham, ME 04038
Phone: (207) 839-7600
Fax: (207) 839-7655
bri@briloon.org
www.briloon.org

This project was undertaken as part of The Northeastern Ecosystem Research Cooperative (NERC). NERC is an initiative to promote collaboration among ecosystem research scientists in the northeastern U.S and eastern Canada. For more information, visit: www.ecostudies.org/nerc

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Executive Summary

From 2001 to 2005, BioDiversity Research Institute (BRI) and Environment Canada led a comprehensive effort to compile mercury data from across the northeastern U.S. and eastern Canada. This groundbreaking project produced a database of over 30,000 measurements, mostly from freshwater environments (Figure 1). The results highlight the broad extent and serious effects of mercury across the landscape, the need to expand the view of the problem to include forest ecosystems, the occurrence of biological hotspots in sensitive environments, and the demand for enhanced mercury monitoring.

The BRI effort produced a series of 21 scholarly papers published in a special issue of the journal *Ecotoxicology* (see page 22). These papers present the most comprehensive understanding of mercury pollution in freshwater ecosystems of northeastern North America. Here the results are condensed into a report that highlights and translates the key findings of these papers for policy makers, the public and others interested in mercury in the environment.

This report is organized into five sections: mercury overview; mercury in air, sediments, water and fish; mercury in other wildlife; mercury hotspots; and environmental monitoring. The facts and figures presented in these sections are also summarized in the "Fact Finder" on pages 12 and 13.

A comprehensive analysis of air, water and fish data shows that mercury levels are high and pervasive in northeastern North America.

Four key messages emerge from this report:

1. A comprehensive analysis of air, water and fish data shows that ***mercury levels are high and pervasive in northeastern North America.*** A new map showing model estimates of total mercury deposited on the landscape predicts higher mercury loading to some areas of the Northeast than previously projected (see Figure 4 on page 7). While the map is limited by the lack of mercury monitors in urban areas and near large emissions sources, it shows elevated mercury across the region and particularly high levels in montane forests.

   Extensive water and fish data further illustrate the widespread nature of the mercury problem. Water samples from more than 1,000 locations identified particularly high mercury in the Adirondack Mountains of New York as well as the Canadian provinces of Nova Scotia and Newfoundland. The waters with high mercury levels were generally distant from direct point sources and urbanized land use, suggesting airborne mercury is a likely source. However, the data also demonstrate that large sources can have a considerable impact in local areas.

   An analysis of fish showed that 15 and 42 percent of the water bodies sampled for brook trout and yellow perch, respectively, had average fish mercury concentrations exceeding the U.S. Environmental Protection Agency (EPA) criterion of 0.3 ppm. Moreover, most species sampled had average regionwide mercury concentrations above this criterion.

2. Until now, most research has focused on mercury in fish and fish-eating birds in aquatic environments. ***New research shows that many animals, even forest songbirds, have elevated mercury burdens.*** Based on these findings, it is increasingly clear that mercury can no longer be viewed as strictly an aquatic pollutant. Conventional thinking holds that mercury is limited to aquatic environments since mercury is most readily converted to its toxic form (methylmercury) in water. However, elevated mercury levels in Bicknell's thrush and other forest songbirds demonstrate that methylmercury can be produced in terrestrial ecosystems as well. This new finding has implications for the way scientists and policy makers view the nature and extent of mercury in northeastern North America.

Bald eagle *(Haliaeetus leucocephalus)*

3. Mercury is commonly evaluated as an environmental issue at national and global scales. Yet this approach can overlook small locales with regionally significant mercury pollution. Here, ***biological hotspots that pose an ecological risk are identified and mapped for the first time in northeastern North America*** (see Figure 13 on page 20)**.** Hotspots can form in watersheds with high mercury deposition or within highly sensitive ecosystems. In northeastern North America, areas of high mercury loading prevail in upper elevation ecosystems that receive more mercury deposition than surrounding lowlands, as well as areas near large mercury sources. Often however, *biological* hotspots develop in watersheds where conditions are conducive to methylmercury production or the build-up of mercury in the food chain. This finding illustrates that watershed characteristics can be as important as mercury loading in determining mercury sensitivity. Moreover, the high mercury levels documented in these biological hotspots suggest the need for stronger mercury standards to protect fish and wildlife (see Box 4 on page 18).

4. Last, it is clear from this analysis that ***environmental monitoring programs must be expanded in order to fully document the extent and impact of mercury pollution in North America.*** The current federal monitoring program is limited to the Mercury Deposition Network (MDN). While the 70 existing MDN sites are operating well, they are located primarily in rural areas and are sparsely distributed. They are also limited to collecting mercury in rain and snow. Moreover, connecting air deposition with changes in fish and wildlife is a scientific challenge that must be addressed through an expanded monitoring network. Current programs for measuring water chemistry and fish and wildlife effects are inadequate to detect changing mercury levels and determine ecological effects in a standardized way. A comprehensive system designed to meet mercury monitoring needs nationally is described in a recent paper by Robert Mason and his colleagues entitled, "Monitoring the Response to Changing Mercury Deposition" which appeared in the January 2005 issue of the journal *Environmental Science and Technology.*

Given the changing levels of mercury in the environment, the increasing global pool of mercury and the risk posed to human and ecological health, a collection system for basic information on mercury in the environment should be a high national priority.

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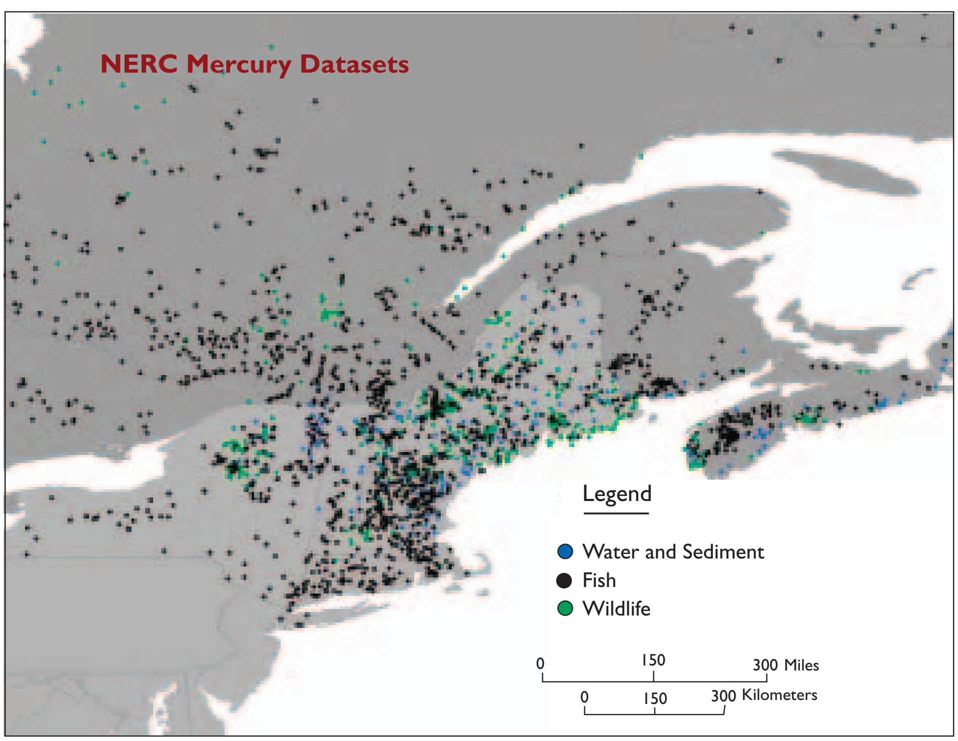


Figure 1: Map of the study area and mercury data compiled by the mercury working group of the Northeastern Ecosystem Research Cooperative. Areas north to Newfoundland, Labrador and central Quebec were in the study area but are not shown here.

1. The Mercury Problem – An Overview

What is mercury and where does it come from?

Mercury is an element that is found in rocks in the earth's crust. Through mining and industrial processes, mercury is brought to the earth's surface and used in manufacturing, electricity generation and consumer products (such as lamps, thermometers and dental material). Eventually, the mercury is emitted to the air or discharged to water as a byproduct of combustion or improper waste disposal. Once in air and water, mercury presents a risk to ecological and human health.

The ***mercury cycle*** describes the sources and movement of mercury through the environment. The modern-day sources of mercury can be broken down into airborne sources and water sources. In the United States, the major sources of airborne mercury include coal-fired power plants, industrial boilers, incinerators and chlorine manufacturing plants. Major water sources include wastewater treatment plants, gold mining operations, landfills and some manufacturing facilities.

The northeastern U.S. and eastern Canada receive mercury from local, regional and global emissions. However, most estimates show that U.S. emissions constitute the largest source of mercury that is deposited to the Northeast (approximately 60 percent) (NYSERDA 2002). Regulations to address mercury emissions from incinerators and other sources have been successful and, as a result, total U.S. emissions have declined 40 percent since 1990 (Figure 3) (EPA 2003).

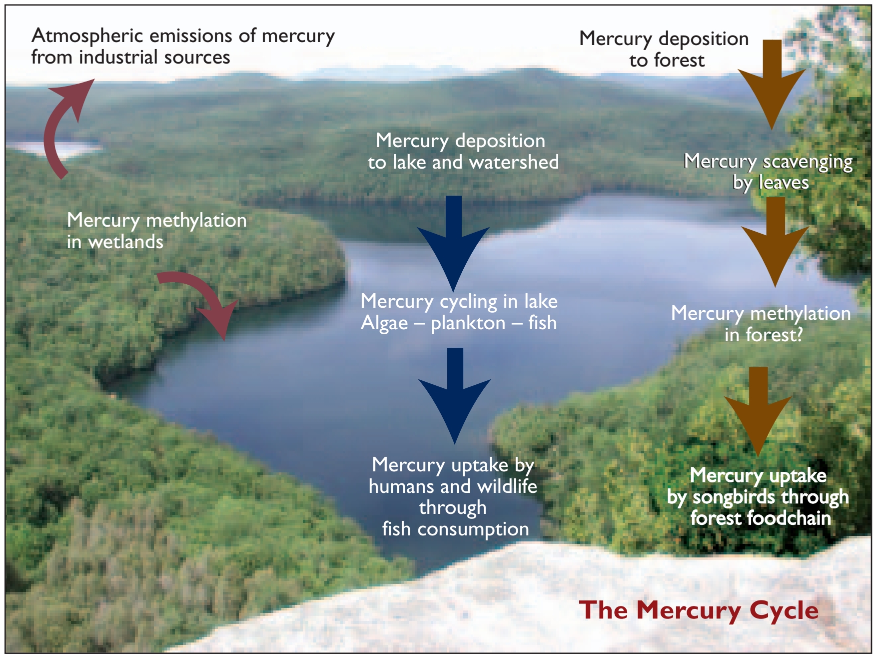


Figure 2: A simplified mercury cycle showing both aquatic and terrestrial pathways for mercury bioaccumulation.

Mink *(Mustela vison)*

Mercury is emitted to the atmosphere in several different forms, or *species*. As described in Box 1, the characteristics of these species determine the ultimate fate of mercury in the environment. To complicate matters, once these different species of mercury are emitted to the air they may change into a different species before being deposited.

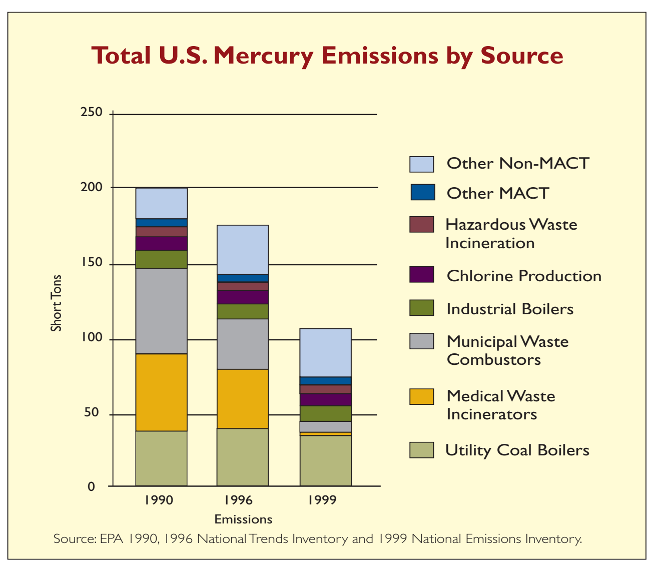


Figure 3: Mercury emissions in the U.S. have decreased since 1990 due to effective regulation of waste incinerators and combustors. MACT = maximum achievable control technology.

What happens to mercury in the landscape?

After mercury is emitted from a smokestack (such as from a coal-burning power plant or incinerator) and travels through the atmosphere, it deposits on land and water. Together with mercury from surface water discharges and other large sources, it makes its way through a watershed and ultimately to a nearby lake or stream. The extent to which mercury poses a human health or ecological risk depends, in part, on whether or not it is converted into the bioavailable toxic form known as methylmercury.

If the mercury is converted to methylmercury, it can be consumed by organisms and move up the food chain. An unfortunate characteristic of methylmercury is its ability to build up in the body over time (bioaccumulation) and increase in concentration as one organism eats another (biomagnification). Consequently, a very low level of methylmercury in the environment can produce extremely high body burdens in animals at the tops of food chains. In the case of mercury, a little bit goes a long way.

Why is mercury a problem to fish, wildlife and people?

Once mercury enters the body of an animal or a person, it can have a wide range of effects — from sublethal to lethal. Birds are particularly at risk for mercury poisoning because many species exclusively eat mercury-laden fish. They are also long-lived animals and therefore accumulate mercury in their bodies over a long period of time. For these reasons, birds such as loons are one of the most intensively studied animals in mercury research. From past research it is known that mercury can have adverse effects on individual birds, as well as on the population as a whole through changes in their behavior, reproduction and body chemistry. The mercury effects that have been documented in fish and wildlife are summarized in Table 1.

Although this report does not focus on human health, it is important to mention that fish consumption is the primary mode of human exposure to mercury. Children under 12 and people who frequently eat fish with mercury are the most likely to be at risk for mercury exposure. In July 2000, the National Academy of Sciences completed a review of the latest scientific evidence regarding the human health effects of methylmercury. They concluded that children of women who consume large amounts of fish and seafood are at highest risk (NAS 2000). A recent report estimates that over 600,000 children born each year are at risk for nervous system effects due to methylmercury exposure in the womb (Mahaffey 2004).

In 2003, the Centers for Disease Control and Prevention found that eight percent of American women of childbearing age had blood mercury levels above those deemed safe by the EPA (Shober 2003). To address this significant public health risk, fish consumption advisories have been posted by the EPA in 44 states due to mercury contamination (EPA 2004).

What has been done to reduce mercury? (Papers 2 & 3)

Mercury is difficult to remove from the environment, but a variety of programs and policies have been proposed or adopted to reduce mercury use and pollution. Northeastern North America is a leader in mercury reduction and has implemented several important initiatives, including the New England Governors and Eastern Canadian Premiers Mercury Action Plan. The basic elements of mercury reduction efforts at the national, regional and state level are outlined in Table 2.

Given the global circulation of mercury in the atmosphere, the problem must be addressed worldwide. The United Nations Environment Program has established a program to focus attention on the problem globally. This effort is supported by the ratification of the United Nation's Convention on Long-Range Transboundary Air Pollution in 2003.

Despite policy efforts, the research presented here demonstrates that mercury remains ubiquitous and persistent in the environment and that more work is needed to reduce ecological and human health risks associated with mercury pollution.

Box 1: Mercury Species

The three major forms, or species, of mercury emitted to the air are: elemental, reactive gaseous and particulate mercury. Each of these species behaves differently once emitted. As outlined below, elemental mercury can circulate in the air for the longest period of time before depositing. Therefore, it is the species most likely to travel long distances from its original source. However, elemental mercury may also be oxidized in the atmosphere to a form that deposits locally. Therefore, while elemental mercury is often considered a "global pollutant," scientists have identified many pathways for its conversion to a "local pollutant."

Reactive gaseous mercury (RGM) and particulate mercury tend to fall out of the atmosphere more quickly than elemental mercury and are more likely to deposit closer to the source from which they are emitted. Therefore, they have historically been considered the mercury species of greatest concern. Yet, despite the different characteristics of each form, it has become increasingly clear that ***all*** mercury species have the potential to deposit relatively close to the source.

Species	Estimated residence time	Transport distance
Elemental mercury (Hg^o)	150 – 350 days	0 – global
Reactive gaseous mercury (RGM)	0 – 5 days	0 – 300 km
Particulate mercury	0 – 10 days	0 – 500 km

Table 1: Mercury Effects on Fish and Wildlife

Organism	Exposure level		Effect
FISH	0.07 to 0.10 ppm by maternal transfer		Embryo mortality in lake trout eggs (a)
			Adverse effects on growth, development and hormonal status of early life stages (a, b)
	0.88 to 8.46 ppm in diet		Spawning success decreased in low, medium and high doses by 50% to 64% (c, d)
	0.959 ppm in diet		Altered schooling movements (e)
	10 to 30 ppm in diet		Acute toxicity (a)
BIRDS	0.1 to 0.16 ppm in diet	***Reproductive***	Fewer eggs produced (i, j)
			Lower reproductive success (i, j)
			Offspring less responsive to maternal calls (i, j)
			Lower reproductive success in wild common loons (l, m, n, o)
	0.5 to 5.5 ppm in eggs		Reduced hatchability (j, p, q, r)
			Reduced chick survival (p)
			Decreased egg volume (o, q, s)
			Compromised embryonic development (j, q, r)
	0.5 ppm in diet	***Behavioral***	Less likely to hunt, seek shade (h)
			Less time flying, walking or pecking (h)
			Increased time preening (h)
			Exaggerated response to fright stimulus (i, j)
			Altered chick behavior (k)
	5.0 ppm in diet	***Neurological***	Brain lesions (f, g)
			Spinal cord degeneration (f)
			Central nervous system dysfunction (f)
			Tremors (f)
			Difficulty flying, walking and standing (g)
			Inability to coordinate muscle movement (g)
			Reduced feeding, weight loss (f)
			Progressive weakness in wings and legs (f)
	0.5 to 5.0 ppm in diet	***Physiological***	Lower packed cell volume (g)
			Greater bone marrow cellularity (g)
			Increased perivascular edema in lung (g)
	3.0 ppm in blood		Decreased nest attendance (o)
			Lower reproductive success (o)
			Increased feather asymmetry (o)
			Disrupted hormone levels (o)
			Decreased egg volume (o)
MINK & OTTER	1.1 ppm in diet		Neural necrosis leading to impairment of sensory and motor skills (t)
	1.8 ppm in diet		Anorexia, weight loss (t)
	1.8 to 5.0 ppm in diet		Acute toxicity leading to death (t, u, v)
	20 ppm in fur		Sublethal toxicity in the wild (x)
	47 ppm in fur		Acute toxicity in the wild (w)

Adapted from Chan et al. 2003. Specific references denoted by letters and included in bibliography.

Table 2: Examples of National, Regional and State Mercury Regulations and Programs

Jurisdiction	Air	Water	Product Use	Waste Disposal
Selected National Regulations	The Clean Air Act standards for municipal waste combustion and medical waste incinerators call for controlling mercury emissions from large facilities by more than 90% from 1990 levels. Emissions limits for municipal solid waste incinerators set at 0.08 mg/dscm. Emissions limits for medical waste incinerators set at 0.055 mg/dcsm. EPA has proposed standards to reduce mercury emissions from coal-fired power plants.	The Clean Water Act has led to reductions in the direct releases of mercury to surface waters through the National Pollution Discharge and Elimination System and Total Maximum Daily Load Programs.	Mercury-Containing and Rechargeable Battery Management Act calls for the phase out of mercury in batteries.	Universal Waste Regulations allow for the streamlined collection for certain wastes, including mercury-containing batteries, pesticides, lamps and thermostats.
Summary of Regional Mercury Action Plan (Adopted by New England Governors and Eastern Canadian Premiers)	Reduce mercury emissions within the region 50% from mid-1990s levels by 2003, and by 75% by 2010. The final goal is virtual elimination. Emissions limits for municipal solid waste incinerators of 0.028 mg/dscm. Emissions limits for medical waste incinerators set 10 times lower than EPA limit.	Adopted proposal calling for installation of mercury amalgam separators in 50% of dental offices by 2005.	Minimize mercury stockpile entry into commerce. Eventually retire U.S. mercury stockpile.	Segregate and recycle mercury from waste stream to the maximum degree possible.
Examples of Programs in the Northeast States	Emission limits set for municipal waste combustors (0.028 mg/dscm) and medical waste incinerators (ranging from 0.055 to 0.028 mg/dcsm). Proposed limits on coal-fired power plants ranging from 80-95% control efficiencies.	Wastewater discharge permits are required for mercury releases from wastewater treatment plants. Some states and municipalities require use of amalgam separators.	In some states there are: Bans on sales of certain products containing added mercury such as thermometers, auto switches, batteries, thermostats. Phase-out of other uses of mercury in products. Requirements for mercury-added product labels.	In some states there are: Mercury source separation plans required in some states. Mandatory mercury recycling programs and disposal bans. School mercury clean-out programs. Passage of mercury source separation plans. Mercury thermometer exchange programs.

(mg/dscm = milligrams per dry standard cubic meter)

2. Mercury Levels are High and Pervasive in Northeastern North America

Scientists completed a massive data compilation effort in order to quantify mercury loading and accumulation in watersheds of the Northeast.
This section presents information regarding:

1. Deposition of mercury from the air;
2. Accumulation of mercury in sediment; and
3. Concentrations of mercury in water and fish.

Mercury deposition (Papers 4, 5 and 6)

Mercury travels for days to years after it is emitted to the air and eventually settles out onto the landscape. This settling process is called "deposition" and includes dry gases and particles, as well as rain and snow. Mercury deposition in wet forms (such as rain and snow) is measured by the national Mercury Deposition Network (MDN). There are 13 MDN sites within the northeastern United States that have been operating since 1996 and most are located in rural and semi-rural areas. In addition to MDN, there is a comprehensive mercury monitoring site at the Proctor Maple Research Center in Underhill, Vermont (operating since 1993) and other sites near Boston operated by the Northeast States for Coordinated Air Use Management (NESCAUM) and the U.S. Geological Survey. Scientists have used the MDN and Underhill data to estimate the changes in wet mercury deposition with time and to map mercury deposition across the landscape.

In reviewing the mercury deposition data, scientists found that the annual deposition of wet mercury ranged from 3.1 to 9.5 micro-grams per meter-squared ($\mu g\text{-}m^2$) in 2002. Seasonal patterns show that the concentration and amount of wet mercury deposited was greatest in the spring and summer months. Much of the wet mercury deposited by precipitation at the MDN sites arrived during specific storm events (20 to 60 percent of the total annual loading). The time period covered by the MDN data is too short to determine whether a trend exists in the amount of mercury deposited for the period 1996-2002. However, the number of weeks with very high mercury deposition decreased markedly in 2001 and 2002 compared to previous years. These high deposition periods may have ecological importance. The "fresh" new mercury deposited on the surface of a lake is more rapidly converted to toxic methylmercury than pre-existing mercury in the water. This conversion process is most pronounced during the summer growing period when high deposition events are more likely to occur.

Like at the MDN sites, wet forms of mercury deposited in precipitation at the Underhill site did not show a clear trend from 1993 to 2003, despite the decrease in emissions from nearby sources. This may be due to the impact of large sources to the west and southwest of the Underhill site.

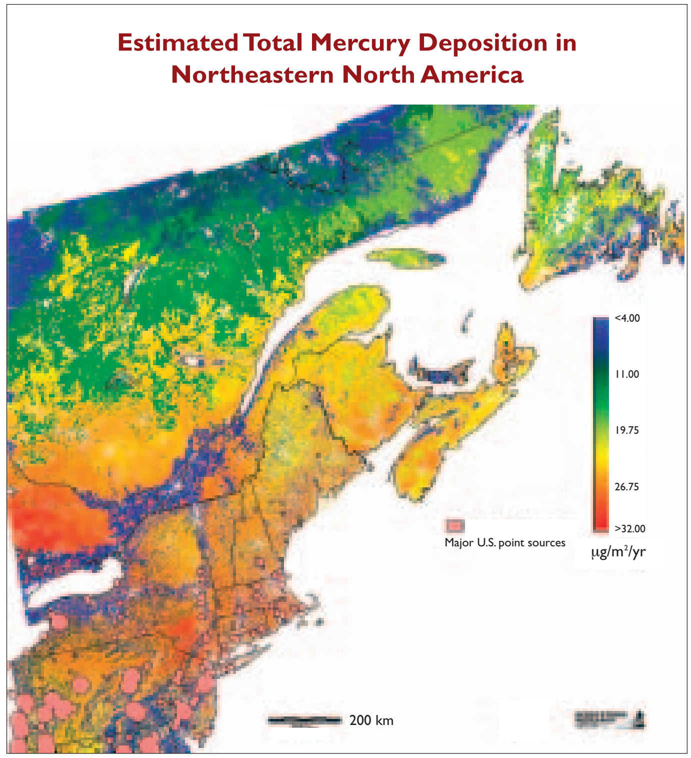


Figure 4: Total mercury deposition based on a new model intended to better depict dry deposition. The model does not fully incorporate the effects of large point sources in the region and those areas are masked in pink.

The data from these monitoring sites were used as part of a larger effort to map the estimated total (wet and dry) mercury deposition across the region. While this analysis was limited by the number and location of monitoring sites, the final map depicts higher mercury inputs in some areas of the Northeast than previously estimated. This is because all of the major deposition pathways were included in the model for the first time.

The mercury deposition model includes two important pathways for the dry deposition of mercury and highlights the important effects of forest cover and elevation on mercury deposition. According to these new model estimates, the greatest amount of mercury is deposited in forested and mountainous terrain (41.0 $\mu g/m^2/yr$) and grades to lower amounts in flat northern landscapes (3.0 $\mu g/m^2/yr$) (Figure 4). The new model also estimates that *total* mercury deposition is likely two to three times greater than wet mercury deposition that is currently measured by the national Mercury Deposition Network.

In addition to providing initial estimates of deposition, this map draws attention to the ecological importance of mercury uptake and release in forests. Forests enhance mercury deposition by "scavenging" mercury out of the air with their rough foliage. It is also thought that trees may assimilate mercury through gas exchange sites on the foliage known as stomata. For example, research has shown that tree leaves contain a higher proportion of mercury in the bioavailable methyl form than once thought. While it is not yet understood how this methylmercury is produced, it is reasonable to expect that once the leaves fall from the trees, the mercury can be ingested by insects, which are then eaten by amphibians, reptiles, birds or mammals. Methylmercury in leaves may also wash to streams as water flows over the forest floor during snowmelt and thereby serves as an important mercury input to nearby surface waters.

Last, the mercury deposition map points out the difficulty in estimating mercury deposition in urban areas or areas affected by point sources. More monitoring sites are needed to better depict this variation across the landscape and more accurately assess mercury exposure risks.

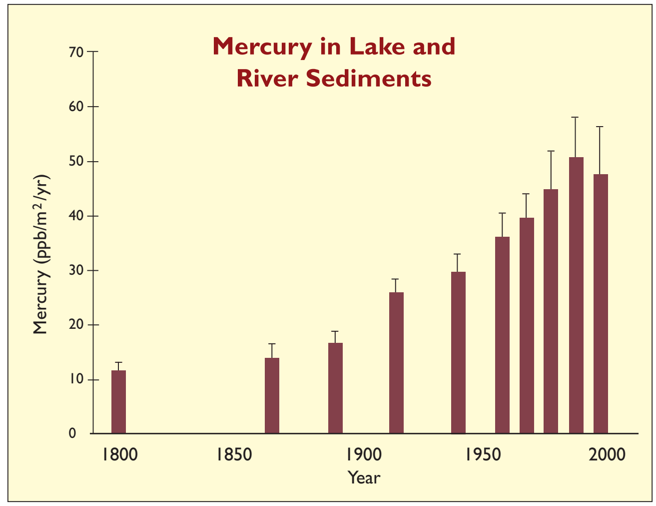


Figure 5: Accumulation of mercury in lake sediments of Vermont and New Hampshire peaked in 1980 and have declined since. Rates are still higher than baseline conditions.

Mercury in lake and river sediments (Papers 7 & 8)

Scientists use cores of lake and river sediments to document changes in mercury deposition over time and to provide a baseline against which to measure future changes in mercury loading. By comparing the amount of mercury in sediments to mercury emissions, these data illustrate the connection between airborne mercury and mercury in lakes.

An analysis of historical mercury accumulation rates in lake sediments shows a clear and consistent pattern. Mercury accumulation was slow prior to 1850, increased with industrialization and peaked across the region from 1970 to 1980 (Figure 5). Mercury accumulation in sediments has declined since that time, consistent with the decrease in mercury emissions in North America. Even with this reduction, mercury is currently accumulating in lake sediments at a rate two to five times faster than pre-industrial rates.

Researchers also analyzed surface sediments that reflect present-day conditions at more than 570 sites. They found that total mercury concentrations ranged from 0.01 to 3.7 ppm with the highest levels reported in lakes. Methylmercury concentrations in the sediments spanned 0.15 to 21.0 ppb, with rivers showing higher proportions of mercury in the methyl form. Forty-four percent of the waterbodies sampled exceed federal guidelines for the protection of aquatic biota (NOAA 1999). No quantifiable spatial pattern was observed from the data, but high values tended to occur in sediments in lakes in Massachusetts and southeastern New Hampshire.

Mercury in water (Paper 9)

Once mercury is deposited to the landscape, most of it flows into rivers and lakes where it becomes available for fish, wildlife and human consumption. Understanding the levels and patterns of mercury in surface waters is critical to addressing this widespread environmental threat.

Scientists have compiled data for mercury in water from more than 1,000 locations from Massachusetts to Newfoundland. They used this information to determine whether spatial patterns exist and to identify the factors that make a waterbody sensitive to methylmercury loading. The analysis was limited to data that were collected under low flow conditions in order to minimize the effects of seasonal changes associated with periods of high streamflow.

The measurements of total mercury in water ranged from 0.5 to 19.5 ppt, with the highest concentrations found in Nova Scotia, Newfoundland and the Adirondacks of New York (see Figure 6). The waters with high mercury levels were often distant from direct point sources and urbanized land use, suggesting airborne mercury as a likely source. However, the data also demonstrate that point sources can have a considerable impact in local areas, as seen at two well known sites in the region. Very high mercury concentrations were detected in surface waters near Portland, Maine, and in the urban corridor of Boston, Massachusetts.

These findings point to the need for a two-pronged approach to address mercury levels in surface waters; reducing mercury emissions to the air and controlling direct mercury discharges to surface waters.

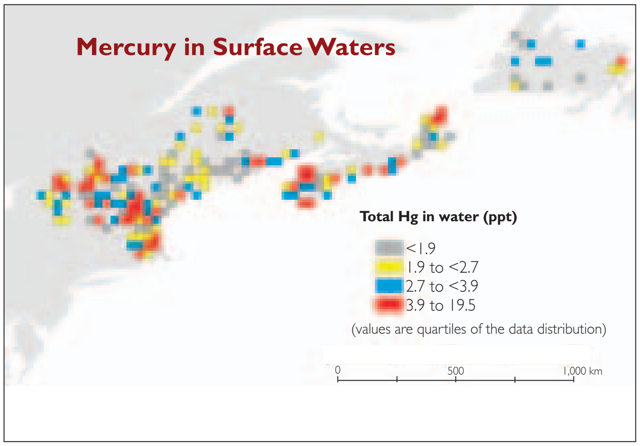


Figure 6: Water mercury concentrations vary across the landscape and do not necessarily correspond to deposition estimates.

Mercury in freshwater fish (Papers 11 & 13)

Scientists analyzed mercury measurements from 1980 to the present for more than 15,000 fishes, spanning 64 different fish species to assess the extent and nature of mercury contamination in the Northeast. This analysis is considered the first published work to utilize such an extensive dataset to describe fish tissue mercury concentrations at the sub-continental scale.

Mercury levels across all fish species ranged from 0.09 to 1.02 ppm, with the highest concentrations in white perch that reside in reservoirs. Overall, 15 and 42 percent of the waterbodies sampled for brook trout and yellow perch, respectively, had average fish mercury concentrations (in fillets) above the EPA methylmercury criterion of 0.3 ppm. The scientists also identified specific species that tend to have high mercury levels; bass species, pike, lake trout, white perch and walleye were highest (Figure 7A). Other factors such as fish length and habitat (lake, river or reservoir) are good predictors of mercury levels (Figure 7B).

Individual waterbody characteristics also strongly influence fish mercury concentrations. A detailed analysis of the conditions that most likely lead to mercury problems in fish identified several important parameters (see the list that follows). In general, acidic water bodies that have complex food chains and numerous wetlands tend to have fish with high mercuy concentrations.

Attributes of mercury-sensitive surface waters:

Chemical

- High acidity
- Low acid neutralizing capacity
- High sulfate

Physical

- Abundant wetlands (particularly along the shore)
- Small lake with a large watershed area
- Summer water level fluctuations > 6 feet

Biological

- Low zooplankton abundance
- Low nutrient levels
- Numerous trophic levels in the food chain

Given the variation in waterbody characteristics across the landscape, no distinct spatial pattern was detected in average fish mercury concentrations, although some areas had high fish mercury levels compared to others. Overall, the characteristics of a watershed may be as important as the actual deposition in predicting mercury levels in fish. For this reason, it is not possible to pick and choose where to reduce mercury pollution across a region to achieve fish mercury goals. Rather, an approach where reductions occur at *all* facilities would likely be more effective.

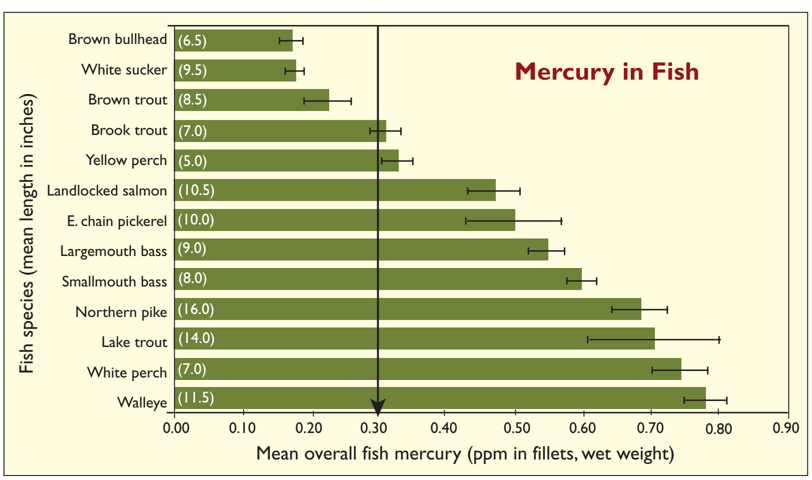


Figure 7A: Fish data from the NERC database show that several fish species have average mercury concentrations that exceed the EPA criterion to protect human health (0.3 ppm).

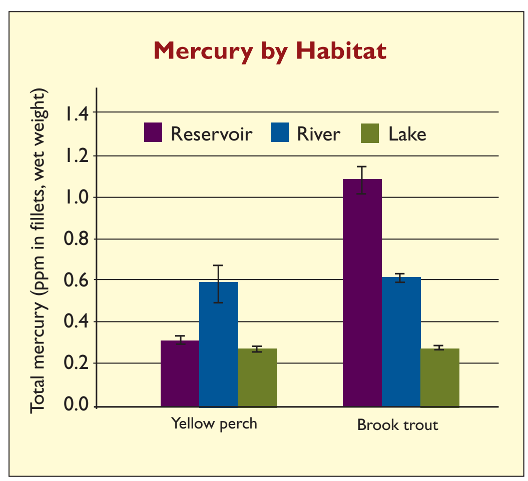


Figure 7B: Mercury levels vary by habitat type.

Fact Finder – Mercury (Hg) and Methylmercury (MeHg)

Deposition (Papers 4, 5 and 6)

- Hg concentration in precipitation ranged from 7.8 to 10.5 ppb at Underhill, Vermont.
- Annual average deposition at Underhill was 9.7 $\mu g/m^2/yr$ in 2002.
- A new mercury model estimated total deposition in the Northeast from 3.0 to 41.0 $\mu g/m^2/yr$.
- Higher concentrations of Hg occured in spring and summer.
- The highest levels of Hg in precipitation were associated with regional transport from the west and southwest, regardless of season.

Sediments (Papers 7 and 8)

- The total Hg in sediment ranged from 0.01 to 3.7 ppm.
- MeHg in sediments ranged from 0.15 to 21.0 ppb.
- Sediment cores Hg accumulation has declined since 1970–1980.
- Hg accumulation rates in sediment were 3-5x above background.
- At least 44% of waters across the region had sediments in excess of U.S. guidelines.
- Highest Hg values values were observed in lakes.
- No spatial pattern was detected, but high values occur more commonly in Massachusetts and southeastern New Hampshire.

Water (Papers 9, 10 and 11)

- Total Hg values in surface waters across the region ranged from below detection of 0.5 to 19.5 ppt.
- MeHg levels ranged from 0.01 to 3.12 ppt. The highest average value occured in Nova Scotia.
- MeHg was generally 15% of total mercury, except in urbanized Massachusetts which was lower.
- Waters with the highest total Hg and MeHg levels were distant from point sources and had abundant wetlands.
- Waters with very high total Hg were detected near urbanized regions of Boston, Massachusetts and Portland, Maine; areas with high MeHg are reported in central Massachusetts and southern New Hampshire.

Fish (Paper 13)

- Hg levels across all fish species ranged from 0.09 to 1.02 ppm.
- 42% of waters had average Hg levels in yellow perch above current U.S. EPA MeHg tissue criterion.
- 15% of waters had average Hg levels in brook trout that exceeded the U.S. EPA MeHg tissue criterion.
- Highest Hg concentration occured in white perch in reservoirs (1.02 ppm).
- Fish length was an important predictor of Hg content.
- In 8 of the 13 fish species analyzed, Hg was highest in reservoirs.
- Forested areas with acidic or tannic waters showed higher fish Hg concentrations.

Crayfish (Paper 12)

- Hg concentrations ranged from 0.04 to 0.50 ppm.
- Half of the crayfish examined had mercury levels above the expected background level of 0.10 ppm.
- Larger crayfish and crayfish living in streams had the highest Hg.
- Nearly all of the Hg existed in the toxic MeHg form (88%).

Salamanders (Paper 14)

- Mercury concentrations in salamanders ranged from 0.02 to 0.08 ppm.
- MeHg comprised up to 97% of total Hg in larval salamander composites.
- The highest concentrations of Hg were in salamanders in the unburned watersheds of Acadia National Park (ANP).
- Acidic streams in the Bear Brook Watershed had significantly higher total Hg in salamander larvae.
- Both larval and adult salamanders had significantly higher total Hg concentrations than brook trout.

Fact Finder – Mercury (Hg) and Methylmercury (MeHg)

Aquatic Birds (Papers 15, 17 and 18)

- Hg in aquatic birds increased from marine areas to estuaries and rivers, and was highest in lakes.
- Hg levels ranged from low to high as follows: wood duck < tree swallow < belted kingfisher < common merganser < common loon.
- Adult blood Hg was 5-10x > nestling blood.
- Male loon Hg levels were > female levels due to males averaging 20% larger.
- Hg levels increased with age if Hg consumption exceeded elimination.
- Ratio of liver, muscle, blood Hg levels in loons followed the 7:3:1 rule.
- Some waterfowl species exceeded the EPA MeHg criterion in their breast muscle; although most edible species were below 0.30 ppm.
- More than 1,800 blood and egg Hg levels in loons indicated at least 9 distinct biological hotspots.
- Insect-eating songbird Hg levels generally increased with body mass.
- Some insect-eating songbirds (such as northern waterthrush) had blood Hg levels that exceed much larger fish-eating species (such as eagles).
- The percent of wetlands within 500 feet of common loon territory were positively correlated with loon blood mercury levels.
- 92% of adult loons in Kejimkujik National Park in Nova Scotia had blood mercury levels >4.0 ppm, levels associated with lowered reproduction.

Forest Songbirds (Paper 16)

- Hg concentrations in blood ranged from 0.10 to 0.80 ppm and were highest in the Bicknell's thrush (BT).
- Hg content in feathers ranged from 0.10 to 1.60 ppm and was highest in BT.
- Blood Hg levels were highest in the western mountains of Maine and southernmost Quebec, and lowest in the Gaspe Peninsula of Quebec.
- Average feather Hg levels in BT were highest in birds >2 yrs.
- Average blood Hg levels in BT were higher in their wintering grounds.
- All four bird species showed MeHg to Hg ratios of 1:1.

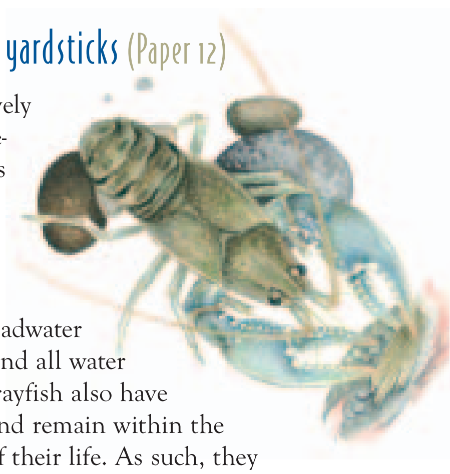
Mink & Otter (Paper 19)

- The average Hg concentrations in mink liver ranged from 1.01 to 3.01 ppm.
- The highest levels occurred in Massachusetts and Connecticut.
- Average Hg levels in river otter liver ranged from 0.85 to 2.10 ppm.
- There was no clear regional pattern for otter Hg.
- 36% of the mink and otter had levels of Hg in fur that exceeded the adverse effects threshold of 20 ppm.
- The maximum Hg levels in mink and otter fur exceed the acute toxicity thresholds.
- Hg in the liver of otters decreased approximately 26% between 1982–1984 and 1998–2000.
- Hg in mink liver declined roughly 37% between 1982–1984 and 1998–2000.

3. Mercury Exists in Animals Throughout the Food Chain – Even Forest Songbirds

By examining data for animals such as crayfish and salamanders, researchers have identified new ways of comparing mercury levels both within and across watersheds. In addition, by carefully analyzing new data scientists have discovered high mercury levels in unexpected places. Not only does mercury pose a threat to fish and the people eating them, but animals living in habitats as diverse as mountain-tops and small headwater streams should now be considered at risk for mercury poisoning.

Crayfish as mercury yardsticks (Paper 12)



Crayfish are relatively long-lived invertebrates (organisms without backbones) that reside in many different habitats within a watershed. They live in small headwater streams, large lakes and all water types in between. Crayfish also have small home ranges and remain within the same area for most of their life. As such, they reflect mercury in their immediate surroundings and provide a useful yardstick for comparing mercury levels throughout a specific watershed (Figure 8). These same characteristics make crayfish useful locators of high mercury levels that may originate from local point sources such as an old landfill.

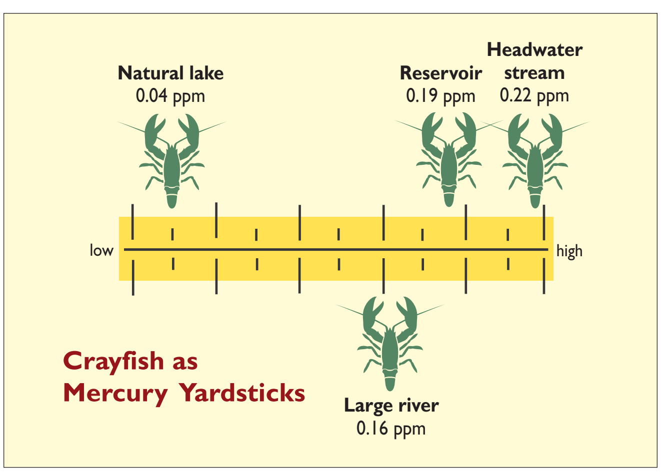


Figure 8: Crayfish depict changes in mercury concentrations in different habitats of the upper Connecticut River watershed.

Researchers collected and analyzed crayfish over a period of four years from sites in Vermont, New Hampshire and Maine. Mercury concentrations ranged from 0.04 to 0.50 ppm. Half of the crayfish examined had mercury levels above the expected background level of 0.10 ppm. Larger crayfish and crayfish living in rivers and streams showed higher mercury levels than other individuals. As is the case for fish and wildlife, nearly all of the tail mercury existed in the toxic methyl form (88 percent). Animals that regularly eat crayfish include bass, loons and raccoons.

Salamanders detect mercury in headwaters (Paper 14)

Scientists analyzed mercury in northern two-lined salamanders that inhabit streams throughout eastern North America. Their study sites included Acadia National Park (ANP) and Bear Brook Watershed (BBW) in Maine, as well as Shenandoah National Park (SNP) in Virginia. Streams in each of these study sites represent differences in mercury deposition and land use history. This is the first study to analyze the effects of chronic acidification, fire history and forest cover on mercury levels in a stream-dwelling amphibian species.

The mercury in two-lined salamanders was elevated and ranged from 0.02 to 0.08 ppm. The mercury concentrations in these salamanders were higher than those found in brook trout, and most of it occurred as methylmercury.

Data from the acidic stream in BBW indicate that mercury bioaccumulation was higher in this acidic environment. This is presumably due to the greater presence of sulfate reducing bacteria and transfer of mercury through the food web in this acidic environment.

The highest mercury levels in two-lined salamanders were found in the conifer-dominated watershed in ANP where there was no history of fire. This result suggests that fire history and forest cover may also affect mercury bioaccumulation, as has been suggested by previous research. This study illustrates the important role that acidification, land use and forest cover play in mercury cycling and underscores the importance of assessing sensitive watersheds.

Northern two-lined salamander *(Eurycea bislineata bislineata)*

Scientists document widespread mercury in aquatic birds (Papers 15, 17 and 18)

The use of aquatic birds as indicators of mercury contamination has been a common practice for years. Recently, scientists have discovered the importance of using several bird species to compare pollution levels across different ecosystem types (e.g. lakes versus wetlands). A dataset of more than 4,700 records representing 38 different bird species was compiled to assess differences among bird species, geographic areas, habitat types, size, age and gender.

Elevated mercury levels were detected in most aquatic and even some terrestrial habitats (Figure 11). Selected indicator species that represent fish and insect food chains are useful for monitoring changing mercury levels and identifying sensitive areas across the Northeast. In particular, the common loon serves this role well because of its position on the food chain, prey choice, habitat, and abundance (Box 2).

To understand how mercury levels compare in different bird species living in the same environment, researchers evaluated mercury data for five species on Aziscohos and Flagstaff lakes in Maine. The results show that large fish-eating birds had the highest mercury levels and plant-eating birds had the lowest. In general, mercury levels ranged from low to high as follows: wood duck < tree swallow < belted kingfisher < common merganser < common loon. This information is useful when choosing indicators species and confirms the common loon serves that role well.

Insect-eating birds in aquatic environments generally had lower mercury than their fish-eating neighbors, but some did not follow this pattern. Specifically, a northern waterthrush from a river in Massachusetts had mercury levels of 1.6 ppm in its blood. This level was higher than the mercury found in all of the more than 100 juvenile bald eagles that were sampled. Scientists attribute these high mercury levels in a non-fish-eating bird because it is at the top of a food chain that has multiple links. The more linkages there are in a food chain, the greater the rate of biomagnification.

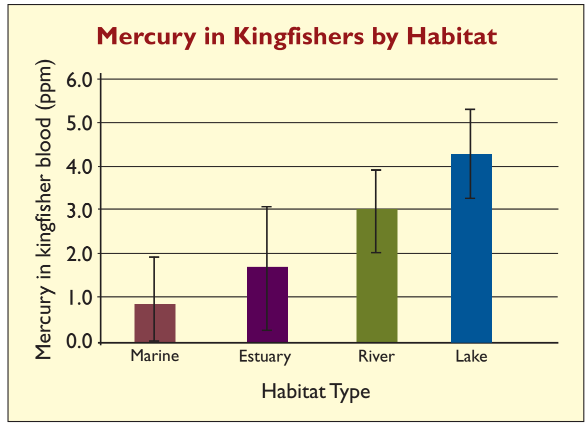
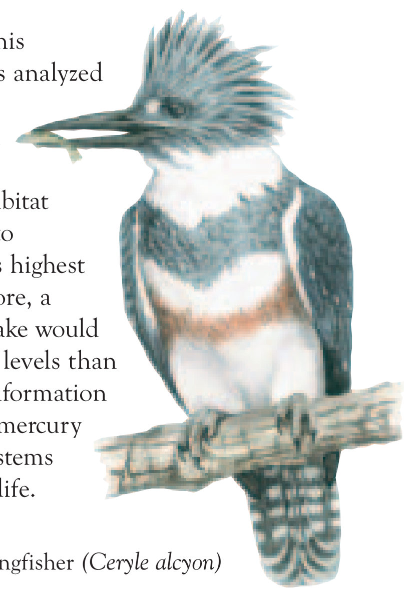


Figure 9: The availability of methylmercury to fish-eating birds like the belted kingfisher is four times higher in lake habitats versus marine environments.

In another review of this extensive dataset, scientists analyzed samples from bald eagles and belted kingfishers and determined that mercury tends to increase across habitat types from marine areas, to estuaries and rivers, and is highest in lakes (Figure 9). Therefore, a bald eagle nesting near a lake would likely have higher mercury levels than one near the coast. This information can be used to help focus mercury reduction efforts on ecosystems with high mercury in wildlife.



Belted kingfisher *(Ceryle alcyon)*

Box 2: Common Loon, Uncommon Indicator

Common loons are one of the best indicators of mercury pollution in lakes. As a large, long-lived bird that feeds nearly exclusively on fish and tends to nest on nutrient poor lakes, loons often accumulate more mercury than most other bird species. They have therefore been identified as the most important high-trophic level indicator species for lakes in North America. Scientists analyzed a large dataset of mercury in loons to evaluate geographic differences in mercury pollution for the Northeast as well as much of North America.

Continental trends indicate a significant increasing west to east pattern with the highest blood and egg mercury levels in the Northeast. Within the Northeast, high mercury levels in loons were most common in four situations (1) where water chemistry is sensitive, (2) when summertime lake level fluctuations are greater than six feet, (3) where large point sources exist, and (4) where shoreline wetlands are extensive. The biological hotspots of mercury in loons shown in Figure 13 provide specific examples of some of these conditions.

Common loon *(Gavia immer)*

Research reveals mercury in forest songbirds (Paper 16)

One of the most significant discoveries made in this comprehensive data analysis is the presence of mercury in non-aquatic songbirds. Scientists collected blood and feather samples from four species of mountain-dwelling songbirds at sites on Mt. Mansfield in Vermont: Bicknell's thrush, blackpoll warbler, white-throated sparrow and yellow-rumped warbler. In addition, they sampled Bicknell's thrush at 20 other sites from Vermont to Gaspe Peninsula in Quebec. The data on Bicknell's thrush provide the most comprehensive information to date on mercury in a strictly terrestrial, insect-eating songbird.

The results from this new study show that songbirds in mountain forests are accumulating mercury. Among the four species sampled on Mt. Mansfield, mercury concentrations in blood were highest in the Bicknell's thrush (0.08 to 0.38 ppm). Feather mercury levels were greatest in Bicknell's thrush older than two years, suggesting that the mercury in these birds is building up over time. Nearly all of the mercury measured in these birds was in the methyl form, indicating that mercury is accumulating in food webs within high elevation forest environments.

The spatial pattern of mercury in the blood of Bicknell's thrush shows that levels are highest in areas that are expected to receive high inputs of mercury in litterfall (Figure 10). The higher mercury blood concentrations of Bicknell's thrushes in the southern versus northern Green Mountains of Vermont parallels deposition estimates for these sites. Overall, Bicknell's thrush blood mercury levels were highest in the western Maine mountains and lowest in the Gaspe Peninsula, Quebec. Known mercury sources, mercury deposition models, and new songbird and fish mercury data all suggest that the Catskill Mountains and nearby areas of the Appalachian Mountains are potentially at greater ecological risk for mercury accumulation.

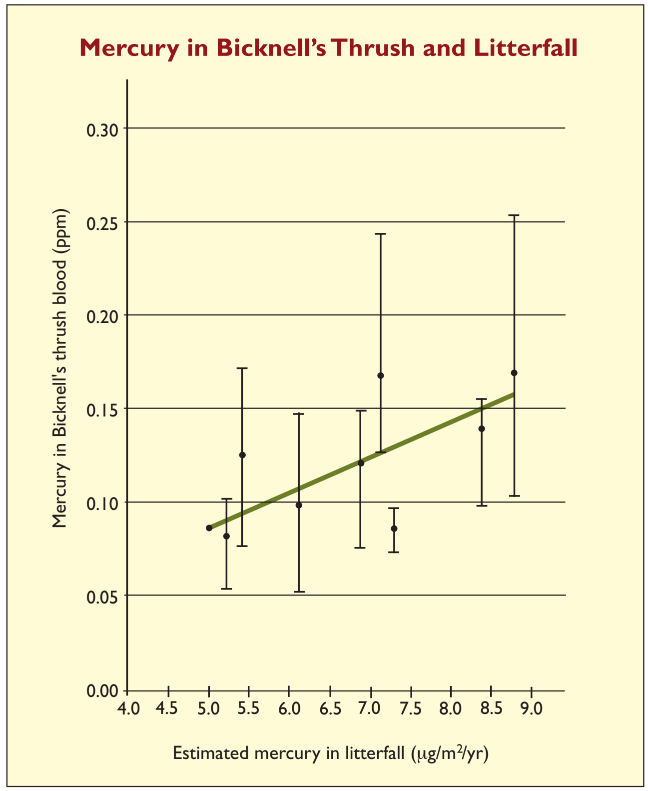


Figure 10: Comparison of blood mercury levels in the Bicknell's thrush with associated forest litterfall mercury levels for 21 mountaintops (grouped into 9 areas) in the Northeast.

Bicknell's thrush *(Catharus bicknelli)*

Box 3: Spotlight on Bicknell's Thrush

While mercury was once thought to be limited to fish-eating birds that spend their lives in or around water, it is now clear that insect-eating songbirds have been exposed as well, including those inhabiting terrestrial habitats, such as mountaintops. This surprising finding suggests that airborne mercury is pervasive and its impacts are no longer limited to surface waters and the wildlife that use them.

The Bicknell's thrush is a forest-dwelling songbird that breeds almost exclusively in high elevations in the northeastern U.S. and eastern Canada, and winters in the Caribbean Greater Antilles. This species is the most highly ranked migrant songbird for conservation priority in the Northeast due to its small global population (fewer than 50,000 individuals), its limited breeding range, and its dwindling winter habitat. Since it eats primarily insects and lives in montane fir forests (that are known to receive high inputs of airborne mercury), the Bicknell's thrush can help scientists address the new questions raised by this research. The specific pathway by which the birds consume the mercury is not fully understood, nor are the effects mercury burdens will have on these birds as well as other organisms and processes in forest ecosystems. There is much to learn from these forest songbirds.

Figure 11: Mercury in Birds Across the Landscape

Many bird species serve as good indicators of the availability of methylmercury across the landscape. Pictured are preferred indicator species.

Fish-eating birds

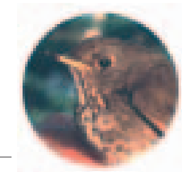
Ecosystem:
Natural lake
Indicator:
Common loon
Mercury levels:
0.1 – 8.6 ppm

Ecosystem:
Small river
Indicator:
Common merganser
Mercury levels:
0.7 – 2.4 ppm

Ecosystem:
Reservoir
Indicator:
Bald eagle*
Mercury levels:
0.1 – 1.2 ppm

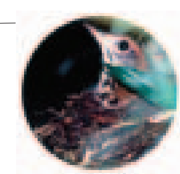
Ecosystem:
Large river
Indicator:
Belted kingfisher
Mercury levels:
0.1 – 4.6 ppm

Insect-eating birds



Ecosystem:
High elevation forest
Indicator:
Bicknell's thrush
Mercury levels:
0.10 – 0.80 ppm

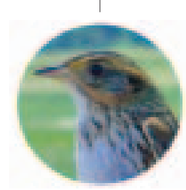
Ecosystem:
Riverine forested wetland
Indicator:
Northern waterthrush
Mercury levels:
0.30 – 1.60 ppm



Ecosystem:
Upland forest
Indicator:
Wood thrush
Mercury levels:
0.02 – 0.14 ppm

Ecosystem:
Emergent wetland
Indicator:
Tree swallow
Mercury levels:
0.10 – 1.00 ppm

Ecosystem:
Nearshore marine
Indicator:
Common tern*
Mercury levels:
0.1 – 1.0 ppm



Ecosystem:
Estuary
Indicator:
Saltmarsh sharp-tailed sparrow
Mercury levels:
0.20 – 1.70 ppm

Note:
Mercury concentrations are in adult blood, except for the bald eagle and common tern which are in juvenile blood.

Mercury found in mink and river otter (Paper 19)

Mink and river otter are mammals that feed on fish and crayfish and have the potential to accumulate toxic levels of mercury in their bodies. Scientists compiled mercury data for mink and otter across New York, New England and Nova Scotia. The average mercury concentrations in mink liver ranged from 1.01 to 3.01 ppm with the highest levels occurring in Massachusetts and Connecticut. Average mercury levels in river otter liver ranged from 0.85 to 2.10 ppm, with no clear regional pattern.

When evaluating ecological impacts, it is important to compare mercury concentrations to levels that are associated with adverse effects. For mink and otter, that level has been established at 20 ppm of mercury in fur. It can also be helpful to look beyond the average mercury level to the maximum level, since these high levels could have acute effects. Thresholds for acute mercury toxicity leading to the death of mink and otter have been defined from laboratory studies and field observations as approximately 47 ppm in fur. Figure 12 compares these thresholds to mercury levels found in mink and otter fur in the Northeast.

A long-term dataset from New York state allowed scientists to evaluate changes in mercury levels over time. They found a statistically significant decrease in both otter and mink mercury levels between the periods 1982-1984 and 1998-2000. Mercury in the liver of otters decreased approximately 26 percent between these two periods and mink liver mercury declined roughly 37 percent. The declines were remarkably similar between adult and young otter as well as between male and female mink. The uniform decline suggests decreases in mercury will produce improvements in mink and otter regardless of species, age and gender.

River otter *(Lontra canadensis)*

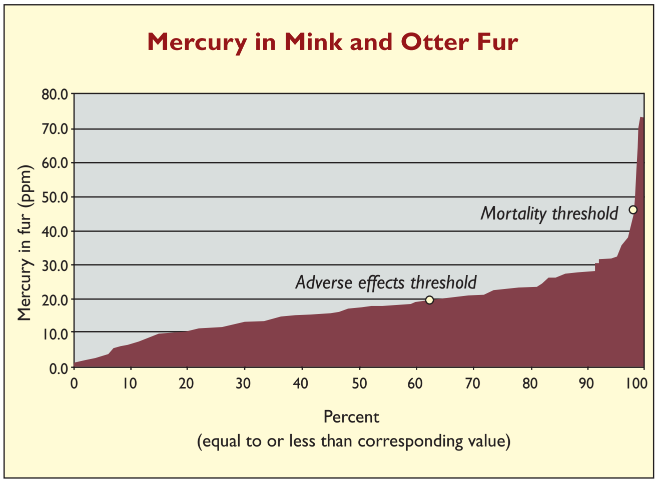


Figure 12: Mink and otter data show that 36% of the animals sampled exceed the threshold for adverse effects and 1% exceed the threshold for acute toxicity leading to death.

Box 4: Predicting Wildlife Population Effects (Paper 21)

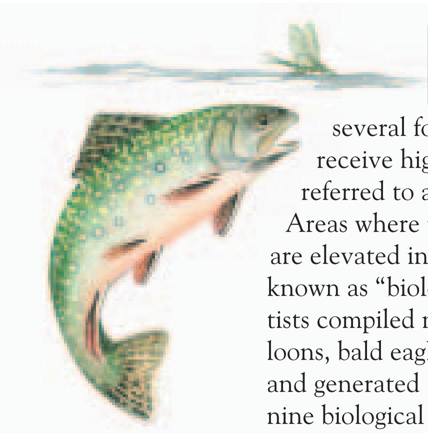
The U.S. Environmental Protection Agency (EPA) has undertaken a new effort through its National Health and Environmental Effects Research Laboratory (NHEERL) to move beyond water quality standards that protect human health to standards that incorporate "ecological health" to protect biological resources. The EPA is charged with restoring and maintaining the chemical, physical and biological integrity of the Nation's waters by the Federal Clean Water Act. To meet this mandate, it is developing new criteria to protect aquatic species and aquatic-dependent wildlife from toxic chemicals such as mercury.

In the past, water quality standards for mercury and other chemicals have been based on a narrow approach that does not account for the consumption of mercury and its bioaccumulation in aquatic food webs. To address these shortcomings, NHEERL has developed a Wildlife Research Strategy that will more effectively assess the effects of methylmercury and habitat alteration on aquatic-dependent wildlife using the common loon. This research effort will combine information regarding the distribution and magnitude of mercury across the region and the biological response of loons to this stress. The information on individual loon response will be extrapolated to determine how it effects the loon population (e.g. loon distribution, abundance and growth rates) across the region.

Over 40 collaborators from government agencies, universities and non-profit organizations have contributed data to this effort. After the data have been analyzed EPA will develop a new method to support improved ecological risk assessments for mercury and other stresses, and stronger wildlife protection criteria at the state and federal level.

4. Hotspots of Mercury Occur in Northeastern North America and Pose a Risk to Ecological Health

What is a hotspot and how is it measured?



Mercury hotspots can occur in several forms. Locations that receive high mercury loading are referred to as "deposition hotspots". Areas where mercury concentrations are elevated in fish and wildlife are known as "biological hotspots". Scientists compiled mercury in fish, common loons, bald eagles, mink and river otter and generated a preliminary map of nine biological hotspots in freshwater ecosystems. Except for two locations, these biological hotspots are not necessarily linked to any one particular source and are therefore areas that scientists believe are likely associated with airborne mercury emissions. The two exceptions are the biological hotspots near large point sources in southeastern New Hampshire (#3) and a defunct chlorine factory in Orrington, Maine (#6).

The preliminary map of biological hotspots for freshwater ecosystems shown in Figure 13 represents nine areas that meet the following criteria.

1. Two or more organisms with mercury levels consistently above thresholds for documented adverse effects.
2. A relatively large area impacted.
3. A high density of measurements showing elevated mercury in biota.
4. A substantial deviation in mercury levels from the surrounding landscape.

The threshold level used for identifying potential fish hotspots is 0.16 ppm (wet weight, whole body mercury levels). Scientists have determined that this level potentially poses a population level risk for fish-eating birds such as the common loon (Evers et al. 2004). For loons, an area is highlighted as a possible location of concern if values for adult blood levels exceed 3.0 ppm or egg levels greater than 1.3 ppm. This level has been identified as a threshold for ecological effects on the physiology, behavior, reproduction, and survival of common loons (see Table 1). In bald eagle young an estimated threshold of 0.7 ppm of mercury (wet weight) in blood is used. This estimate corresponds to the mercury level documented in bald eagles at locations where common loon mercury exceeds 3.0 ppm. Mink and otter are known to exhibit sublethal toxicity at fur mercury levels above 20 ppm.

Where are the hotspots in the region?

At the present time, nine major biological hotspots have been identified in the area from New York state to Nova Scotia. Seven of these biological hotspots are not associated with a known point source. The map is a preliminary depiction of the extent of biological hotspots as it is possible that more biological hotspots will emerge as additional information is collected and as areas of concern are potentially identified in forest ecosystems.

Fish and loons are most broadly represented on the map, consistent with the large databases for these organisms. The hotspots for wildlife are evenly distributed, except for the bald eagle which occurs only in Maine. It is also noteworthy that six of the nine biological hotspots show elevated mercury in three or more organisms.

Why are some areas "hot"?

Many reasons exist for the occurrence of biological hotspots. Beyond long distance transport of mercury emissions, the reasons include hydrological impacts on reservoirs (such as in western Maine), local emission sources (like the defunct chlorine plant in Maine) and lakes with chemical conditions that are conducive to methylmercury production. This latter category encompasses much of the region and includes acidic lakes in the Adirondack Mountains of New York, Quebec and Nova Scotia.

Kejimkujik National Park in Nova Scotia provides an interesting case study in the patterns of biological hotspots. Ninety-two percent of adult loons at Kejimkujik had blood mercury levels >4.0 ppm, and several individuals had among the highest levels found in breeding common loons across North America (up to 7.8 ppm). Reduced reproduction has been observed in loons at Kejimkujik for the last 15 years (Kerekes et al. 1994 and Burgess et al. 1998). Yet, the map of mercury deposition (Figure 4) indicates that Kejimkujik receives relatively low mercury deposition compared with much of the region. Acidic surface waters in Kejimkujik have the ideal conditions for converting mercury to methylmercury, which facilitates the uptake and accumulation of mercury in the food chain. The Kejimkujik hotspot underscores the importance of achieving significant reductions in mercury deposition across the landscape, as well as the importance of reducing acidity in surface waters in order to achieve biological recovery.

Figure 13: Biological Hotspots in Northeastern North America

A preliminary map of biological hotspots in aquatic systems shows nine areas of concern where mercury levels in biota exceed levels at which adverse impacts occur.

Key:

1. Western Adirondack Mountains, NY
2. La Maurice Area, Quebec
3. Lower Merrimack River watershed, NH and MA
4. Rangley Lakes Region, ME
5. Upper Penobscot River watershed, ME
6. Midcoast Maine
7. Downeast Maine
8. Kejimkujik National Park, Nova Scotia
9. Central Nova Scotia

5. Environmental Monitoring of Mercury Must be Expanded

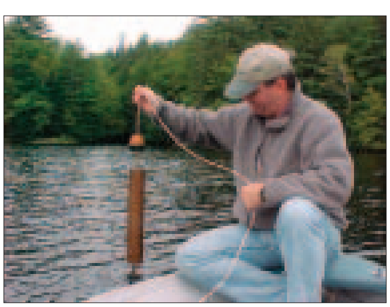
The most effective way to evaluate the extent and effect of mercury pollution is through a comprehensive monitoring program. Monitoring programs are also the only way to assess the environmental response to mercury emissions reductions. With that in mind, a team of scientists has developed a vision for mercury monitoring in North America. Published in the journal *Environmental Science & Technology,* this program calls for a network of 200 new long-term monitoring sites across different ecosystems, as well as 10 sites for intensive investigation.

Long-term network sites

The long-term network sites would measure six indicators:

1. Atmospheric wet deposition (weekly);
2. Surface soil sampling for elemental mercury and methylmercury (twice per year);
3. Surface water measurements of elemental and methylmercury (twice per year);
4. Yearling fish mercury concentrations (twice per year);
5. Piscivorous/commercial fish mercury levels (annually); and
6. Wildlife mercury levels (annually).

Eggs from this duck box provide a useful and efficient method for monitoring mercury levels in aquatic systems. Birds are regularly representative of wildlife that are most at risk for environmental mercury. Eggs from three species of ducks are represented here: Common goldeneye, Common Merganser, and Hooded Merganser.



Sampling of water for total and methylmercury can be conducted with relative ease and should be accompanied by water chemistry measurements such as dissolved organic carbon and lake acidity.

Intensive study sites

Monitoring at the intensive study sites would involve additional detailed atmospheric, watershed, aquatic and biota sampling including:

1. Atmospheric mercury by species (continuously);
2. Mercury evasion (monthly);
3. Watershed yield from surface and groundwater (monthly);
4. Long-term sediment depth mercury profiles (every 3-5 years);
5. Mercury and methylmercury profiles throughout the water column (twice per year);
6. Phytoplankton and algae mercury levels (monthly); and
7. Zooplankton and benthic invertebrate sampling (monthly).

Although significant efforts have been made over the past decade to understand the many connections between emissions that occur across continents and the human and ecological effects, many questions remain. The first step in answering these questions is the development, funding and implementation of a national (and international) mercury monitoring program. Since change is already occurring and it is critical to assess how changing emissions affects the environment and human health, this program should be initiated as soon as possible.

For more information on the proposed mercury monitoring strategy see:

Mason, R.P., M.L. Abbott, R.A. Bodaly, O.R. Bullock, C.T. Driscoll, D.C. Evers, S.E. Lindberg, M. Murray and E.B. Swain. 2005. Monitoring the Response to Changing Mercury Deposition. Environ. Sci. & Tech. Vol. 39. Pages 15A-22A.

Since 1998, the Wolf's Neck Mercury Deposition Network (MDN) station (in Freeport, Maine) has measured atmospheric deposition of mercury. Initial funding for this station came from the Casco Bay Estuary Program and it is now maintained and operated by the Maine Department of Environmental Protection.

Ecotoxicology Papers

The content for this report was distilled, in large part, from: Biogeographical patterns of environmental mercury in northeastern North America. 2005. *Ecotoxicology.* Volume 14, numbers 1 and 2. Guest Editors: David C. Evers and Thomas A. Clair. Editor: Lee R. Shugart.

1. Mercury in northeastern North America: a synthesis of existing databases. D.C. Evers and T.A. Clair.
2. Approaches to reducing mercury in North America. J. Weiss.
3. Mercury policy and science in northeastern North America: The Mercury Action Plan of the New England Governors and Eastern Canadian Premiers. C.M. Smith and L.J. Trip.
4. Patterns of mercury deposition and concentration in northeastern North America (1996-2002). A. VanArsdale, J. Weiss, G.J. Keeler, E.K. Miller, G. Boulet, R. Brulotte and L. Poissant.
5. Estimation and mapping of wet and dry mercury deposition across northeastern North America. E.K. Miller, A. VanArsdale, G.J. Keeler, A. Chalmers, L. Poissant, N.C. Kamman and R. Brulotte.
6. Long-term atmospheric mercury deposition at Underhill, Vermont. G.J. Keeler, L.E. Gratz and K. Al-Wali.
7. Deconstruction of historic mercury accumulation in lake sediments, northeastern United States. E. Perry, S.A. Norton, N.C. Kamman, P.M. Lorey and C.T. Driscoll.
8. Factors influencing mercury in freshwater surface sediments of northeastern North America. N.C. Kamman, A. Chalmers, T.A. Clair, A. Major, R.B. Moore, S.A. Norton and J.B. Shanley.
9. Distribution patterns of mercury in lakes and rivers of northeastern North America. I.F. Dennis, T.A. Clair, C.T. Driscoll, N.C. Kamman, A. Chalmers, J.B. Shanley, S.A. Norton and S. Kahl.
10. Physical controls on total and methylmercury concentrations in streams and lakes of the northeastern U.S. J.B. Shanley, N.C. Kamman, T.A. Clair and A. Chalmers.
11. Patterns of mercury bioaccumulation and transfer in aquatic food webs across multi-lake studies in the northeast U.S. C.Y. Chen, R.S. Stemberger, N.C. Kamman, B. Mayes and C. Folt.
12. Mercury in the northern crayfish, *Orconectes virilis (Hagen)*, in New England, USA. C.M. Pennuto, O.P. Lane, D.C. Evers, R.J. Taylor and J. Loukmas.
13. Mercury in freshwater fish of northeast North America – a geographic perspective based on fish tissue monitoring databases. N.C. Kamman, N.M. Burgess, C.T. Driscoll, H.A. Simonin, W.M. Goodale, J. Linehan, R. Estabrook, M. Hutcheson, A. Major and A.M. Scheuhammer.
14. Mercury bioaccumulation in two-lined salamanders from streams in the northeastern U.S. M.S. Bank, C.S. Loftin and R.E. Jung.
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18. Relating cover characteristics and common loon mercury levels using geographical information systems. D. Kramar, W.M. Goodale, L. Kennedy, B. Carstensen and T. Kaur.
19. Mercury levels in mink and river otter in northeastern North America. D. Yates, D. Mayack, K. Munney, D.C. Evers, R.J. Taylor, T. Kaur and A. Major.
20. Developing a cyber infrastructure for integrated assessments of environmental contaminants. T. Kaur, J. Singh, W.M. Goodale, D. Kramar and P. Nelson.
21. An approach to predict risks to wildlife populations from mercury and other stressors. D. Nacci, M. Pelletier, J. Lake, R. Bennett, J. Nichols, R. Haebler, J. Grear, A. Kuhn, J. Copeland, M. Nicholson, S. Walters and W.R. Munns Jr.

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About Biodiversity Research Institute

BioDiversity Research Institute (BRI) is a nonprofit organization located in Gorham, Maine. Founded in 1994, BRI is dedicated to progressive environmental research and education that furthers local, regional and global sustainability and conservation policies. BRI's research efforts emphasize conservation biology issues in New England and across North America. Examples include activities related to assessing avian toxicology and evaluating impacts of anthropogenic stressors on ecosystem integrity. BRI is actively evaluating many of the stressors affecting conservation of the common loon and other loon species across North America. Efforts include collection of empirical data, professional presentations and publications, and linking such information with landscape managers and decision-makers. Much of BRI's avian ecotoxicology efforts focus on the exposure to and effects of mercury on loons and other bird behavior, physiology, productivity, and survival. BRI is the lead organization for two international bird mercury monitoring efforts: the Gulf of Maine Seabird Contaminant Assessment Network and the Global Loon Mercury Monitoring and Research Program.

About the author

Dr. David C. Evers specializes in research on avian toxicology and biological diversity. He earned his PhD in Conservation Biology from the University of Minnesota while working on continental trends and patterns of methylmercury availability as measured in the common loon. In 1994 he founded BioDiversity Research Institute and serves as its executive director. He is also adjunct professor of biology at the University of Southern Maine and adjunct senior scientist at the Maine Center for Toxicology and Environmental Health. Dr. Evers has written two books on endangered and threatened species, co-authored multiple book chapters and published over 40 peer-reviewed papers. He has given over 100 professional presentations. Current research efforts are focused on establishing a wildlife criterion value for mercury based on empirical studies at the population level, investigating the relationship of hydrological regimes and biotic mercury uptake, determining spatio-temporal mercury exposure profiles and associated risk assessments for high trophic level biota (e.g., birds and mammals), completing a regional effort to compile existing mercury databases into a standardized format and helping to establish a national mercury monitoring program.

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