Mercury in Terrestrial Ecosystems of the Northeast

Hidden Risk

A publication of the Biodiversity Research Institute in partnership with The Nature Conservancy
Hidden Risk is a summary of the major findings of a series of research studies undertaken by the Biodiversity Research Institute in cooperation with The Nature Conservancy.

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Suggested Citation for This Report


All data collected can be found in:

Mercury is a pollutant that is cause for concern at local, regional, and global scales. While areas of high contamination (known as biological mercury hotspots) may occur near mercury-emitting sources, often they do not. Because mercury released into the atmosphere can circle the world before being deposited, habitats located far from point sources of mercury can still be of major concern to wildlife health. Although great strides have been made to reduce mercury released into the air and water from human activities, this report illustrates that high levels of mercury persist in many wildlife species distributed across many habitat types.

**Why Care about Invertivores?**

Insect-eating species are integral components of healthy ecosystems, with roles ranging from seed dispersers to insect controllers (see page 5).

The human health effects of mercury contamination are well documented; adverse effects include impacts on cardiovascular health, IQ, workplace productivity, and motor control. Similarly, mercury negatively affects wildlife populations by hindering behavior and reproduction. Past investigations have emphasized adverse impacts to fish-eating wildlife, such as common loons, bald eagles, and river otters. In this report, we synthesize current research and document elevated mercury concentrations in a new group of animals—terrestrial invertivores—that until now has largely been ignored in mercury investigations. We show that mercury concentrations in this animal group are significant enough to cause physiological and reproductive harm, creating a major paradigm shift in ecotoxicological research, assessment, monitoring, management, and policy.

**Major findings include:**

- At-risk habitats and associated indicator species are identified based on the species' level of conservation concern, relative abundance, and ability to build up mercury in their bodies.
- Current environmental mercury loads have the ability to significantly reduce reproductive success in several songbird species of conservation concern in the northeastern U.S. including the saltmarsh sparrow and rusty blackbird.
- Bats also build up significant body burdens of mercury; individuals from multiple species from all 10 areas sampled exceeded the subclinical threshold for changes to neurochemistry.
- Mercury loading in songbirds is not only restricted during the breeding season; some species, such as the northern waterthrush, build up high levels of mercury during migration and in tropical wintering areas.
- Standardized monitoring of environmental mercury loads is needed to measure how changes in mercury emissions are related to new U.S. EPA regulations; we suggest that terrestrial invertivores are important indicators for assessing short and long-term changes.

Despite rising global mercury emissions, there are actions that both managers and policy makers can take to limit future ecosystem degradation. Through greater understanding of both the extent of wildlife exposure and harmful impacts to ecosystem health, it is now clear that increased conservation efforts are necessary to reduce this neurotoxin in our environment for the benefit of wildlife and people.
Mercury: Local, Regional, and Global Concerns

How does Mercury Enter the Environment?

Mercury is a naturally occurring heavy metal found within the Earth’s crust. Used in many industrial processes, mercury is emitted into the atmosphere through a variety of anthropogenic sources. While some source types, such as waste incinicators, have reduced their mercury emissions 95% between 1990 and 2005, utility coal boilers continue to emit more than 50 tons of mercury each year [1]. In December 2011, the U.S. Environmental Protection Agency (EPA) finalized a rule called the Mercury and Air Toxics Standards (MATS) that requires all electric generating plants to upgrade to advanced pollution control equipment by 2016 [2].

Why Are We Still Concerned about Mercury?

Although great strides have already been made in reducing mercury emissions from incinicators, and the MATS rule will likely have the same effect on coal-fired power plants, it is important to continue to monitor the effect of mercury at local, regional, and global scales.

Local Concerns. Researchers have shown that mercury levels in soil are higher in areas close to power plants, with the areas downwind of the power plant usually receiving higher inputs [3]. Combining this influx of mercury into an ecosystem with certain ecological factors, such as precipitation or soil acidification, can lead to a biological mercury hotspot, where we see elevated mercury levels in a relatively distinct geographic area. Areas of high contamination are often related to local environmental conditions that have an ability (via a process called methylation) to convert mercury into its most toxic form. For example, wetland habitats are prime areas where this process occurs, and are therefore highlighted in this report.

Regional Concerns. Because the availability of mercury depends on both atmospheric deposition and habitat type, certain regions can be at higher risk to mercury contamination than others. For example, researchers have found high mercury levels across taxa (fish, birds, mammals) in the Great Lakes region [4]. A similar synthesis was completed in the northeastern U.S. and eastern Canada; a third synthesis is currently being planned for the western U.S., Canada, and Mexico (www.briloon.org/mercuryconnections).

Global Concerns. When mercury is released into the atmosphere, some settles into the surrounding area but some can move great distances on the prevailing wind patterns before settling back to earth. Because of this, we must look at mercury concerns on a global scale as well, and remember that mercury is truly a pollutant without borders [5].
Mercury is a potent neurotoxin with wide ranging implications for human health and wellness. With more than 3,700 fish consumption advisories in the United States, mercury is a risk for many people, not just those who subsist on fish [6]. The impact of mercury in the U.S. has both economic and health effects (see box at left).

**Why Care about the Effect of Mercury on Humans?**


The MATS rule will prevent up to:

- 11,000 premature deaths
- 2,800 cases of chronic bronchitis
- 4,500 heart attacks
- 130,000 asthma attacks
- 5,700 hospital and emergency room visits
- 3,200,000 restricted activity days

**Impact of Mercury on People**

High mercury levels in adult males has been tied to increased risk of heart attack [7] and cardiovascular disease [8].

**Adults**

- Majority of dietary intake of methylmercury (MeHg) is due to fish consumption

**Children**


**Pregnant Women**

Mercury exposure in utero has been linked to developmental problems related to motor control (such as walking and speech) [9].

**Future Work: Brain Science Bridging**

In extreme cases, mercury exposure in utero can lead to Minimata Disease, where irreversible brain damage occurs in children born to mothers who consume high amounts of mercury.
Impact of Mercury on Wildlife

While the effect of mercury on humans is apparent, we are still learning about its effects on wildlife. This report focuses on invertivores, due to their unique and often overlooked roles within the ecosystem (see box at right), but other studies have shown effects of mercury on common loons [12], Florida panthers [13], ivory gulls [14], river otters [15], and California clapper rails [16].

Wildlife are exposed to mercury in all life stages

**Adults**

Mercury impacts overall adult yearly survival [17], immune function [18], and hormone levels [19].

**Eggs**

Mercury can decrease egg hatchability [20].

**Nestlings**

Mercury can reduce fledging success of nestlings [21, 22].

**Why Care about the Effect of Mercury on Invertivores?**

Besides contributing to the beauty of nature, invertivores provide many vital roles within the ecosystem [23]:

**Insect Control**

Simply put, invertivores eat a lot of insects!

A bluebird family of two parents and five nestlings requires 124g of insects per day. The presence of nesting birds in vineyards reduces the amount of pesticides that are required to maintain healthy crops [24].

A single colony of big brown bats eats nearly 1.3 million pest insects each year. Pest suppression services provided by native bats in U.S. agricultural landscapes is valued at $22.9 billion per year [25].

**Seed Dispersal**

Almost all the invertivores described in this report supplement their diet with seeds and grains, serving the vital function of dispersing seeds throughout the ecosystem [26].

Preliminary research shows that birds exposed to mercury during development respond similarly, exhibiting brain abnormalities [unpublished data]. More research is needed on this subject to fully understand the parallel between human and avian neurochemistry.

Females transfer methylmercury into their eggs

Adult birds ingest methylmercury through their food

Nestlings are also fed methylmercury-laced food
Why Do Species Vary in Mercury Levels?

Mercury in the Food Web

Wildlife vary in their mercury exposure based primarily on what they eat. Mercury increases as it moves up the food web, a process called biomagnification. Organisms that feed at high trophic levels generally have higher mercury levels than those that feed at lower trophic levels.

Abiotic (non-living)

Atmospheric Deposition
Mercury released into the air can be incorporated directly into primary producers, such as tree leaves.

Soil and Leaf Litter are the sites of primary mercury methylation by bacteria.

Biotic (living)

Invertebrates such as pill bugs and millipedes consume leaf litter contaminated with mercury.

Spiders eat other spiders and insects, adding 1-2 trophic levels. With each link in a food web, mercury biomagnification increases, meaning that spiders generally have higher mercury content than plant-eating insects [27].

Wood thrushes, blackbirds, and sparrows forage on the ground, eating invertebrates from the leaf litter.

Bats accumulate mercury from a diverse prey base, including flying insects and spiders.

Vireos and warblers forage in tree canopies and consume predatory insects and spiders, making them a top-level predator.
Habitat Sensitivity to Mercury

Elemental mercury released into the ecosystem cannot readily be incorporated into the food web without first being “methylated” or made available to living organisms. The process of methylation occurs with the help of bacteria found primarily in wet areas. This causes large variation in the amount of mercury found in wildlife based on habitat type.

For example, atmospheric deposition of mercury can be similar in two adjacent habitats—an upland meadow and a wet bog. If little mercury in the meadow is made available by methylation, then wildlife living in that habitat would be relatively protected from mercury toxicity. The wet habitat of the bog, however, could allow for high rates of methylation, which would be reflected in high mercury levels in the organisms that live there.

Interaction of Species and Habitat

The goal of much mercury research is disentangling the interaction between habitat and species sensitivities. On the following pages, we will illustrate both how individual species vary in mercury based on what they eat, and how specific habitats vary in mercury based on the rate of mercury methylation.

Food Web Research: New York, USA

Dome Island

Mercury concentrations in songbirds from Dome Island, Lake George, NY, rank among the highest in the state and the region[28]. Researchers have discovered that “island” spiders have higher mercury concentrations than spiders collected from forested areas directly adjacent to Lake George, prompting more research into the mechanism behind this difference [29].

Long Island Saltmarsh

At Pine Neck Preserve and North Cinder Island, Long Island, saltmarsh sparrows exhibit elevated blood mercury concentrations, without any known mercury inputs in the area. Research traced these high mercury levels down the food web, starting with lower-level organisms such as amphipods (also known as skuds) which consume sediment organic matter and detritus. Amphipods are then preyed upon by marsh spiders which, in turn, are the preferred prey items for saltmarsh sparrows during the summer breeding season.
How Do We Assess Mercury Exposure?

Limitations of Opportunistic Sampling
The data reported here were collected opportunistically over 11 years across 11 states. Most of the bats and birds were sampled as part of larger projects; the different study sites are shown in the sampling locations maps on the adjacent page. We purposefully excluded a vast dataset summarizing wildlife mercury exposure on contaminated sites to focus exclusively on the impact of air pollution. There are many other places, such as U.S. EPA-designated Superfund sites, where mercury levels in wildlife exceed those presented here.

Maximum Blood Levels
The goal of this summary is to answer the question “How bad can mercury contamination get?” Given our opportunistic sampling, we can provide an answer by examining the maximum mercury levels detected in terrestrial invertivores. We also present more conventional statistics (means and standard deviations—see box at right). For species with large sample sizes, mean mercury values can give insight into overall population mercury loads, but these values can be misleading for species with small sample sizes.

Mercury Effects Levels
In order to calibrate what these blood levels mean in terms of the health of invertivores, we use data collected in two studies to create effects levels for songbirds and bats. Based on a model of mercury effects on reproductive success in Carolina wrens, we have developed a gradient of effects levels for songbirds (below) [22]. For bats, we do not have data to support a range of effects, instead we must use a preliminary subclinical threshold developed for changes to neurochemistry of little brown bats [30].

### Songbird Effects Levels

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Reduction in Nest Success</th>
<th>Blood Mercury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>less than 10%</td>
<td>&lt; 0.7 ppm</td>
</tr>
<tr>
<td>Moderate</td>
<td>between 10% and 20%</td>
<td>0.7 - 1.2 ppm</td>
</tr>
<tr>
<td>High</td>
<td>between 20% and 30%</td>
<td>1.2 - 1.7 ppm</td>
</tr>
<tr>
<td>Very High</td>
<td>more than 30%</td>
<td>&gt;1.7 ppm</td>
</tr>
</tbody>
</table>

The thermometer graphic is used to illustrate low, moderate, high, or very high risk.
Mercury in Songbirds and Bats of the Northeast

**Songbird Mercury Concentrations**

We sampled 1,878 individual songbirds, representing 79 species, between 1999 and 2010. Mercury data by species is presented in order from lowest to highest blood mercury concentrations, regardless of sampling location.

**Bat Mercury Concentrations**

We sampled 802 individual bats, representing 13 species, between 2006 and 2008.

**Figure 3**: Blood levels of songbird species with blood mercury levels that put them at risk of reduced nesting success. Lines show blood mercury levels associated with 10% (0.7 ppm), 20% (1.2 ppm), and 30% (1.7 ppm) reduced nesting success [22].

**Figure 4**: Fur levels of bat species sampled in the northeastern United States. Red line shows a preliminary subclinical threshold for mercury exposure in bats (10 ppm in fur), above which researchers have shown changes to their neurochemistry [30]. Further research is needed to link such subclinical changes with adverse outcomes.
Mercury exposure depends on both species characteristics (such as trophic level) and habitat characteristics (such as wet-dry cycles). To disentangle differences between habitat and species, we chose an indicator songbird species to best represent the mercury risk in each ecosystem type. Because little brown bats are found in many different ecosystems, we chose them as an unrestricted ecosystem indicator. On the following pages, we will describe mercury levels in these species and explain why we see variation among them.

**Target Indicators for Mercury in the Northeast**

- **Ecosystem Type**: Estuaries
  - **Indicator**: Saltmarsh Sparrow

- **Ecosystem Type**: Bogs and Beaver Ponds
  - **Indicator**: Rusty Blackbird

- **Ecosystem Type**: Unrestricted
  - **Indicator**: Little Brown Bat

- **Ecosystem Type**: High Elevation Forests
  - **Indicator**: Bicknell’s Thrush

- **Ecosystem Type**: Upland Forests
  - **Indicator**: Wood Thrush

- **Ecosystem Type**: Forested Rivers and Creeks
  - **Indicator**: Louisiana Waterthrush

**Ecosystem Type**: Estuaries
- **Indicator**: Saltmarsh Sparrow
Ecosystems Studied

As expected, birds found in habitats with pronounced wet-dry cycles, such as bogs, beaver ponds, and estuaries have the highest blood mercury concentrations. Interestingly, we also found elevated blood levels in birds found in upland areas such as deciduous and high elevation forests. In the following pages, we will explain each species’ habitat and food preferences so that you can better understand how they can acquire methylmercury body burdens of concern.

For two species of high conservation concern, the rusty blackbird and the saltmarsh sparrow, we found atmospheric deposition of mercury to reduce nesting success by an average of 10%, which could have implications for already struggling populations.

Figure 5: Blood mercury concentrations of indicator songbirds, representing risk associated with different terrestrial ecosystems.

Figure 6: Geographic area studied. We captured birds and bats across 11 states from Virginia to Maine. Blood mercury concentrations in this report are based on sampling from these 19 study sites. Due to the opportunistic nature of our sampling program, we do not necessarily have complete geographic data for each species, but we are able to discern some trends between different regions.
The Louisiana waterthrush is not a thrush at all; it belongs in the warbler family. However, unlike other warblers, this species prefers to spend its time near swift moving forested streams and small rivers. Its song, a mix of high-pitched ringing sounds and metallic chirps, is loud enough to be heard above the rushing water of its favored habitat.

A distinguishing characteristic of the Louisiana waterthrush is its tail bob; it constantly wags its tail as it forages along the ground (genus and species names both mean “tail-wagger”). Some suggest that this tail-wagging may help to camouflage the bird against the moving waters.

Other Birds of Conservation Concern in this habitat: prothonotary warbler, yellow-throated warbler, and hooded warbler.

Habitat

When breeding in the eastern United States and southern Canada, the Louisiana waterthrush requires fast-flowing streams or small rivers that wind through closed-canopy, hilly, deciduous forest. This bird nests on the ground along the riverbanks—in small hollows, under fallen logs, or in the exposed roots of upturned trees. Its habitat requirements are similar in its wintering grounds in the West Indies, Central America, and northern South America. In areas of the Northeast with pronounced spring runoff, these types of streams have extreme wet-dry cycles, leading to increased mercury methylation.

Feeding

Foraging at the edge of flowing water, this warbler eats many aquatic invertebrates, along with higher trophic-level organisms such as spiders, amphibians, and small fish.
Mercury Risk

Although our findings show that the Louisiana waterthrush is at low risk due to atmospheric deposition of mercury, the negative effect of point-source mercury on aquatic ecosystems is well documented and mercury has been shown to persist in rivers more than 80 miles from its original source [31]. Both habitat and dietary habits compound to create a higher risk of mercury exposure along heavily contaminated rivers. For species like this warbler, which face population declines due to habitat loss, mercury contamination poses an added ecological burden.

Current and Future Risks

Pollution to rivers and streams, rising water temperatures, loss of forest area due to human development, and infestation of hemlock woolly adelgid (which defoliates this particular evergreen), are all reasons for concern for this bird species.

Recommendations

Protecting forests and waterways on both breeding and wintering grounds are important conservation actions for this species. Research should focus on habitat use and ecology in the tropical regions to which this bird migrates. Also, more information is needed on migration routes and stopover habitats.

Figure 7: Geographic differences in mercury exposure in Louisiana waterthrushes. While sample sizes are low for this species, our data suggest biological mercury hotspots in southern New York and southwest Virginia.
The wood thrush, a bird of the deep forest, sings a haunting and complex array of songs that have been described as flutelike, ethereal, hollow, sometimes exhibiting an electrical quality. A complicated syrinx (song box) allows this thrush to sing two notes at once, creating the effect of a harmony with itself; the males take full advantage of this talent when courting.

In the mid-19th century, Henry David Thoreau, one of the earliest and most profound environmental writers, declared the abundant wood thrush an indicator of the health of a forest; sightings of the wood thrush have become increasingly rare over the last four decades.

Other Birds of Conservation Concern in this habitat: cerulean warbler, worm-eating warbler, Kentucky warbler, and Swainson’s warbler.

**Habitat**

This thrush spends its breeding season in a wide variety of deciduous and mixed forests throughout the eastern half of the United States—from the Gulf States to southern Canada and from the eastern edge of the Great Plains to the Atlantic Coast. It prefers thickly forested areas with a dense understory, moist soil, and abundant leaf litter (also prime sites of mercury methylation). In early fall, the wood thrush migrates to the broad-leaved forests of Central America. They often return to the same breeding and wintering grounds each year.

**Feeding**

The wood thrush feeds mostly on invertebrates at ground level, foraging in leaf litter, and on fruits from shrubs (especially important during migration).
Mercury Risk

Since the wood thrush feeds primarily on the forest floor by moving leaf litter to locate prey, the pathway of methylmercury through its prey is likely connected with the organic soil and the leaf litter. High mercury levels in soil relate with high mercury levels in the wood thrush; in these same areas, soil calcium levels were low, most likely due to acid rain. For a breeding bird feeding in this habitat, this is a worrisome combination. Wood thrush populations are declining significantly across their range; and in New York and neighboring states that decline is linked to the loss of calcium, a vital nutrient for reproduction [32].

Current and Future Risks

Causes for the recent wood thrush decline may include forest destruction and fragmentation, as well as acid rain. The combination of high mercury levels in areas with acid rain may combine to create a “1-2 punch” that is more damaging to the population than either effect in isolation. However, more research is needed to better understand this complex interaction.

Recommendations

Protecting large tracts of forests in breeding areas, as well as maintaining habitat that these birds need for migration are critical for the survival of this species.

Wintering grounds in Central America must also be protected to ensure the long-term success of wood thrush populations. Further work in understanding the ecology of this species on its wintering grounds will provide valuable clues to understanding population declines.

Figure 8: Geographic differences in mercury exposure in wood thrushes. Wood thrushes in Virginia and southern New York show elevated mercury levels compared to the other sampling areas.
Habitat

This species is extremely restricted in its habitat and range. It breeds in dense areas of stunted balsam fir and spruce found at high elevations from the northern Gulf of St. Lawrence and easternmost Nova Scotia, to the White Mountains of New Hampshire, the Green Mountains of Vermont, and the Catskill Mountains of New York State. Its wintering grounds are also restricted; this species migrates to one of only four islands in the Greater Antilles, in the Caribbean Sea.

Feeding

These birds feed primarily on insects, especially beetles and ants; they will eat wild fruit during migration. During the breeding season, they feed on or close to the ground, but will also forage for food in the branches of trees, sometimes fly-catching from their perches.
Mercury Risk

Based on habitat and diet alone, we would expect Bicknell’s thrush to be relatively removed from mercury exposure. This is not the case because high elevation mountain areas are prone to increased precipitation, and therefore, increased pollution from cloud water [33]. These conditions are ripe for the production of methylmercury. High elevation species such as the Bicknell’s thrush have proportionally higher mercury levels than associated low-elevation mountainside neighbors, such as other thrushes.

Figure 9: Geographic differences in mercury exposure in Bicknell’s thrushes. Due to their particular habitat requirements, Bicknell’s thrush are not found in all the geographic region studied, but those captured in western Maine show higher mercury levels than other areas.

Current and Future Risks

Recreational and commercial development (e.g., ski trails, telephone towers, and wind turbines) in mountain forests contribute to increased habitat fragmentation and loss. Climate change also puts the Bicknell’s thrush at risk as it diminishes the already narrow band of habitat in the bird’s mountain breeding grounds. Extensive loss and degradation of primary overwintering forests may pose the greatest threat to the long-term viability of the Bicknell’s thrush.

Recommendations

Efforts are needed to continue to protect or manage known and potential breeding habitat; land management agencies can partner with timber companies to develop and implement best management practices to maintain a target amount of Bicknell’s thrush habitat in working forests.

It is equally important to protect, manage, and restore known and potential winter habitat. Working with and developing strong collaborative efforts with Caribbean partners is critical to the protection of habitat on the wintering grounds. It is also important to identify migratory stopover sites, routes, and patterns.
**Rusty Blackbird** *(Euphagus carolinus)*

**Habitat**

The vast boreal region of Canada and Alaska along with the Acadian forest of eastern Canada and New England represent the core breeding habitat of the rusty blackbird. They select forested wetlands, muskeg swamps, and beaver bogs for breeding, laying speckled blue and brown eggs in nests constructed in the stunted spruce or fir trees typical of these habitats. In early autumn the blackbird migrates to the southern U.S. for the winter, feeding on invertebrates and grains in both wet bottomlands and dryer uplands, such as pecan plantations.

**Feeding**

The rusty blackbird feeds preferentially on aquatic insect larvae and large adult flying insects, taking advantage of spring emergence events while breeding. In winter they become opportunistic as insects become scarcer, feeding on grains and tree masts.

**Named for its rust brown winter plumage, the rusty blackbird is occasionally mistaken for its near relative, the common grackle. Although rusty blackbirds were once abundant enough to “blacken the fields and cloud the air” during migration, today migrating and wintering flocks rarely exceed a few dozen due to an unexplained yet dramatic population crash.**

Unlike many other North American blackbirds, rusty blackbirds will form monogamous pairs while breeding that will often persist the following breeding season. They can be aggressive while breeding, attacking larger species, such as jays, that could prey on their young. When food is scarce during harsh winters, these blackbirds have been known to attack and eat other songbirds.

**Potential Very High Hg Risk**

Other Birds of Conservation Concern in this habitat: olive-sided flycatcher, bay-breasted warbler, and Canada warbler.
Mercury Risk
Rusty blackbirds are exposed to levels of mercury that may negatively affect them while breeding in New England and Maritime Canada; concentrations of mercury for individuals breeding in the Northeast are more than four times that of those breeding in Alaska, with an average concentration of about 0.9 ppm. The high mercury exposure is due to a diet based on aquatic macroinvertebrates and spiders, allowing for multiple intermediate trophic levels and a high bioconcentration of aquatic mercury. Additionally, the acidic water typical of their breeding habitat promotes a high bioavailability of mercury for uptake [34].

Current and Future Risks
Rusty blackbird populations have declined more than 90% since the 1960s, with an upper estimate of 13% decline per year—a rate exceeding that of other boreal breeding birds. While several factors have been proposed, no consensus has been reached to explain the population loss. Likely factors: the interaction of habitat loss due to human development; intensive forestry; wetland draining and flood control; climate change; and environmental contaminants, including mercury.

Recommendations
Although the habitat preferred by rusty blackbirds is relatively inaccessible and somewhat inhospitable, breeding populations may still be in danger; more careful monitoring, in addition to the Breeding Bird Survey, is needed to confirm this. This species is more adaptable during migration and in wintering areas, however, preliminary analyses of Christmas Bird Count trends in the southeastern U.S. during the latter half of the 20th century suggest that closer attention should be paid to migrating and wintering populations, especially regarding potential impacts associated with current agricultural practices.

Figure 10: Geographic differences in mercury exposure in rusty blackbirds. Rusty blackbirds are increasingly hard to find on their breeding grounds, but those that we sampled appear to have high mercury levels at all sites.
In her *Hymn to Aphrodite,* the ancient Greek poet Sappho describes “wing-whirring sparrows” pulling the goddess’s chariot across the sky. Throughout history, these common birds—the sparrow family is the largest bird family in the world—have found their way into classic literature from the Gospels, to Shakespeare’s plays, to Stephen King’s thrillers.

The saltmarsh sparrow, now genetically distinguished from the Nelson’s sparrow, spends its entire life cycle in the transitional areas between land and sea. During the breeding season, the non-territorial males have earned a reputation for promiscuity; they often breed more than once during a season. These birds synchronize nesting with the tides, fledging their young in only eight days.

Other Birds of Conservation Concern in this habitat: Nelson’s sparrow, seaside sparrow, clapper rail, and willet.

**Habitat**

Salt marshes are found along the intertidal shores of estuaries and sounds where salinity ranges from freshwater (further inland) to ocean levels (coastal). These coastal marshes, subject to the ebb and flow of the tides, often experience rapid changes in salinity and temperature, to which the birds must adapt. The saltmarsh sparrow migrates only at night to their wintering estuaries in the southeastern United States.

**Feeding**

Saltmarsh sparrows feed mostly on insects, spiders, amphipods, and small snails, supplementing this diet with seeds and wild rice. When foraging, they run in short spurts, walk, or slowly hop.
Mercury Risk

Saltmarsh sparrows showed elevated blood mercury concentrations across much of their breeding range, most likely due to both dietary and habitat preferences that put them at high risk to mercury exposure [35]. Findings of elevated blood mercury concentrations at several sites suggest that mercury accumulations may be high enough in the blood of saltmarsh sparrows to cause regular nest failure at a rate that may put local populations at risk. Mercury, as a neurotoxin, is especially a problem for these estuary dwellers, as it may affect the sparrow’s ability to time its nesting patterns with the tides.

Figure 11: Geographic differences in mercury exposure in saltmarsh sparrows. Saltmarsh sparrows show overall higher mercury levels than any of the other species studied, with a potential biological mercury hotspot in coastal Massachusetts.
The little brown bat is found in a wide range of forested areas throughout North America, from southern Alaska eastward through the southern half of Canada to Newfoundland, south through most of the continental United States, and in higher elevation forested regions of Mexico. They roost in tree cavities and caves, as well as in barns and attics.

Feeding

These bats forage over both land and water, usually feeding on swarms of insects to save time and energy in their search for food.
Mercury Risk

Bats are long-lived and have the potential to accumulate high concentrations of mercury over time. High mercury levels may lead to a myriad of problems such as compromised immune systems, which would make it harder to fight infections like white-nose syndrome. The interaction of bats and windfarms is an additional concern as bats approaching the blades of wind turbines may suffer from pulmonary death (i.e., the bursting of capillaries). The ability of bats with elevated mercury body burdens to avoid wind turbines requires further investigation.

Figure 13: Mean bat fur mercury concentrations for little brown bats in different geographic regions in the Northeast. All regions sampled have individuals with fur concentrations that exceed the 10 ppm preliminary subclinical threshold (red line). At concentrations above 10 ppm, researchers have shown changes to little brown bat brain neurochemistry [30].
Birds and other wildlife living in forests are often limited by the amount of calcium available for uptake. Acid deposition created from the burning of fossil fuels can intensify the leaching of calcium from the soil [32]. In areas that are also subject to a high amount of mercury deposition, this can become a dangerous combination of threats. Besides the need for control of mercury emissions, forests can be managed for reducing soil acidification that will alleviate the effect of multiple environmental stressors.

**Primary Indicator:** Bicknell’s thrush  
**Secondary Indicators:** blackpoll warbler, yellow-bellied flycatcher

**High Elevation Forests**

**Reduce acid deposition**

Forest fires have the ability to mobilize mercury sequestered in the soils and vegetation of forests [37, 38]. This mercury is then free to enter the atmosphere or be remobilized into nearby habitats and then ingested by organisms. Fire is often necessary for the overall health of forests, but allowing for more frequent, less severe forest fires will reduce the risk of large scale mobilization of mercury into the ecosystem.

**Primary Indicator:** wood thrush  
**Secondary Indicators:** cerulean warbler, worm-eating warbler, Kentucky warbler, Swainson’s warbler, Acadian flycatcher

**Upland Forests**

**Improve fire management**

Logging near forested rivers and creeks not only enhances erosion, it also remobilizes mercury previously sequestered in the soils [39, 40]. By restricting logging near water bodies, direct movement of mercury into the watershed can be minimized. The contamination of streams and rivers in one place may have significant ramifications more than 80 miles downstream [31].

**Primary Indicator:** Louisiana waterthrush  
**Secondary Indicators:** prothonotary warbler, yellow-throated warbler, hooded warbler, northern waterthrush, Canada warbler

**Forested Rivers and Creeks**

**Restrict logging near water bodies**
Reduce mercury emissions

Mercury emissions must be controlled at the source, and the U.S. EPA has recently finalized its Mercury and Air Toxics Standards (MATS) rule to regulate mercury emissions from power plants in the United States [2]. Implementation of this rule is necessary for protection of ecosystem health, including areas particularly sensitive and/or close to sources that are likely biological mercury hotspots [41].

*Primary Indicator:* little brown bat and our songbird indicator species  
*Secondary Indicator:* all North American bat and songbird species, particularly those associated with wetland habitats

Control reservoir water level fluctuations

Large fluctuations in water levels within reservoirs can intensify the amount of mercury methylation in an ecosystem [41, 42]. The repeated wetting and drying of water body edges allows the bacteria that methylate mercury to thrive and increase the amount of biologically available mercury. The most reasonable way to control this methylation is to maintain more constant water levels in these reservoirs, particularly in late summer and early fall.

*Primary Indicator:* rusty blackbird  
*Secondary Indicator:* olive-sided flycatcher, bay-breasted warbler, Canada warbler, Virginia rail, spotted sandpiper

Trace hidden or unknown point sources

Because of its prevalence in various industrial processes and wastewater treatment plants, mercury has historically been released in varying quantities into many different water bodies throughout the United States. Estuaries are often the final destination for this source of mercury, and the high degree of methylation in coastal wetlands allows for much of it to become available to wildlife [35]. Although many of these point sources have known inputs, there are many that are unknown and unexplored. In some cases, the solution can be as easy as discovering and cleaning up the legacy dump site. Without intensive biomonitoring in our nation’s estuaries, we will not be able to determine where these “hotspots” of high mercury levels in wildlife occur.

*Primary Indicator:* saltmarsh sparrow  
*Secondary Indicators:* Nelson’s sparrow, seaside sparrow, clapper rail, willet
Neotropical Connections

While this report documents mercury concentrations in songbirds on their breeding grounds in the northeastern United States, there is growing concern for birds that migrate to wintering grounds in Central and South America and the Caribbean Islands. Biodiversity Research Institute has gathered evidence that the mercury threat in tropical habitats may be much greater than expected.

Mercury—A Migratory Threat

Mercury is a global pollutant that has a potential to adversely affect hundreds of bird species across the western hemisphere. For migratory species, this means that they can encounter mercury contamination on their breeding grounds, as well as along migratory routes and on their wintering grounds. Moreover, migrating birds might be at greater risk to the toxic effects of mercury. Mercury is stored in muscle; most birds will use their muscle reserves to help fuel their migratory flights especially during stressful times when fat reserves are expended. This muscle burn could potentially give birds a high dose of mercury during migration.

Migration accounts for nearly 75% of all annual mortality rates in some songbirds; the added burden of toxic mercury exposure may make the process even more challenging. While mercury exposure during the breeding season is well documented, contamination during migration and over the winter is still relatively unknown. Migration is a fascinating natural process, however, its linkages across the world makes understanding the risks of mercury exposure all the more difficult.

Conservation Complexities

Understanding migratory connectivity, the strength of connections between wintering and breeding areas, has become vital to the conservation of migratory birds. When a species has strong connectivity, traditional conservation measures may not be effective. For example, if the New England breeding population of the northern waterthrush (featured at right) was declining and landscape managers wanted to protect it throughout its annual life cycle, one strategy might be to purchase wintering ground habitat and manage it for waterthrushes. If this population only wintered in the Caribbean, then it makes sense to conserve land in the Caribbean. Without this information well-intentioned efforts might protect land in Central America, but actually achieve very little in meaningful results for the breeding population. Understanding the complexities of migration is crucial to making effective conservation decisions.

BRI’s TERRA Network

BRI has developed the Terrestrial Ecosystems ReseaRch and Assessment (TERRA) Network across the western hemisphere to improve our understanding of mercury threats to migratory birds and bats. Through collaboration with biologists in Canada, the U.S., Mexico, Central and South America, and the Caribbean Islands, we hope to better understand how mercury affects species throughout their life cycle.
Mercury levels found in the northern waterthrush during winter, over migration, and on breeding grounds are similar. Blood mercury concentrations are consistently elevated throughout the year, demonstrating that dietary uptake is a year-round concern, and despite migratory movements this species has less of an ability than some species for ridding its body of mercury burdens during times of low environmental mercury exposure. This “double whammy” of mercury toxicity restricts interseasonal depuration or release of mercury.

**Figure 14:** Blood mercury concentrations of northern waterthrush throughout their migratory cycle.

**Neotropical Migrant Songbirds of Conservation Concern**

- **Olive-sided Flycatcher**
  - 40-year decline: 80%

- **Cerulean Warbler**
  - 40-year decline: 70%

- **Blackpoll Warbler**
  - 40-year decline: 80–90%

- **Wood Thrush**
  - 40-year decline: 50%

- **Bicknell’s Thrush**
  - 40-year decline: No data

*Based on range-wide North American Breeding Bird Survey data*

**Figure 15:** Depicted here is the northern waterthrush’s breeding (dark green) and wintering (light green) ranges along with migratory routes (arrows). This species is emphasized because it is one of the few neotropical migrants where BRI has year-round information on mercury exposure, but many other declining neotropical migrants are potentially exposed similarly (see box at right).
Interaction of Environmental Stressors

Although we focus on mercury exposure and effects in this report, there are many other environmental stressors that can act in concert with mercury to create problems for terrestrial ecosystems.

**Acid Rain**

Acid deposition is a well-documented environmental stressor with various negative impacts on ecosystems.

- Increased acidity in soil promotes increased methylmercury production, resulting in higher mercury exposure in invertevores.
- Acidic deposition leaches calcium from the soil, resulting in the decreased availability and abundance of calcium-rich invertebrate prey that songbirds eat [32, 44]. Decreased calcium availability for egg production combined with the neurotoxic effects of mercury can potentially lead to nest failure.

**Climate Change**

The interaction of environmental mercury and climate change can add additional stress to already threatened species.

- Rising sea levels may lead to loss of coastal wetlands, habitat alterations, and potential changes in mercury cycling in wetlands.
- Rising temperatures could lead to enhanced methylation of mercury for select habitats.
- Increases in precipitation in some parts of the U.S. could lead to increases in atmospheric deposition of mercury.
- Forest fires, expected to increase with global warming, release stored mercury into the environment.
- Changes in food web structure that occur as species adapt to changes in habitat and available food sources may alter mercury exposure.
- More frequent and increased storm intensity could lead to episodes of high mercury exposure as a result of runoff.
- Thawing of permafrost will rapidly release thousands of years of bound mercury (natural and anthropogenic) into the air and water.
There are two goals of this report. First, to characterize the risk of mercury within the terrestrial invertivore community. Second, to offer relevant information for management and policy actions that can be taken to reduce the impact of mercury on the terrestrial ecosystem.

The Importance of Mercury Monitoring

As we look to the future, how will we know if our management and policy decisions are effective? It is critical to establish mercury monitoring networks, both nationally and internationally, so quantitative assessments can be related with regulatory efforts attempting to lower anthropogenic mercury, particularly in sensitive ecosystems, such as wetlands.

For aquatic systems, we demonstrate encouraging results from the Great Lakes Region, where reduction in mercury emissions has helped decrease the amount of mercury in different fish species over time (see figure at right).

![Figure 16: Temporal trends in fish fillet mercury concentrations averaged by year across multiple sites in the Great Lakes and inland water bodies in the U.S. Great Lake states and the province of Ontario [45].](image)

Songbirds and Bats: Candidates for Terrestrial Mercury Monitoring

Although fish represent direct links to the aquatic ecosystem, their mercury levels do not always align with atmospheric deposition. We postulate that the songbirds and bats highlighted in this report are good candidates for terrestrial indicator species for several reasons:

- Songbirds and bats are found in all terrestrial habitat types, aiding in comparisons between different habitats and geographic locations.
- Blood can be sampled nonlethally in conjunction with many ongoing songbird banding and bat monitoring programs.
- Blood mercury concentrations reflect current (~30 day) dietary uptake of methylmercury, meaning that this tissue is responsive to rapid changes in methylmercury in the food web and there are some indications that the deposition of mercury from the air is significantly linked with songbird blood mercury concentrations (BRI unpublished data).
The intent of this report is to present an overview of current information about environmental mercury pollution in the terrestrial ecosystems of the northeastern United States and to support and improve ongoing and future investments that address the risk of environmental mercury loads. We have summarized the most recent data related to songbird and bat mercury exposure, but have also shown that more research and better monitoring is needed to fully understand the scope of this hidden risk to these and other wildlife species.

Reducing anthropogenic sources of mercury is one essential strategy for minimizing the impact of mercury on people and wildlife, but to effectively inform policy decisions at each stage of the process, scientists also need more data.

We recommend a concurrent three-pronged approach for minimizing adverse impacts of mercury on wildlife:

1. Identify the species, habitats, and regions at risk to mercury exposure
2. Address synergistic interactions of mercury with other environmental pollutants

Using Science to Inform Mercury Policy

Establish MercNet [1]
Legislation for a National Mercury Monitoring Network (MercNet) was introduced into the 112th Congress (to the Senate Public Works and the House Energy and Commerce Committees) and will provide a comprehensive and standard way for measuring mercury in the air, water, soil, as well as in fish and wildlife. Songbirds and bats are nominated as part of the mercury monitoring effort [1, 46].

Congress needs to pass legislation authorizing the creation of MercNet, which will allow the federal government to scientifically evaluate the efficacy of policy and management decisions that, in turn, will allow for better decisions in the future and protect past mercury abatement investments.

Set air pollution thresholds for ecosystems [47]
It is time to establish air pollution thresholds to protect and restore U.S. ecosystems. A “critical loads” approach to understanding air pollution impacts requires the assessment of multiple contaminant “loading” to sensitive ecosystems above which significant adverse impacts are detected. This strategy is accepted as superior by the scientific and regulatory communities, and is in use in Europe, Canada, and parts of the United States, but has yet to be used to understand the interaction of mercury with other contaminants. Although critical loads allow for more refined policy decisions, their establishment requires firm commitment and funding in order to enable the most up-to-date scientific determinations.

Congress should direct the U.S. EPA to implement critical loads for sulfur and nitrogen, along with thresholds for mercury, and the U.S. EPA should use these thresholds to assess progress under the Clean Air Act.
Use best available technology [2]
Technological pollution control for reducing mercury pollution has been enormously successful in the regulation of municipal and medical waste incinerators [49] and the U.S. EPA Mercury and Air Toxics Standards Rule will provide similar reductions for power plants with a goal of 90% less mercury emissions.

Ensure implementation of this common sense solution to the largest stationary source of airborne mercury—coal-fired power plants.

Prevent biological mercury hotspots [41]
While “cap and trade” programs are effective in certain pollution strategies, like those for acid rain components, it is inappropriate for a pollutant like mercury. There is a growing body of evidence that local mercury emission sources, such as from coal-fired power plants, can have significant local effects on downwind ecosystems leading to the development of biological mercury hotspots [41, 50].

By avoiding mercury “cap and trade” systems, our expectation is to prevent new mercury hotspots from being created across the United States and globally.

Support UNEP Mercury Treaty [51]
The United Nations Environment Programme (UNEP) intends to ratify a globally binding agreement on mercury in 2013. Reductions in the purposeful use of mercury for small-scale gold mining, chlor-alkali plants, and in manufactured products are planned, while emissions from fossil-fuel burning and other sources are being negotiated.

The U.S. State Department and the U.S. EPA should continue their international leadership roles in guiding new standards for global mercury pollution as well as in helping set comprehensive and standard monitoring programs. Adding new delegates from other federal agencies, such as the Department of Interior, will help facilitate greater connections with environmental mercury studies and management in the United States.


40. Garcia et al. 2007. Seasonal and inter-annual variations in methyl mercury concentrations in zooplankton from boreal lakes impacted by deforestation or natural forest fires. Environ Monit Assess 131:11.


Acknowledgements

We are grateful for a grant from The Nature Conservancy’s Rodney Johnson and Katherine Ordway Stewardship Endowment that supported the development of this publication as well as parts of the original research. This research was the result of years of collaborations and we would like to acknowledge those that offered their assistance.

Many researchers generously shared their data with us. We are deeply indebted to Dr. David Braun of Sound-Science. We thank Chris Rimmer and Kent McFarland of the Vermont Center for Ecosystems for their assistance with sampling Bicknell’s thrushes; Greg Shriver for providing samples from wood thrushes in Delaware; Sam Edmonds, Nelson O’Driscoll, and the numerous researchers involved with the International Rusty Blackbird Working Group for sharing their extensive sampling of rusty blackbirds; Jeff Loukmas from the New York State Department of Environmental Conservation for providing invertebrate mercury data; Gary Lovett from the Institute for Ecosystem Studies for supplying soil data; and Chad Seewagen from the Wildlife Conservation Society for providing multiple years of samples.

Others provided field accommodations, logistical support, and helpful expertise. We thank the SUNY College of Environmental Science and Forestry’s Adirondack Ecological Center for providing access to study sites and lodging for field crews; the staff at the Montezuma National Wildlife Refuge and the Tonawanda Wildlife Management Area for site access; the staff of the Marine Nature Study Area in Hempstead, NY for logistical support and assistance in the field; Al Hicks of the New York State Department of Environmental Conservation and John Chenger of Bat Conservation and Management for their assistance with providing bat samples; Cara Lee at The Nature Conservancy for helping us with field housing, logistics, and site access; Bruce Connelly at Acadia National Park for helping us with field housing, permits, and site access; Dr. Ford and staff for assisting us with site selection and permission in the Fernow Experimental Forest; Bill DeLuca for assisting with sampling efforts, field housing, permits, and site access in New Hampshire; the Boy Scouts of America for providing access and a field camp at Massawepie for multiple years; the YMCA for providing housing/field camps and site access for multiple years; Bill Schuster at Black Rock Forest for providing site access and permission for multiple years; Bob Mulvihill at Powdermill Avian Research Center for providing permission, site selection, site access, sampling assistance, samples, and an incredible learning environment for multiple years; Mike Fowles and site managers at the U.S. Army Corp of Engineers for providing site permits/access and enthusiastically assisting with Pennsylvania field logistics; Tom LeBlanc of Allegany State Park for providing site selection recommendations, logistical support, field housing, and overall enthusiasm for our project; the staff at numerous National Wildlife Refuges including Rachel Carson NWR (ME), Wertheim NWR (NY), Parker River NWR (MA), Ninigret NWR (RI), McKinney NWR (CT); Maine Department of Inland Fisheries and Wildlife; Jen Walsh at the University of New Hampshire for field assistance; and Henry Caldwell of Dome Island for providing all kinds of help with boats, field housing, and permits, as well as being a gracious host for multiple years.

We are especially grateful to the staff of Cornell’s Lab of Ornithology, Conservation Science department, for their support of this project. In particular, we thank James D. Lowe for all his devoted work in the field, banding birds and collecting soil, leaves, and bird samples, and for his assistance with preparing the metadata; Maria Stager for her aid in bird sampling and banding; Kenneth V. Rosenberg for his departmental support; and Kevin Webb, from Cornell’s Lab of Ornithology, Information Science department, for his excellent GIS support.

Within The Nature Conservancy, we appreciate those who supported this work over the years including: David Higby, Peter Kareiva, Mark King, Cara Lee, Nicole Maher, Rebecca Shirer, Brad Stratton, Troy Weldy, and Alan White.

Within Biodiversity Research Institute, this report would not have been possible without the effort of many BRI staffers who offered data and expertise. We thank Evan Adams for help with Neotropical Connections, David Buck for food web information, Seth Dresser for help with website design, Melissa Duron for her leadership and expertise in collecting the field data, Julie Franklin for her early efforts in coordinating this large project, Ian Johnson for his patience in making GIS maps, Oksana Lane for collecting many of the songbird samples, Deborah McKew for design and editing, Dr. Nina Schoch for her insight on the policy recommendations, Dr. Iain Stenhouse for providing the bird life cycle figures, and Dave Yates for providing bat data.

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