Hidden Risk

Mercury in Terrestrial Ecosystems of the Northeast

A publication of the
Biodiversity Research Institute
in partnership with
The Nature Conservancy

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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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Biodiversity Research Institute, headquartered in Gorham, Maine, is a non-profit ecological research group whose mission is to assess emerging threats to wildlife and ecosystems through collaborative research, and to use scientific findings to advance environmental awareness and inform decision makers.

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Table of Contents

Background

Mercury in Terrestrial Ecosystems of the Northeast

Indicator Species for the Northeast

Future Directions

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Executive Summary

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.

What Is an Invertivore?

Often referred to as insect eaters, the songbirds and bats described in this report are more accurately called invertivores because they eat a wide variety of invertebrate species such spiders, snails, and worms, in addition to insects.

- 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.

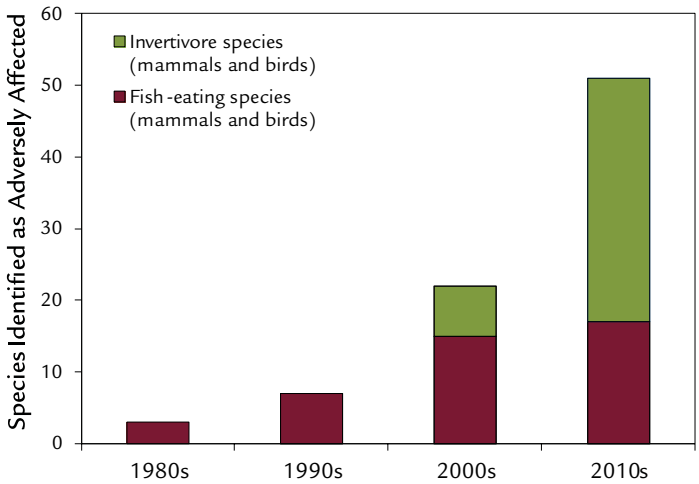


Figure 1: In recent years, researchers have identified an increasing trend of species at risk to the availability of mercury in the environment, particularly within invertivores, such as songbirds and bats. This rising trend demonstrates that the more we look, the more we find; the more we find, the more we understand about the impacts of mercury in the food web. Unfortunately, the impacts are much greater than were realized only a few years ago.

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 incinerators, 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].

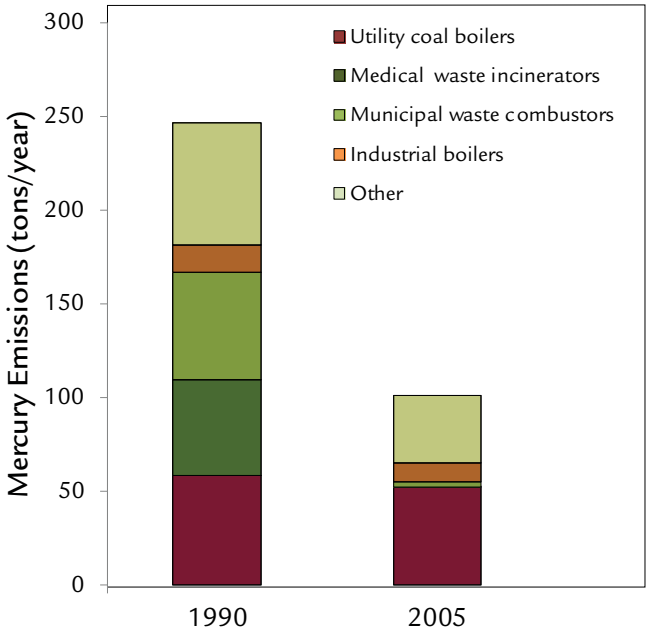


Figure 2: Major sources of U.S. emissions from U.S. EPA inventories (1990 and 2005). Emissions from medical and municipal waste incinerators have been reduced by over 95%, while utility coal boilers remain the same [1].

Why Are We Still Concerned about Mercury?

Although great strides have already been made in reducing mercury emissions from incinerators, 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].

Impact of Mercury on People

Why Care about the Effect of Mercury on Humans?

The U.S. EPA Mercury and Air Toxics Standards (MATS) rule [2] is estimated to improve the health of U.S. citizens at a savings of

$37-90 billion

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

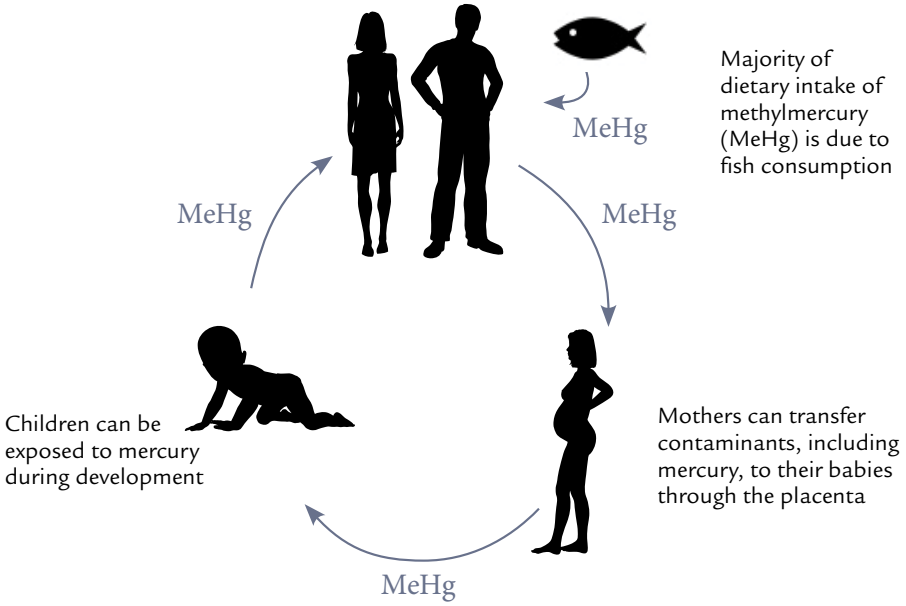
Mercury is a potent neurotoxin with wide ranging implications for human health and wellness. With more than 3,700 fish consumption advisories in the United States, mercury is a risk for many people, not just those who subsist on fish [6].

The impact of mercury in the U.S. has both economic and health effects (see box at left).

People are exposed to mercury in all life stages

Adults

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



Children

Mercury exposure impacts children throughout life, causing deficits in attention, language, memory [10], and IQ [11]

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.

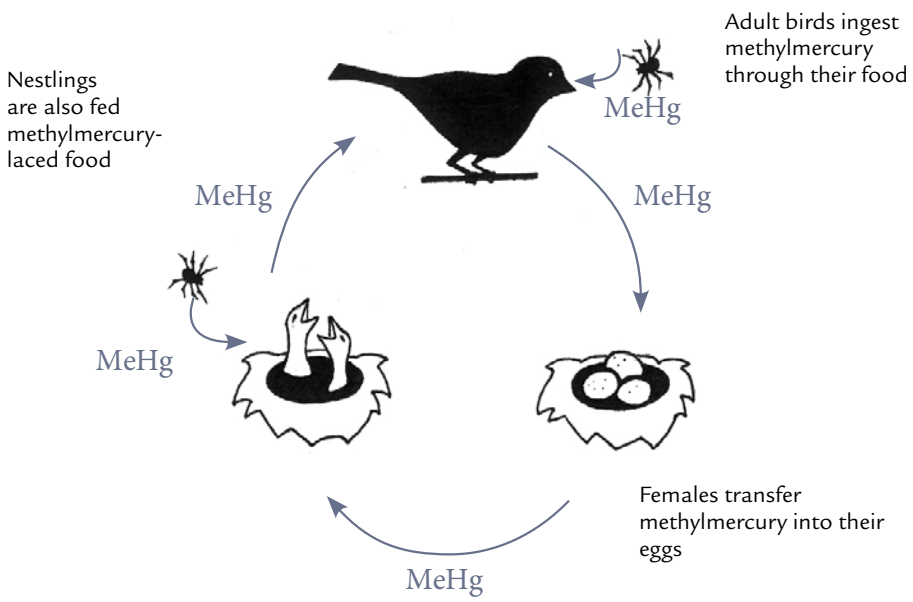
Impact of Mercury on Wildlife

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]



Nestlings

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

Eggs

Mercury can decrease egg hatchability [20]

the Gap between Humans and Birds

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.

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].

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)

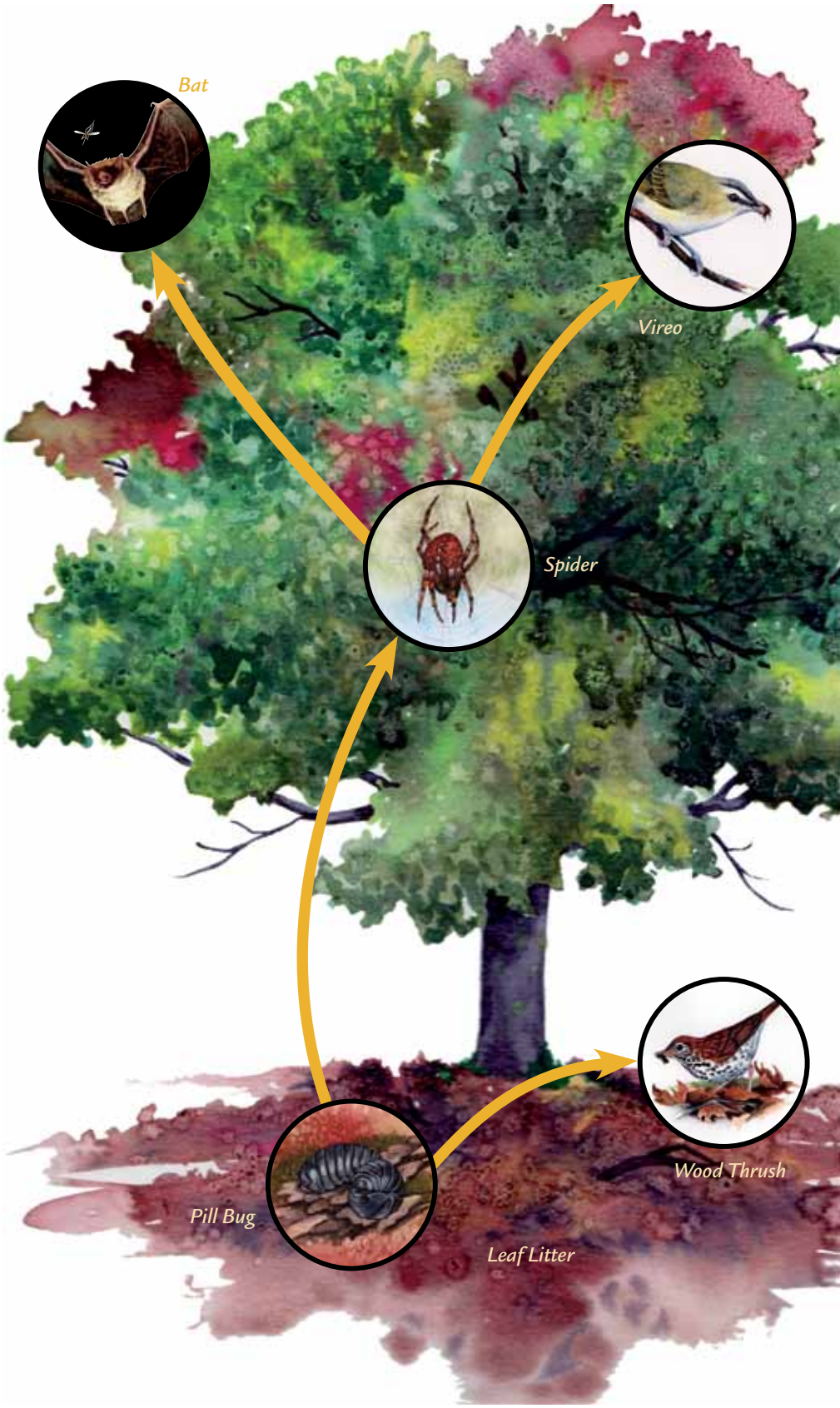
Invertebrates such as pill bugs and millipedes consume leaf litter contaminated with mercury.

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.



Why Do Habitats Vary in Mercury Levels?

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

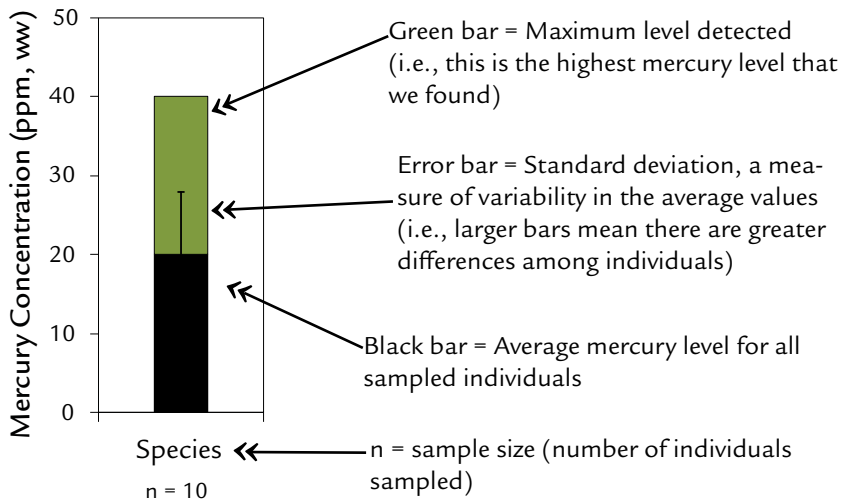
The data reported here were collected opportunistically over 11 years across 11 states. Most of the bats and birds were sampled as part of larger projects; the different study sites are shown in the sampling locations maps on the adjacent page. We purposefully excluded a vast dataset summarizing wildlife 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.

The information presented in this report is the most current and widespread data summarized to date. Despite this effort, there are limitations to the analysis as a result of the opportunistic, rather than comprehensive, way we currently collect mercury information. These limitations are an important reason for dramatically improving mercury monitoring networks (see National and International Mercury Monitoring on page 29).

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.

How to Interpret Bar Charts

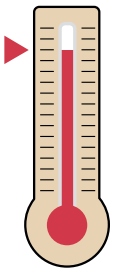


Mercury Effects Levels

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

Risk Level	Reduction in Nest Success	Blood Mercury
Low	less than 10%	< 0.7 ppm
Moderate	between 10% and 20%	0.7 - 1.2 ppm
High	between 20% and 30%	1.2 - 1.7 ppm
Very High	more than 30%	>1.7 ppm



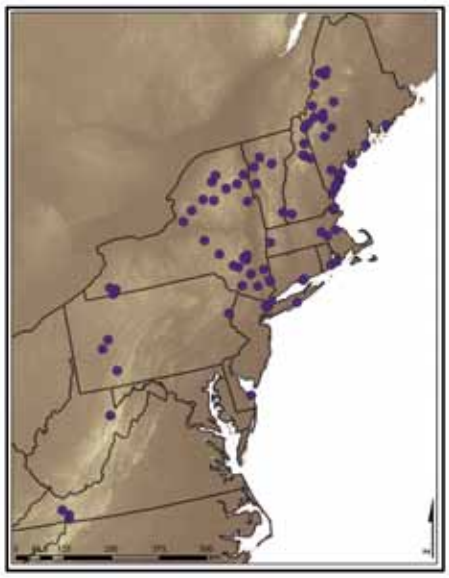
The thermometer graphic is used to illustrate low, moderate, high, or very high risk.

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.

Songbird Sampling Locations



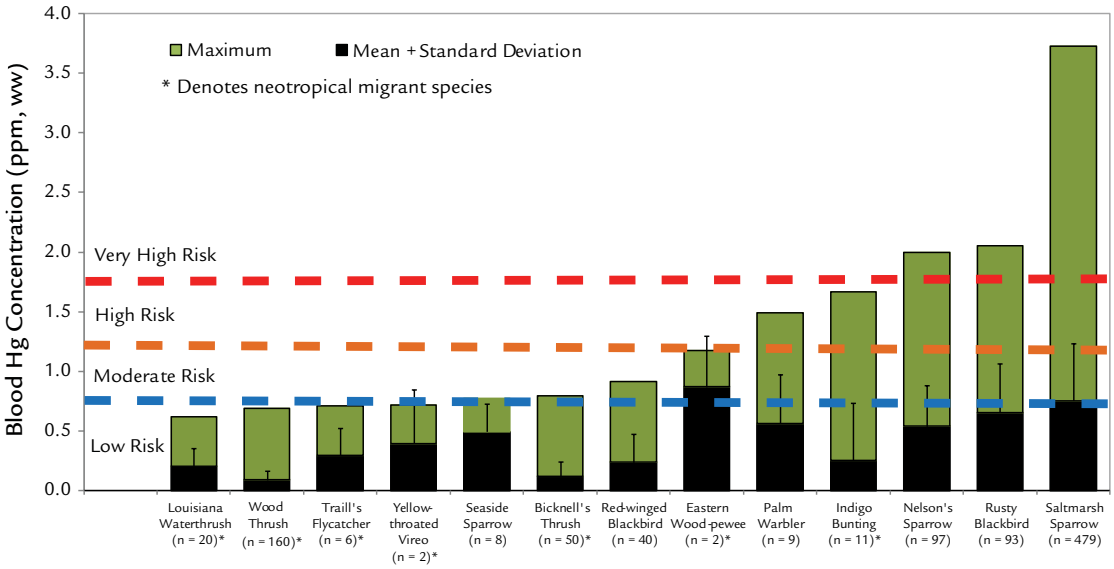
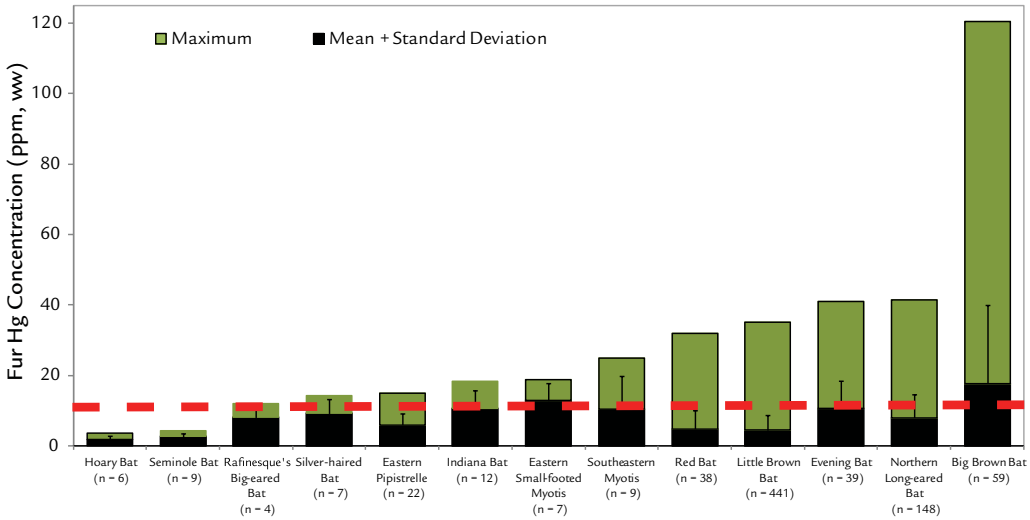


Figure 3: Blood levels of songbird species with blood mercury levels that put them at risk of reduced nesting success. Lines show blood mercury levels associated with 10% (0.7 ppm), 20% (1.2 ppm), and 30% (1.7 ppm) reduced nesting success [22].

Bat Mercury Concentrations

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



Bat Sampling Locations

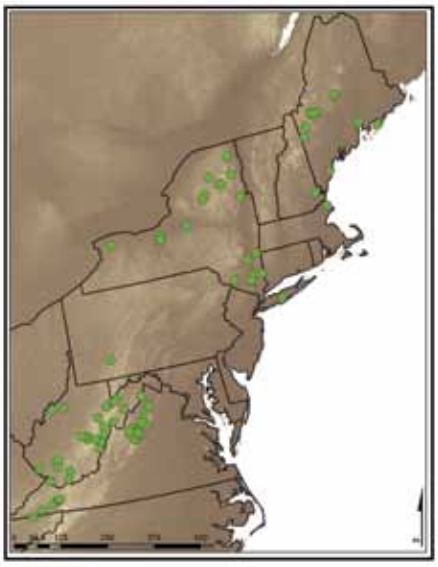


Figure 4: Fur levels of bat species sampled in the northeastern United States. Red line shows a preliminary subclinical threshold for mercury exposure in bats (10 ppm in fur), above which researchers have shown changes to their neurochemistry [30]. Further research is needed to link such subclinical changes with adverse outcomes.

Target Indicators for Mercury in the Northeast

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.

Ecosystem Type
High Elevation Forests

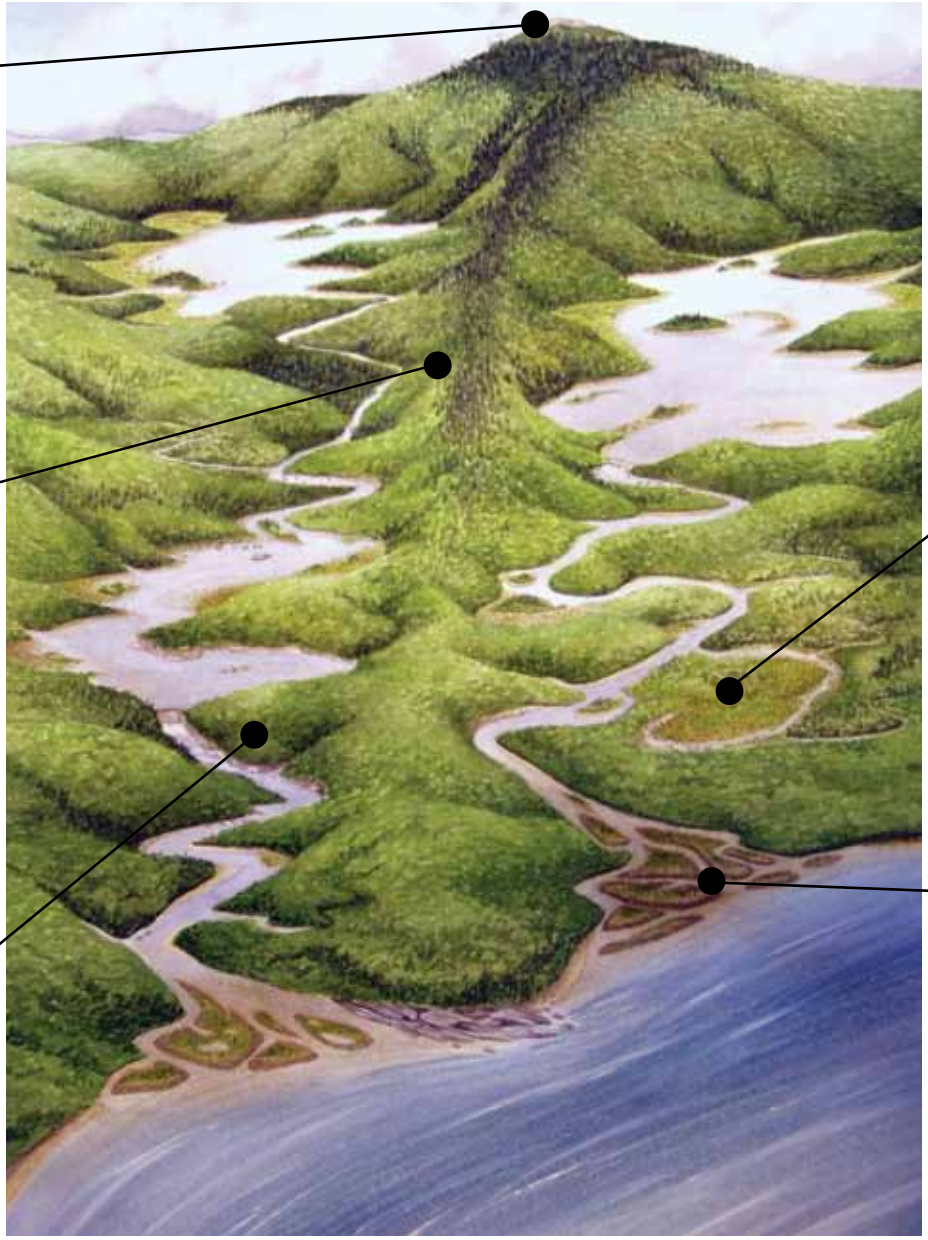
Indicator
Bicknell's Thrush

Ecosystem Type
Upland Forests

Indicator
Wood Thrush

Ecosystem Type
Forested Rivers and Creeks

Indicator
Louisiana Waterthrush



Ecosystem Type
Unrestricted

Indicator
Little Brown Bat

Ecosystem Type
Bogs and Beaver Ponds

Indicator
Rusty Blackbird

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.

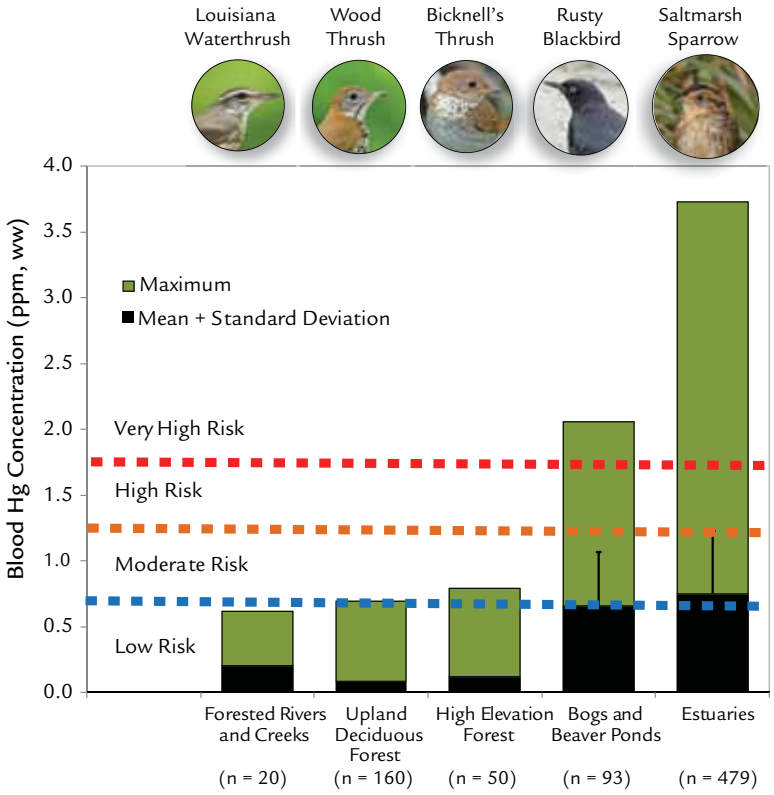


Figure 5: Blood mercury concentrations of indicator songbirds, representing risk associated with different terrestrial ecosystems.

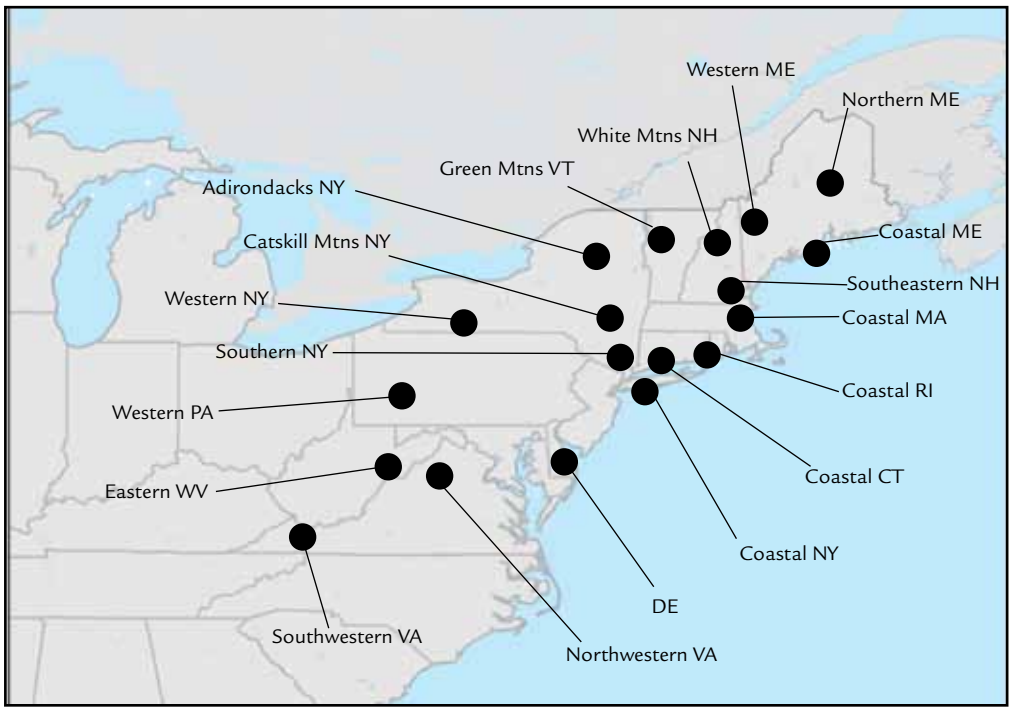
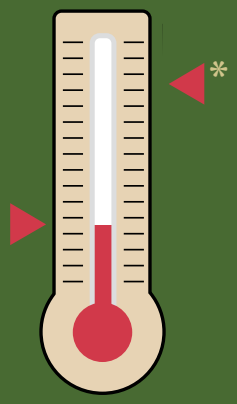


Figure 6: Geographic area studied. We captured birds and bats across 11 states from Virginia to Maine. Blood mercury concentrations in this report are based on sampling from these 19 study sites. Due to the opportunistic nature of our sampling program, we do not necessarily have complete geographic data for each species, but we are able to discern some trends between different regions.

Louisiana Waterthrush *(Parkesia motacilla)*

Potential Low Hg Risk



**Potential for Very High Hg Risk on Contaminated Sites*

Photo © Jeff Nadler Photography

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.

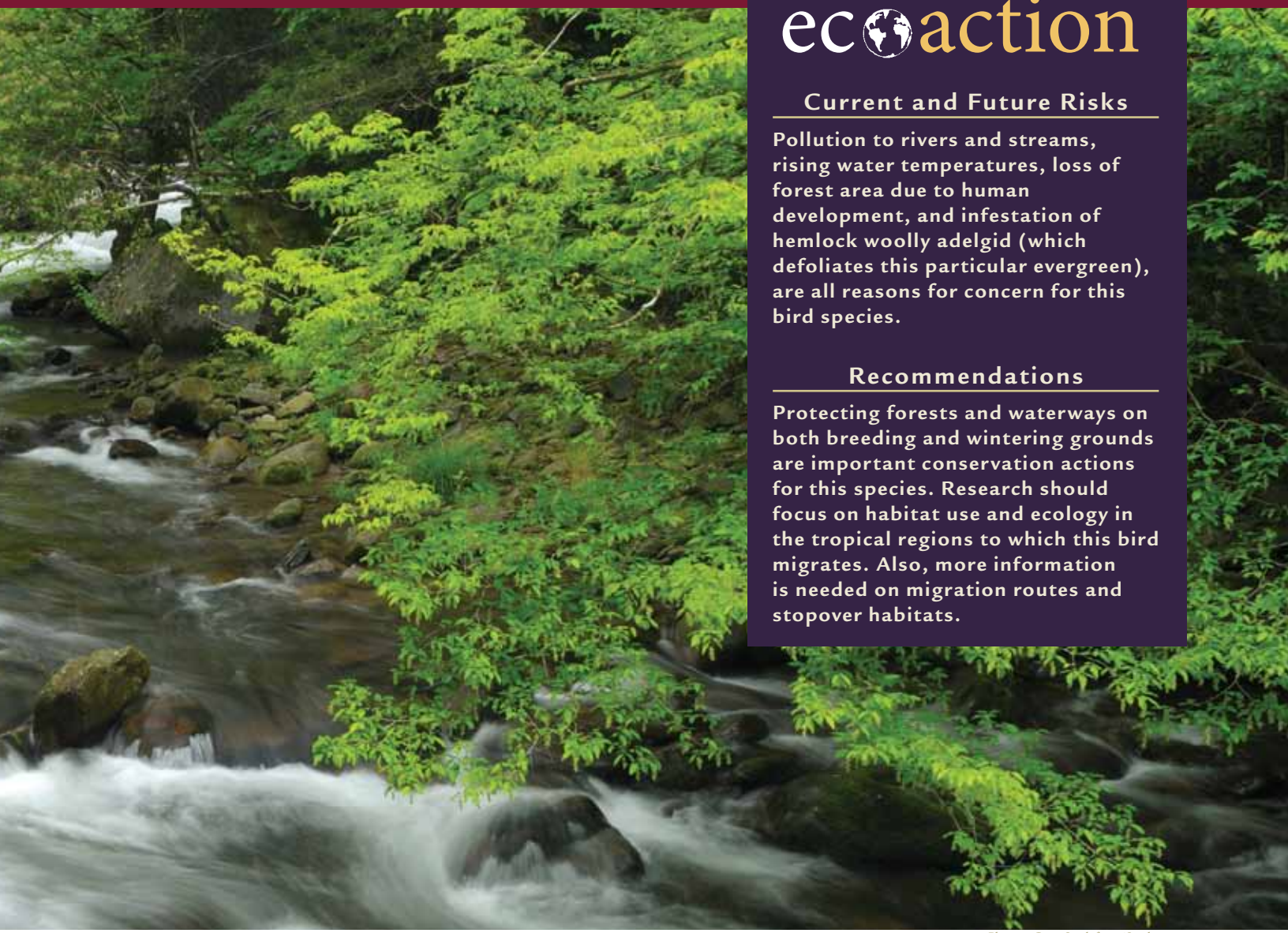


Photo © GreenStock from iStock.com

ecoaction

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.

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.

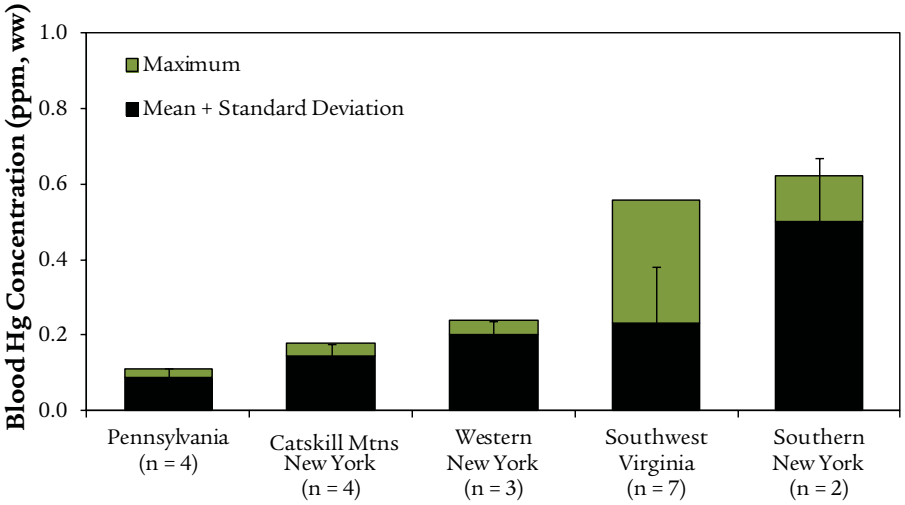


Figure 7: Geographic differences in mercury exposure in Louisiana waterthrushes. While sample sizes are low for this species, our data suggest biological mercury hotspots in southern New York and southwest Virginia.

Wood Thrush *(Hylocichla mustelina)*

Potential Moderate Hg Risk

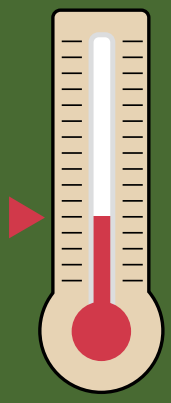


Photo © Jeff Nadler Photography

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).

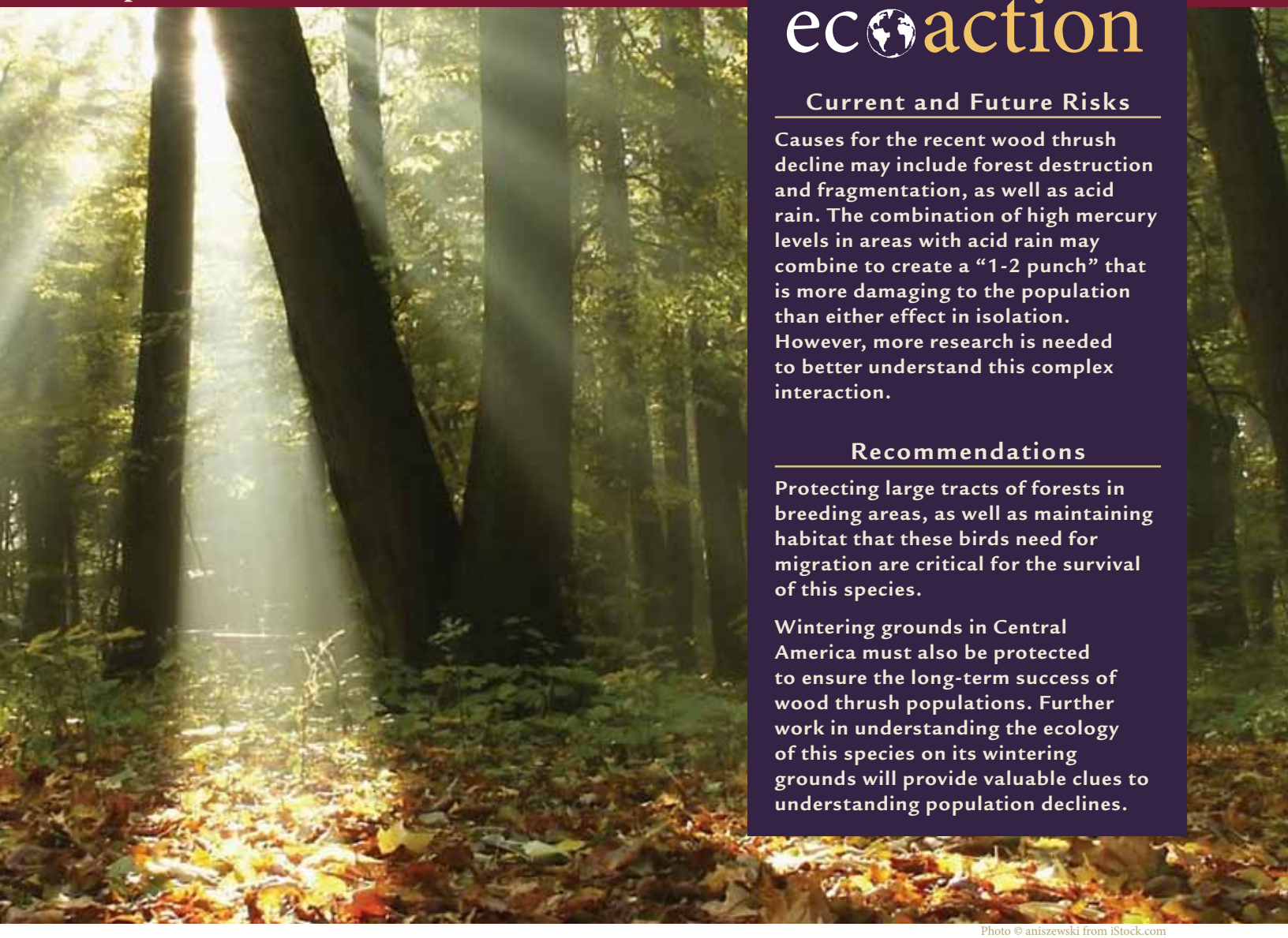


Photo © aniszewski from iStock.com

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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.

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].

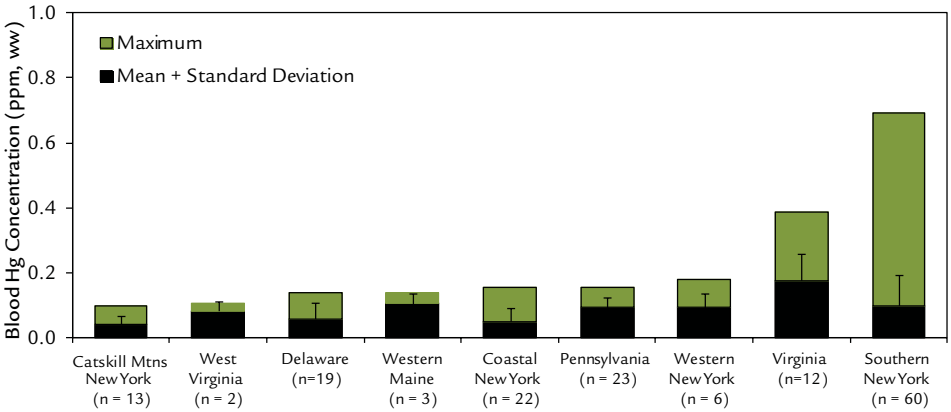

Figure 8: Geographic differences in mercury exposure in wood thrushes. Wood thrushes in Virginia and southern New York show elevated mercury levels compared to the other sampling areas.

Bicknell's Thrush *(Catharus bicknelli)*

Potential Moderate Hg Risk

Photo © Jeff Nadler Photography

In 1904, John Burroughs, literary naturalist in the tradition of Thoreau, described the song of the Bicknell's thrush as a "musical whisper of great sweetness and power." However, the plaintive call of this mid-sized thrush is rarely heard by those other than the most intrepid bird enthusiasts and ornithologists. Reclusive and elusive, this bird is one of the rarest songbirds in North America.

During breeding season, this bird prefers remote, inhospitable habitats high in the mountainous terrain of the northeastern United States and southeastern Canada. The Bicknell's thrush exhibits unusual mating habits; both males and females mate with multiple partners (known as polygynandrous) resulting in mixed paternity in nearly every nest.

Other Birds of Conservation Concern in this habitat: blackpoll warbler, and yellow-bellied flycatcher.

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.

Photo © Jeff Nadler Photography

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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.

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.

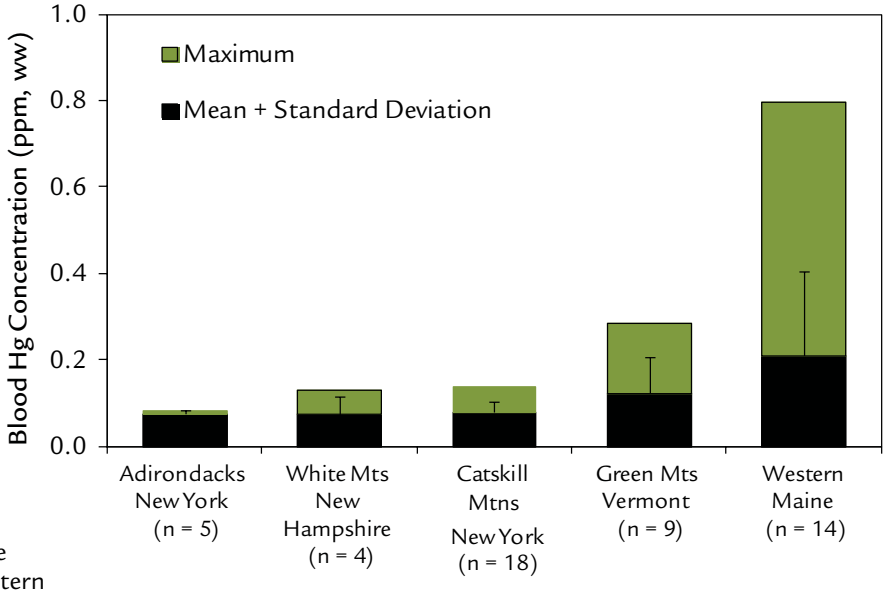

Figure 9: Geographic differences in mercury exposure in Bicknell's thrushes. Due to their particular habitat requirements, Bicknell's thrush are not found in all the geographic region studied, but those captured in western Maine show higher mercury levels than other areas.

Rusty Blackbird *(Euphagus carolinus)*

Potential Very High Hg Risk

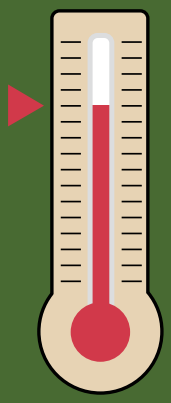

Photo © Jeff Nadler Photography

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 monogomous 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.

Other Birds of Conservation Concern in this habitat: olive-sided flycatcher, bay-breasted warbler, and Canada warbler.

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.

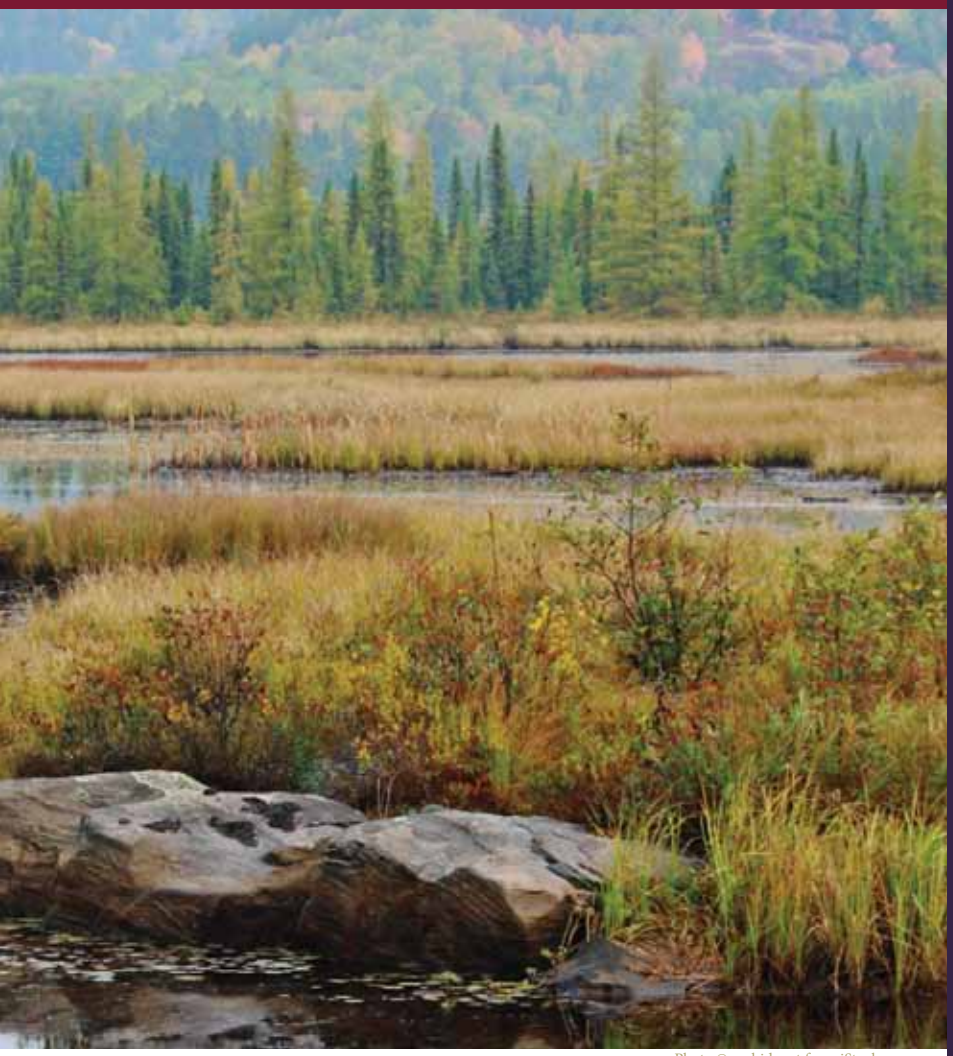

Photo © orchidpoet from iStock.com

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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.

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].

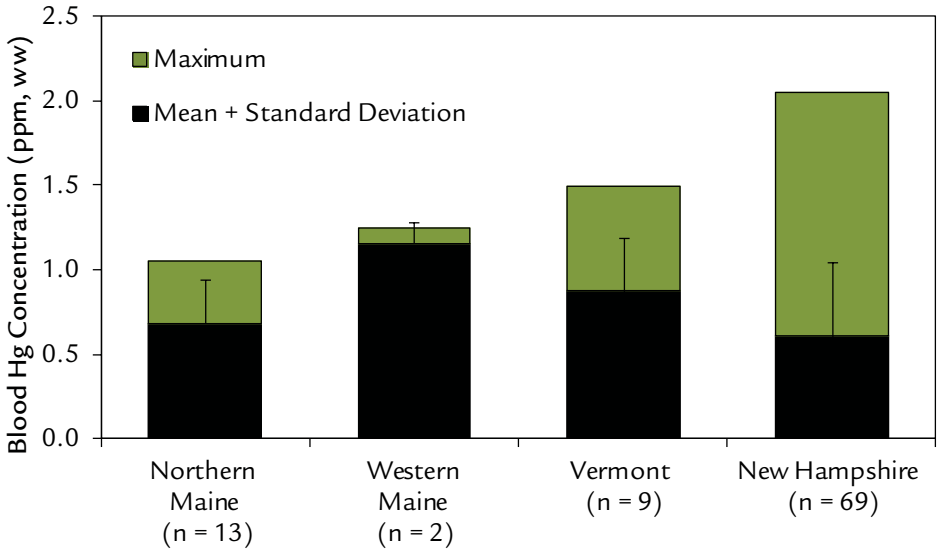

Figure 10: Geographic differences in mercury exposure in rusty blackbirds. Rusty blackbirds are increasingly hard to find on their breeding grounds, but those that we sampled appear to have high mercury levels at all sites.

Saltmarsh Sparrow *(Ammodramus caudacutus)*

Potential Very High Hg Risk

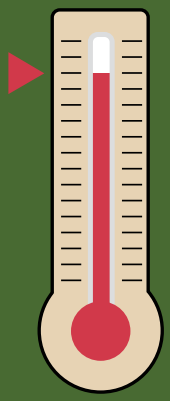

Photo © Garth McElroy

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.

Photo: BRI archives

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Current and Future Risks

Rising sea levels attributed to climate change pose a serious threat to these birds, which spend their entire life cycle near the water's edges. Marsh degradation, invasive species such as phragmites, and loss due to coastal development is also a continuing problem.

Recommendations

The saltmarsh sparrow is an excellent indicator species for contaminants in estuaries: they are endemic to the region; spend their entire life cycle in saltmarsh habitats; and tend to eat high in the food chain. Limiting mercury exposure is critical. Salt marsh managers must identify and reduce sources of mercury by implementing Best Management Practices (BMP) for storm water management where it affects the saltmarsh, use vegetative buffers, remove sources of mercury such as landfills, and support regulations to reduce the amount of mercury entering the water system.

Because these birds are especially vulnerable to rising sea levels as a result of climate change, it is important that land use planners and decision-makers extend coastal protection further inland.

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.

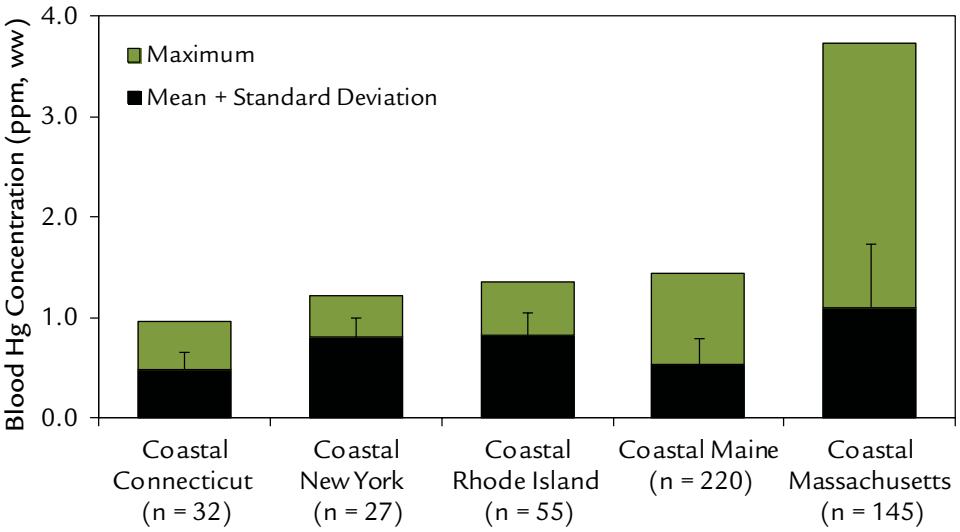

Figure 11: Geographic differences in mercury exposure in saltmarsh sparrows. Saltmarsh sparrows show overall higher mercury levels than any of the other species studied, with a potential biological mercury hotspot in coastal Massachusetts.

Little Brown Bat *(Myotis lucifugus)*

Potential High Hg Risk

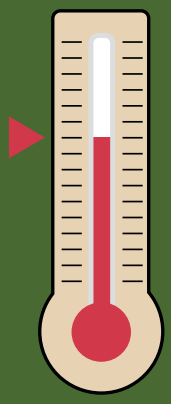

Photo © Philip Myers, Animal Diversity Web

Ancient Egyptians believed they cured illness, the Chinese view them as good luck, Westerners fear they are vampires—there is no lack of myth, legend, or folklore surrounding bats. These creatures, the only mammals that can fly, are actually quite beneficial to people.

The little brown bat, with its glossy brownish-black fur, was once one of the most common bats found in North America. Now, however, because of a fungus causing white-nose syndrome, little brown bat populations have declined dramatically and are now being considered for federal listing. Not a territorial animal, these bats roost in large colonies, some reportedly as large as 300,000 individuals.

The little brown bat, which grows to be about three inches long and weighs a quarter of an ounce, can eat up to 1,200 mosquitoes in an hour; this bat can consume up to its body weight in insects in one night. The service to pest control provided by these voracious eaters is valued at $22.9 billion per year in the U.S. [25].

Habitat

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.

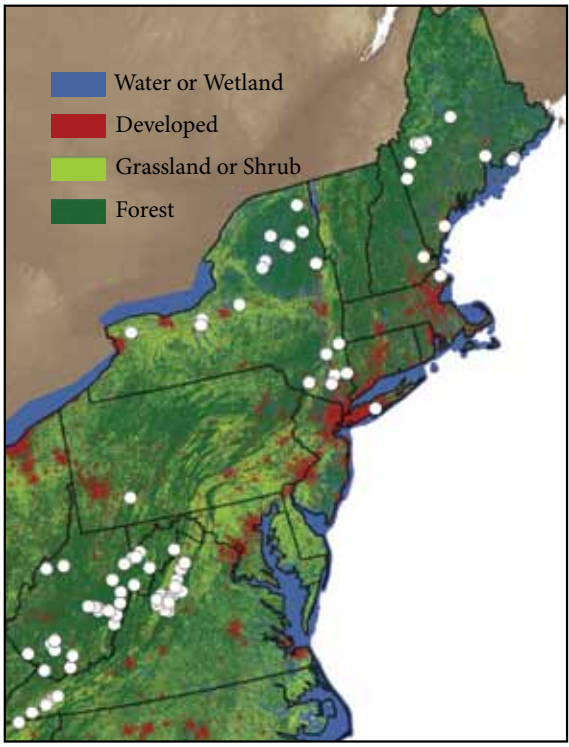

Figure 12: Bat sampling locations occur across a variety of habitats within the Northeast, making bats valuable candidates for monitoring programs. Map landcover types based on the National Land Cover dataset [36].

Photo © Merlin B. Tuttle, Bat Conservation International

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.

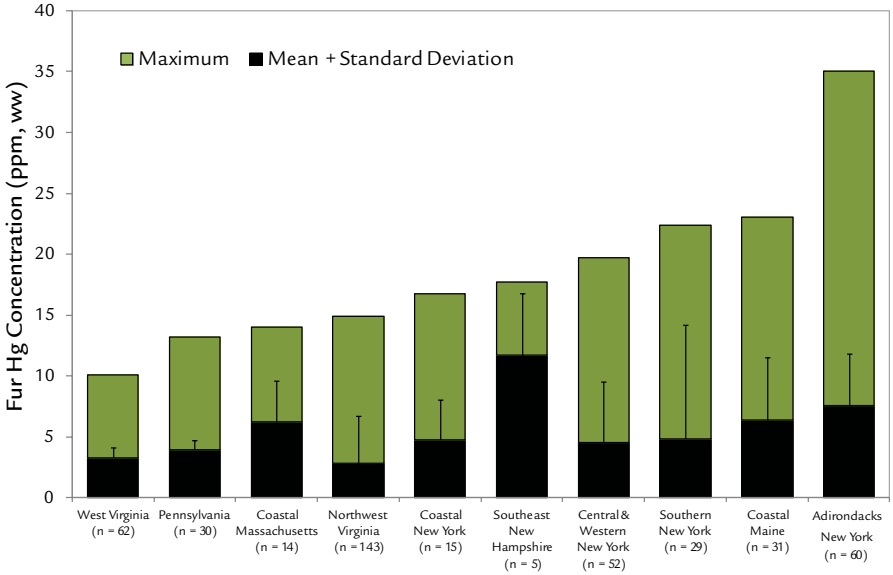

Figure 13: Mean bat fur mercury concentrations for little brown bats in different geographic regions in the Northeast. All regions sampled have individuals with fur concentrations that exceed the 10 ppm preliminary subclinical threshold (red line). At concentrations above 10 ppm, researchers have shown changes to little brown bat brain neurochemistry [30].

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Current and Future Risks

White-nose syndrome (WNS), so named for the white fungus that grows on the muzzle and wings of affected bats, is decimating entire populations of these animals (nine different bat species have been affected). This fungus irritates the bat, causing it to waken more often during hibernation, depleting stored fat reserves. Infected bats, emerging too soon from hibernation dehydrated and malnourished, freeze or starve to death; mortality rates are nearly 100% at some sites.

Recommendations

Northeastern bats are in danger due to multiple threats, including WNS, habitat loss, pesticide use, mercury pollution, and wind-power development. The U.S. Fish and Wildlife Service is coordinating a national management plan to address WNS, but more research is needed to better understand other threats that bats face.

Some bat species, including the Indiana bat (*Myotis sodalis*), are already on the federal endangered species list and a petition has been filed to list little brown bats. Beyond the urgent need to understand and mitigate the effects of WNS, bats should be protected through management of forests and cave exploration, as well as by limiting pesticide use. Debunking myths through education will help raise public awareness as to the value of bats.

Management Recommendations

High Elevation Forests

Reduce acid deposition

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

Upland Forests

Improve fire management

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

Forested Rivers and Creeks

Restrict logging near water bodies

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

Unrestricted Ecosystems

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]. Implemention 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

Artificial Reservoirs

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

Estuaries

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.

What Is a Neotropical Migrant?

A bird that breeds in the U.S. and Canada, then travels to Central or South America or the Caribbean for the winter.

Understanding Migration

Migration is a common life history strategy that manifests in a myriad of ways across species. Hawks and eagles migrate during the day to take advantage of air currents, while songbirds migrate at night to avoid predators. Some songbird species, even those as small as hummingbirds, will embark on 18–72 hour nonstop over-water flights to arrive at their destinations.

Seabirds migrate almost entirely over water: Arctic terns track both coasts of the Atlantic Ocean in their Arctic to Antarctic route, while albatrosses track the winds in the middle of the Southern Ocean. There are about as many types of migration as there are migratory species; understanding how migration works in each species is critical toward understanding the risks that these animals take throughout their entire life cycle.

Small devices, called geolocators, can be attached to a bird to record its migration. Geolocators estimate the global position of the bird by calculating sunset and sunrise to determine latitude and longitude, enabling scientists to learn more about the migration habits of birds as small as wood thrushes [43].

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.

Neotropical Case Study: Northern Waterthrush

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.

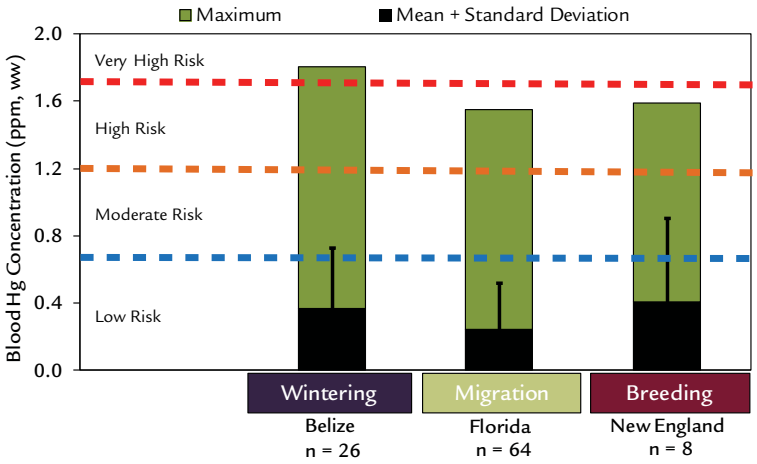

Figure 14: Blood mercury concentrations of northern waterthrush throughout their migratory cycle.

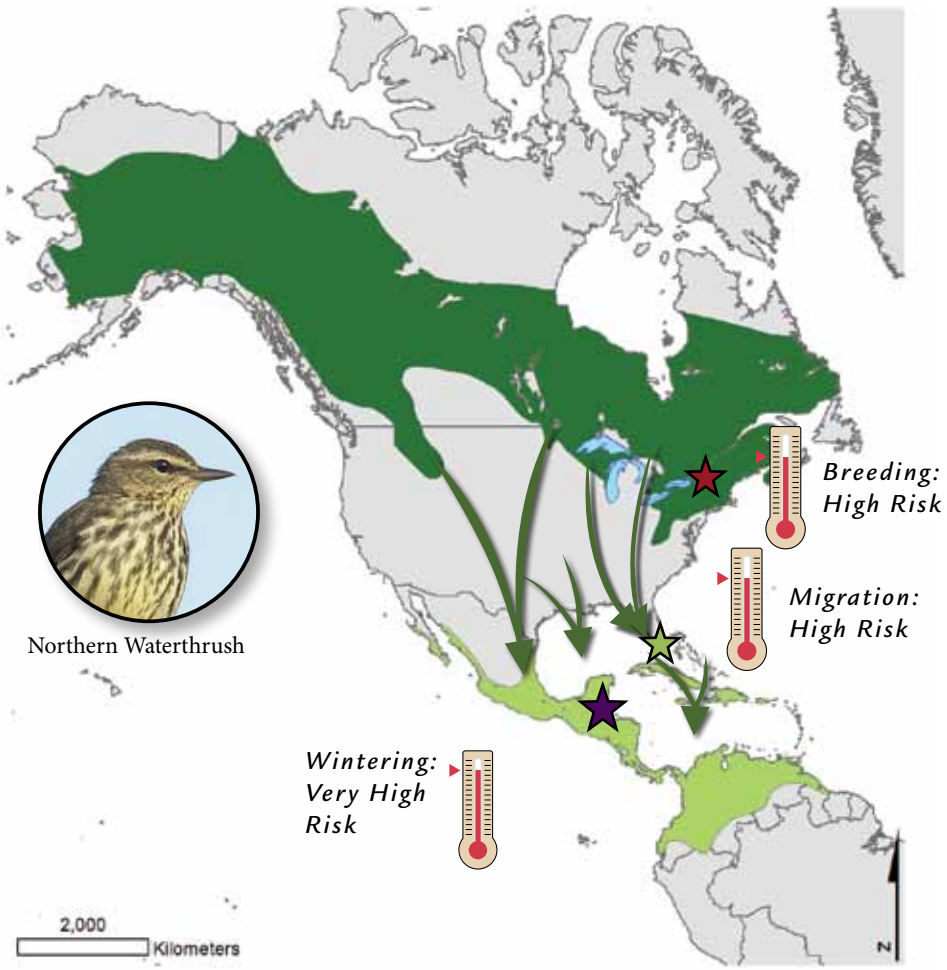

Figure 15: Depicted here is the northern waterthrush's breeding (dark green) and wintering (light green) ranges along with migratory routes (arrows). This species is emphasized because it is one of the few neotropical migrants where BRI has year-round information on mercury exposure, but many other declining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

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*

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 invertivores.
- 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).

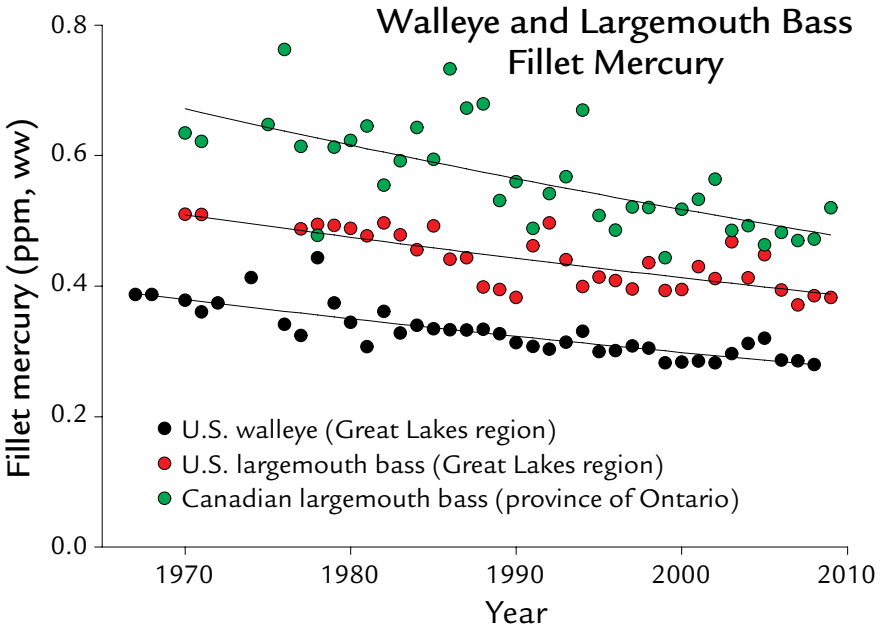

Figure 16: Temporal trends in fish fillet mercury concentrations averaged by year across multiple sites in the Great Lakes and inland water bodies in the U.S. Great Lake states and the province of Ontario [45].

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).

Using Science to Inform Mercury Policy

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
3. Minimize wildlife exposure by reducing mercury emissions.

1. Identify the species, habitats, and regions at risk to mercury exposure

Improve mercury monitoring in both aquatic and terrestrial ecosystems across the United States

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.

2. Address synergistic interactions of mercury with other environmental pollutants

Develop science-based policy recommendations for setting air pollution thresholds to protect ecosystems and species

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.

3. Minimize wildlife mercury exposure by reducing mercury emissions

Reduce mercury emissions from coal-fired power plants

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.

Avoid mercury "cap and trade" systems

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.

UNEP

Regulate global mercury emissions

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.

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