NEW YORK STATE

Mercury Connections

2019

The Extent and Effects of Mercury Pollution in the State

bri

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New York State Mercury Connections **is a summary of the major findings of a series of research studies undertaken by Biodiversity Research Institute in cooperation with the New York State Energy Research and Development Authority.**

Biodiversity Research Institute

Biodiversity Research Institute (BRI), headquartered in Portland, Maine, is a nonprofit 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. For information about BRI's Center for Mercury Studies, visit: www.briloon.org/hgcenter.

New York State Energy and Research Development Authority

The New York State Energy Research and Development Authority (NYSERDA), a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975. To learn more about NYSERDA's programs, visit nyserda.ny.gov or follow on Twitter, Facebook, YouTube, or Instagram.

Synthesis of Environmental Mercury Loads in New York State — NYSERDA Agreement #124842
with additional support from:
Songbirds and Loons for Mercury Bioaccumulation Assessments— NYSERDA Agreement #34358

Syracuse University

Syracuse University, a private research university located in Syracuse, New York, was incorporated in 1870 and grew rapidly, establishing programs in architecture and fine arts that were among the nation's earliest. By 1934, the University's academic divisions had grown to comprise 13 schools and colleges, which persist to the present day.

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New York State Mercury Connections

The Extent and Effects of Mercury Pollution in the State

New York State: Mercury Pollution and Mercury Monitoring Needs

Watkins Glen
New York

Mercury pollution is a local, regional, and global environmental problem that adversely affects ecosystems worldwide—including New York State.

Mercury can be emitted from natural sources such as volcanoes and released by natural processes such as wildfires. However, globally, more than two-thirds of the mercury currently released to the environment originates, either directly or indirectly, from human activities. Since the early 1800s, this translates to an increase of global atmospheric mercury concentrations of between 300 and 500 percent (UN Environment 2019).

Since the early to mid-1800s, mercury has been released into the air and waterways in New York State from human activities such as fossil fuel combustion, waste incineration, metal smelting, chlorine production, and discharges in wastewater and other sources. The elevated loading of mercury into the State's environment contributes to mercury-related fish consumption advisories across many of New York's inland freshwater lakes, two Great Lakes (Erie and Ontario), and its coastal areas. Ultimately, past and present inputs of mercury pollution have created a substantial environmental challenge for New York State.

In 1969, New York State was at the forefront of the burgeoning environmental movement. This year, 2019, marks the 50th anniversary of mercury monitoring in the State.

Mercury has long been recognized as an important problem in New York State. Numerous efforts are underway to curb mercury pollution. Under the Great Lakes Water Quality Agreement, Environment Canada and the U.S. Environmental Protection Agency (US EPA) signed the Great Lakes Binational Toxics Strategy in 1997 calling for virtual elimination of mercury emissions originating from human activities in the Great Lakes region (US EPA 1997). The Great Lakes Regional Collaboration built on this effort and in 2010 produced the Great Lakes Mercury Emission Reduction Strategy with recommendations for decreasing emissions from the largest remaining sources in the basin.

For state-based and regional sources, the Mercury Air Toxics Standards (MATS) rule has curbed the release of mercury into the atmosphere with a goal of reaching 91% reductions. At a global scale, the Minamata Convention on Mercury entered into force in August 2017; the United States is a ratified Party for this important international treaty.

To inform policy efforts and to advance public understanding, the New York State Energy Research and Development Authority (NYSERDA), in 2018, sponsored a scientific synthesis of information on mercury in air, water, fish, and wildlife. This scientific collaboration has resulted in a series of 24 papers published in the journal *Ecotoxicology* (Evers at al. in review) and are distilled here for use by decision makers and the public. This publication, *New York State Mercury Connections*, highlights the major findings of that collaborative effort.

Catskill Mountains

Major Findings of the Mercury Synthesis

Five major findings emerge from the results of the scientific synthesis of mercury in New York State.

1. New York State features natural areas that are ecologically, culturally, and economically significant, but widely contaminated with mercury largely due to atmospheric emissions and deposition.
2. The scope and magnitude of the impact of mercury on fish and wildlife in New York State is much greater than previously recognized. Mercury concentrations exceed human and ecological risk thresholds in many areas, particularly in inland waters.
3. The Adirondacks, Catskills, and parts of Long Island are particularly sensitive to mercury pollution. The impact of mercury emissions and deposition is exacerbated by landscape characteristics. Abundant forests facilitate mercury deposition, while wetlands enhance transport, methylation, and uptake leading to elevated concentrations in aquatic and terrestrial food webs.
4. Mercury concentrations in the environment of New York State have declined over the last four decades, concurrent with decreased air emissions from regional and U.S. sources. After initial declines, however, concentrations of mercury in some fishes and birds from certain locations have stabilized or even increased in recent years—revealing complex trajectories of mercury recovery.
5. While the timing and magnitude of the response will vary, further controls on mercury emission sources are expected to continue to lower mercury concentrations in the food web, yielding multiple benefits to fish, wildlife, and people of New York State. It is anticipated that improvements will be greatest for inland lakes and roughly proportional to declines in mercury deposition

Efforts to advance recovery from mercury pollution in New York State in recent years have yielded significant progress, but have yet to address the full scope of the problem. The findings from this scientific synthesis indicate that: (1) mercury remains a pollutant of major concern; (2) the extent and magnitude of the contamination is greater than previously recognized; and (3) after decades of declining mercury emissions, trends in mercury concentrations in fish and wildlife have stabilized or are increasing in some species in particular areas.

While the reasons behind these shifting trends require further study, they also underscore the need to continue and even expand existing monitoring efforts by NYSERDA and other entities to better track progress. This is particularly important as new pollution mitigation measures are implemented, global sources increase, and the State faces changing environmental conditions.

Common Loon

Study Area—New York State

EPA Level III Ecoregions

The US EPA has identified ecoregions across the country; these are areas where the type, quality, and quantity of environmental resources are generally similar.

In New York, EPA Level III Ecoregions divide the State into areas of environmental similarity based on patterns in the mosaic of biotic, abiotic, aquatic, and terrestrial ecosystem components (Figure 1).

These ecoregions provide a spatial framework that can be used to evaluate mercury exposure patterns and risk for wildlife that are adapted to different environments.

We use ecoregions to examine differences in spatial patterns and temporal trends of mercury exposure, evaluate mercury effects risk, and assess monitoring protocols.

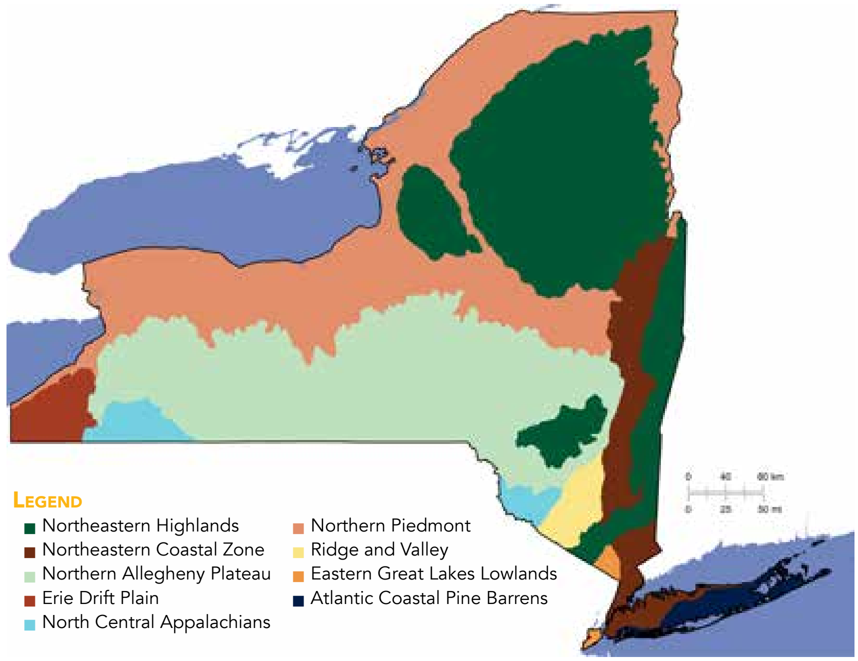

Figure 1. Ecoregions across New York State. More information can be found on pages 28-29.

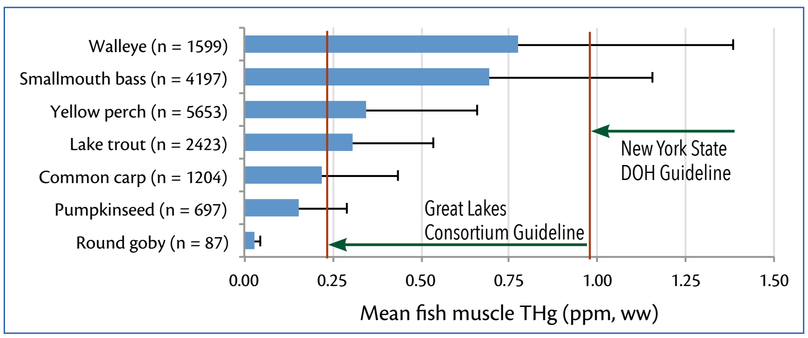

Figure 2. Average total mercury concentrations in fish species in New York State with sample size (n). Error bars represent variation around the average, calculated as standard deviation. Red vertical lines delineate fish consumption guidelines from the GLC and the NYS DOH; the thresholds represent the recommended cut-off for mercury levels in fish if consuming one meal per week.

habitat

The location or environment where a plant or animal naturally or normally lives and grows.

ecosystem

A system that includes all living organisms (biotic factors) in an area as well as its physical environment (abiotic factors) functioning together as a unit.

26 journal articles

Throughout this publication, we refer to research studies included in the *Mercury in the Environment of New York State* Special Issue in *Ecotoxicology*, 2019. They are highlighted in the reference section (page 41).

Effects of Mercury

Through the process of methylation, inorganic mercury is converted to methylmercury (MeHg). This organic form bioaccumulates and biomagnifies through terrestrial and aquatic food webs, potentially resulting in elevated and toxic levels of exposure to humans and wildlife. In this synthesis study, both mercury and methylmercury are referenced where relevant.

Human Exposure to Mercury (as Methylmercury)

Humans are exposed to mercury primarily through fish consumption. Government agencies have set advisories regarding dietary intake of certain fish to avoid harmful effects. The Great Lakes Consortium (GLC) and the New York State Department of Health (DOH) consumption guidelines are used in this study to assess the potential human health risk from fish consumption (Figure 2).

Fish and Wildlife Exposure to Mercury

Fish and wildlife exposure guidelines are difficult to assess because effects vary by species. Using the lowest observed adverse effect level (LOAEL) estimates for each major taxonomic group, context is provided for which species groups are exposed to mercury levels that can cause the population harm (see pages 20-21).

Sampling Analysis Methods

Sampling and Measurement Units

Observations of mercury in biota are available for New York State from 1969 through 2017, representing invertebrates, fish, amphibians, reptiles, birds, and mammals. Mercury data were standardized for each major taxonomic group to a common tissue type (Table 1).

For most species, total mercury (THg) is measured and largely occurs as methylmercury, but in species where methylmercury is a smaller fraction of total mercury, methylmercury concentrations are directly measured. Mercury is generally reported in parts per million (ppm) for wet weight (ww).

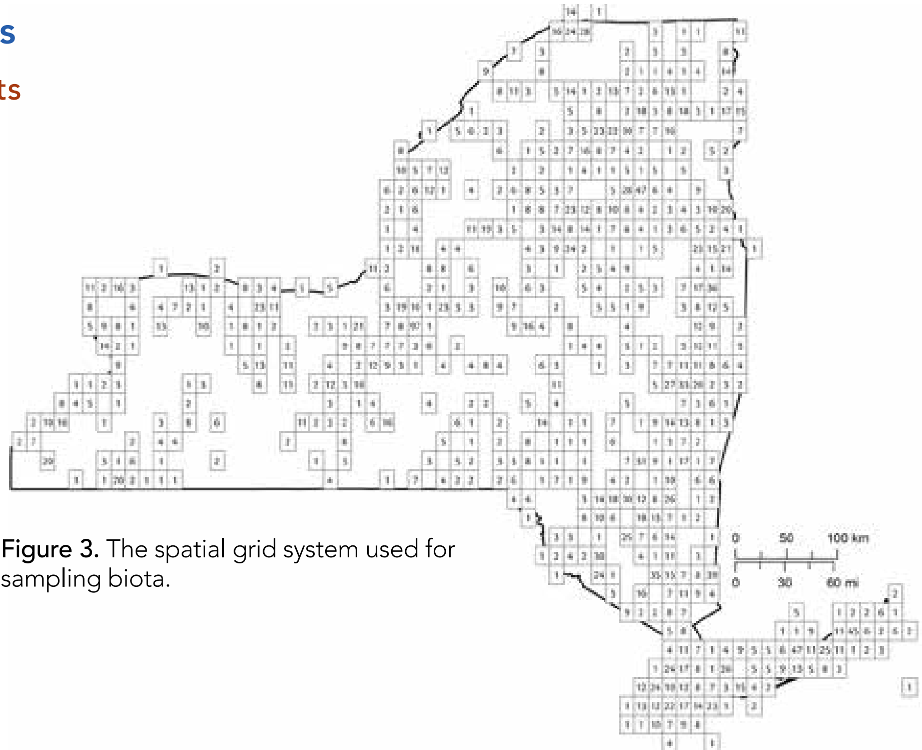

Figure 3. The spatial grid system used for sampling biota.

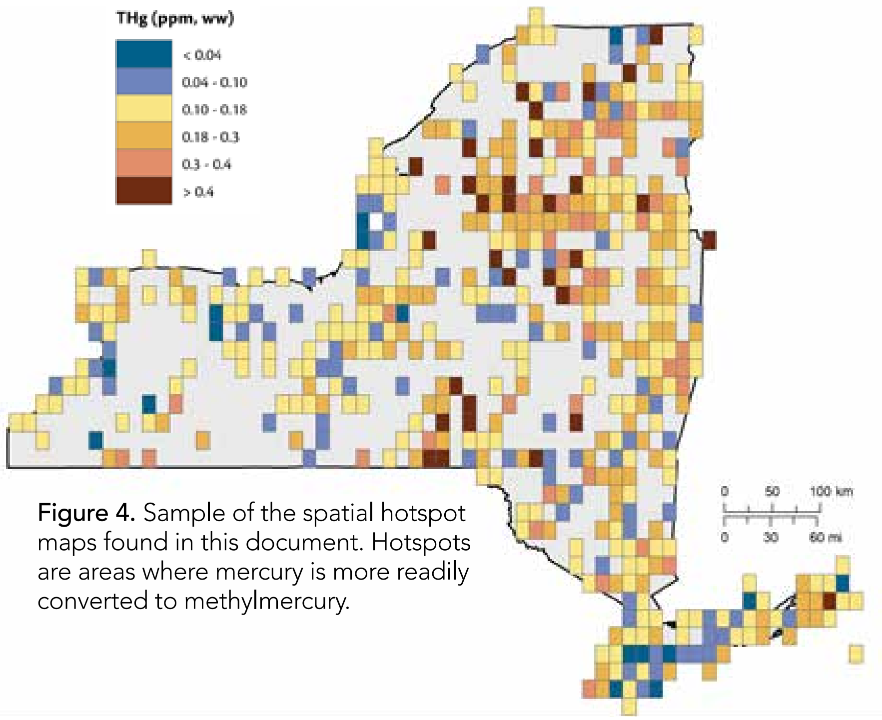

Figure 4. Sample of the spatial hotspot maps found in this document. Hotspots are areas where mercury is more readily converted to methylmercury.

Spatial Grid System

To examine spatial patterns of mercury across New York, the State was divided into 1/8 by 1/8 degree grid cells, each of which represents approximately 250 square kilometers. In Figure 3, the number in each grid cell equals the number of wildlife species sampled for mercury.

Spatial Hotspot Maps

Average total mercury concentrations were calculated for each grid cell (Figure 4). This was done by using wildlife samples from across New York State along with spatially explicit general linear mixed models to account for variation in foraging guild, tissue type, year, and species.

The values in each grid cell represent average mercury concentrations, which can then be compared to different screening benchmarks for wildlife and human health.

Table 1: Biota sampled in New York State from 1969-2017 and standardized tissue type.

Taxa	Tissue	Type/Unit	Sample Size
Mollusks and other Invertebrates	Whole body/ muscle	THg, MeHg ppm, ww	2,733
Fish	Whole	THg/ppm, ww	33,502
Amphibian	Muscle	THg/ppm, ww	109
Reptile	Scute	THg/ppm, fw	96
Bird: Invertivores	Blood	THg/ppm, ww	8,101
Bird: Piscivores/Carnivores	Blood	THg/ppm, ww	1,650
Mammal: Invertivores	Fur	THg/ppm, fw	486
Mammal: Piscivores	Fur	THg/ppm, fw	511
		Total Sampled	**47,188**

unit abbreviations

Hg – mercury
MeHg – methylmercury
THg – total mercury
ppm – parts per million
ww – wet weight
dw – dry weight
fw – fresh weight

Longview Power Station near Morgantown, West Virginia

1 Why Is Mercury Pollution a Problem in New York State?

The State of New York has significant freshwater and marine resources that are widely contaminated with mercury, largely due to atmospheric emissions and deposition as well as point-source releases into land and water.

at a glance

1. Controls on large industrial point-source discharges of mercury to land and surface waters from chlor-alkali plants and to the atmosphere from incinerator emissions have led to a partial recovery from mercury pollution, demonstrating the benefits of mercury controls.
2. Emissions of mercury to air (and subsequent deposition) are the primary source of mercury pollution to New York State. Waste disposal is the largest source of mercury emissions in the State (Figure 10, page 11), followed by fuel combustion.
3. Global sources of mercury continue to increase (Figure 7, page 10) and may influence recovery of mercury contamination in New York State.
4. The amount of mercury that is deposited annually to the landscape varies due to variation in meteorological conditions. The highest wet deposition levels are measured in western to central New York from Lake Erie into the Mohawk Valley, and New York City (Figure 12, page 13).
5. Many habitats and, ultimately, ecosystems in New York State are sensitive to mercury input, which can enhance transport, methylation, and exposure to fish, wildlife, and humans.

Northern Waterthrush

New York State and the Mercury Problem

New York State enjoys an abundance of natural resources, from extensive forested areas—including the Adirondack and Catskill Mountains, and the Allegany Plateau—to important aquatic and fisheries resources. New York's aquatic assets include portions of two Great Lakes, hundreds of inland lakes, and significant marine coastal areas (Figure 5).

In addition to their ecological importance, these resources have great socio-economic value as they provide drinking water, food, recreation, employment, transportation, and other benefits to approximately 20 million New Yorkers.

Pollution of water resources can have serious ecological consequences for aquatic ecosystems and the health of fish and wildlife. Pollution also impacts the economic status of many of New York's valuable industries, such as tourism, and recreational, commercial, and subsistence fisheries.

Inorganic mercury (from emissions and deposition) can be transformed into methylmercury in aquatic ecosystems. Methylmercury is a highly toxic compound that biomagnifies in aquatic food webs to concentrations that can reach levels several million times higher than those in water (Wiener et al. 2003, Chasar et al. 2009, Rolfhus et al. 2011). As it moves through the food web, methylmercury can reach levels that are harmful to consuming organisms, including humans.

The primary pathway of human exposure to mercury in North America is through the consumption of fish (see page 16). New York State provides consumers a bounty of freshwater and marine fish. Sport fishing in New York State supports more than 190,000 jobs, and has a total annual economic impact of more than $20 billion (U.S. dollars; Allen and Southwick 2008). Fish provide an important source of nutritious protein for millions of New York residents who consume sport fish from inland waters (Imm et al. 2005, Allen and Southwick 2008) and from the ocean.

> *New York State enjoys an abundance of natural resources, from extensive forested areas to important aquatic and fisheries resources.*

The contamination of this commercially and nutritionally valuable resource has important socio-economic implications, particularly for communities for whom fish and fishing carries cultural significance (Swain et al. 2007).

New York State Land Cover Types

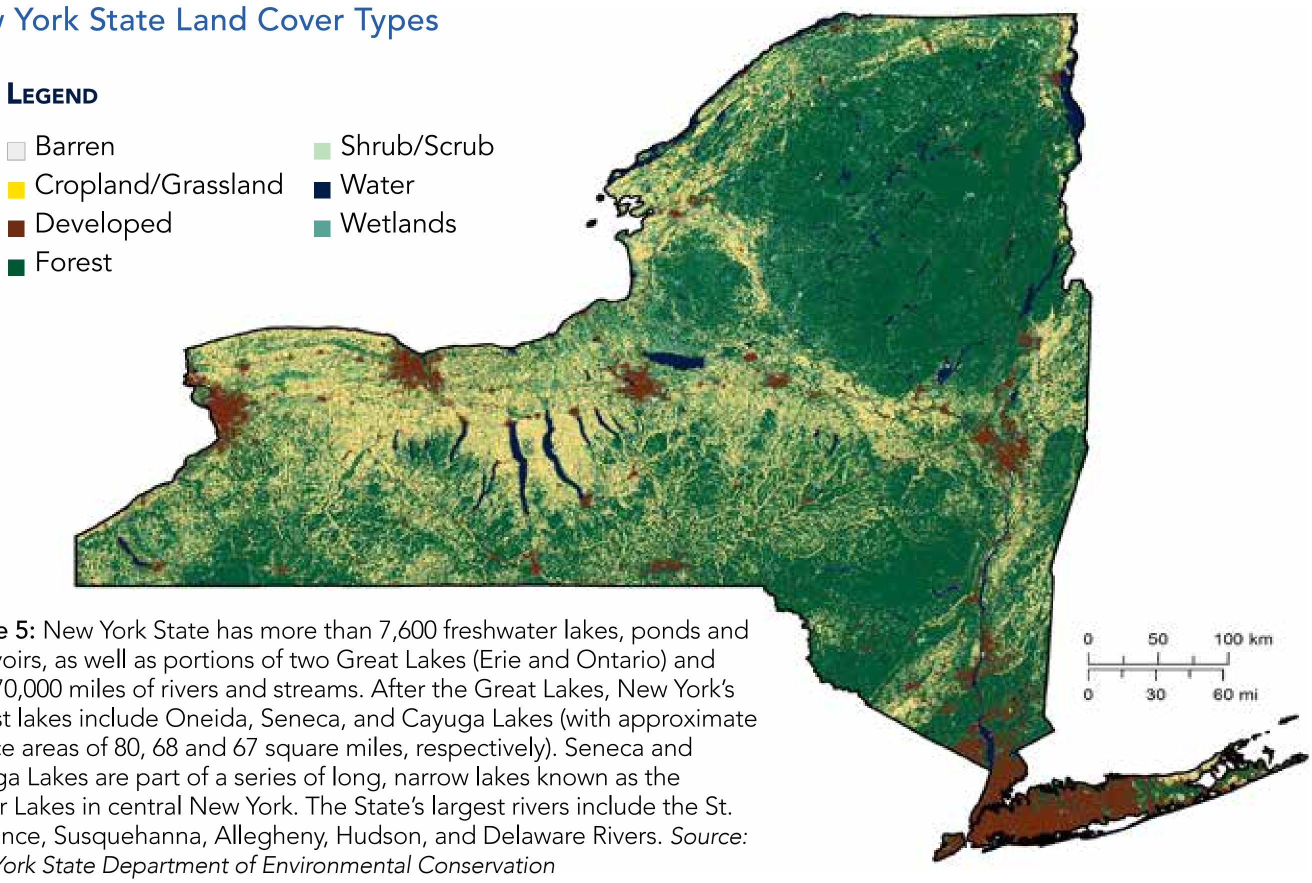

Figure 5: New York State has more than 7,600 freshwater lakes, ponds and reservoirs, as well as portions of two Great Lakes (Erie and Ontario) and over 70,000 miles of rivers and streams. After the Great Lakes, New York's largest lakes include Oneida, Seneca, and Cayuga Lakes (with approximate surface areas of 80, 68 and 67 square miles, respectively). Seneca and Cayuga Lakes are part of a series of long, narrow lakes known as the Finger Lakes in central New York. The State's largest rivers include the St. Lawrence, Susquehanna, Allegheny, Hudson, and Delaware Rivers. *Source: New York State Department of Environmental Conservation*

The Mercury Cycle

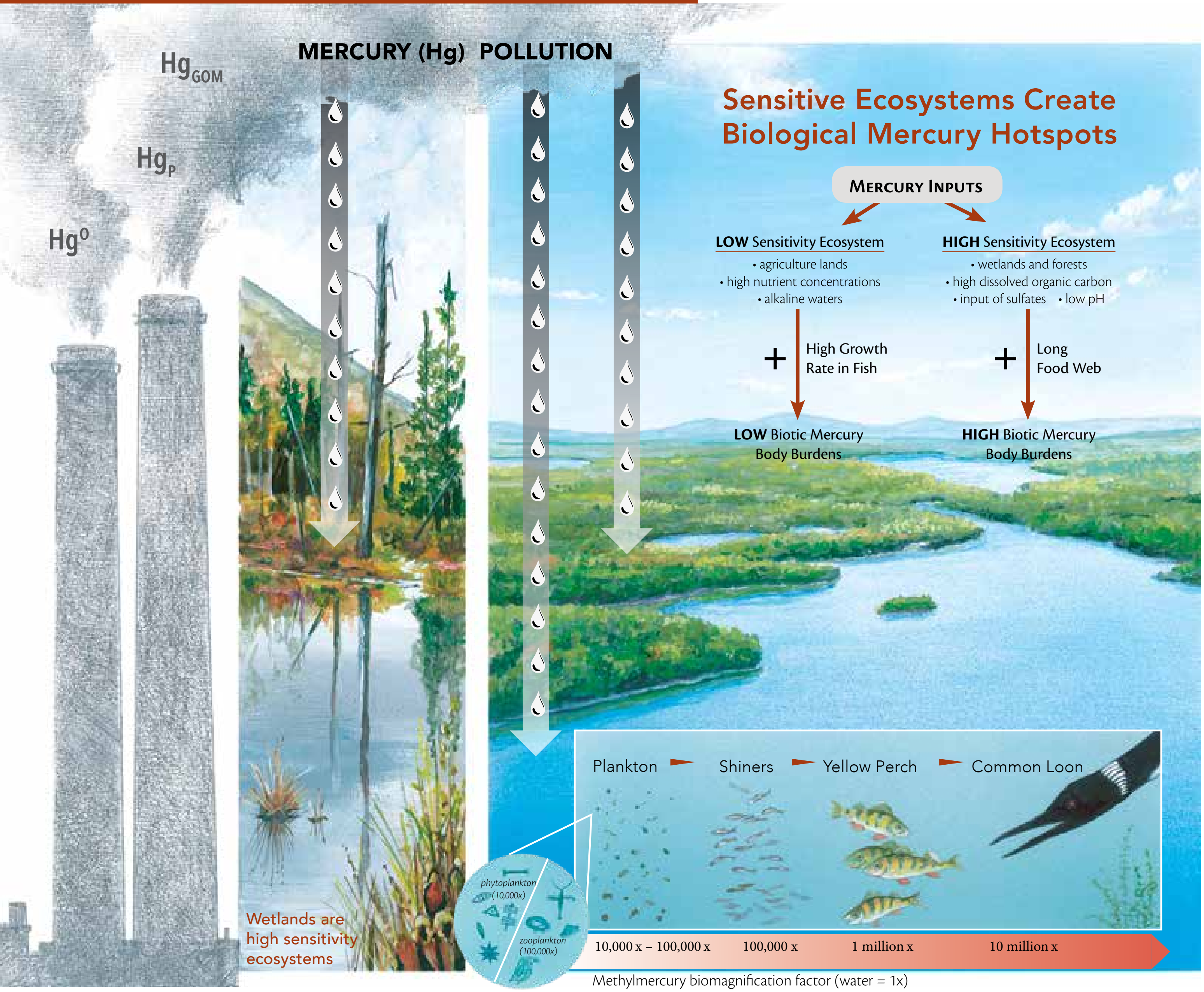

Figure 6. Mercury emissions can be transported hundreds and thousands of kilometers from their sources before being deposited on the landscape. Once deposited, the potential impact of mercury on the environment depends largely on ecosystem sensitivity. Understanding which ecosystems are most susceptible and also which organisms can serve as appropriate bioindicators is a critical component of effective mercury monitoring.

Hg species (from industrial sources)

Hg_{GOM} — gaseous oxidized mercury

Hg^0 — elemental mercury

Hg_p — particulate mercury

methylation

The conversion of inorganic mercury to its organic form (*methylmercury*). This step increases the bioavailability of mercury, its exposure to wildlife and humans, and ultimately its toxicity. Methylation occurs predominantly under oxygen-poor conditions. Sulfate-reducing bacteria are the primary agents of this process.

bioaccumulation

Accumulation of substances, such as methylmercury, in an organism from various sources (e.g., food). Bioaccumulation occurs when an organism absorbs a substance at a greater rate than it is excreted over time. In food webs with elevated methylmercury, older individuals at high trophic levels are at greatest risk.

biomagnification

Increase in concentration of a substance, such as methylmercury, from a lower to a higher trophic level in a food web. Organisms lower on the food web contain lower concentrations of methylmercury than the organisms that feed on them (e.g., phytoplankton < zooplankton < plant-eating fish < fish-eating fish < loons/eagles/humans).

Ecosystem Sensitivity to Mercury

Inorganic mercury enters ecosystems through the air (e.g., from coal-fired power plants and incinerators), water (e.g., from chlor-alkali facilities), and land (e.g., from landfills and other contaminated sites; Kocman et al. 2017, Streets et al. 2018, Hsu-Kim et al. 2018; Obrist et al. 2018). Once in the environment, mercury can be converted to methylmercury by bacteria and other microbes (Gilmour et al. 2013, Yu et al. 2013). Methylmercury is toxic and can accumulate to high concentrations in the tissues of fish, wildlife, and humans, causing numerous negative health effects.

The extent to which mercury is methylated and made available in the environment is complex and can be influenced by numerous factors. Specific ecosystem conditions can facilitate the production and bioavailability of methylmercury. For example, bacteria often produce more methylmercury under moderate amounts of sulphate and low oxygen conditions (Hsu-Kim et al. 2013); these conditions can occur in wetland ecosystems, lake and stream sediments, and riparian areas (Figure 6).

Furthermore, areas with abundant dissolved organic carbon (DOC) from decaying organic matter may generate and transport methylmercury more readily than areas that are low in DOC (Schartup et al. 2015). Also, areas that are acidified from deposition of sulfur oxides from sources such as fossil fuel combustion may be important environments for mercury methylation (Wyn et al. 2009).

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Dragonflies are good bioindicators for freshwater wetlands.

In areas where wet and/or dry mercury deposition is relatively low or moderate, effects on biota may be disproportionately high if environmental conditions promote methylmercury production.

Conversely, ecosystems with low methylation potential may have low levels of methylmercury despite heavy anthropogenic mercury contamination. The decoupling of inorganic mercury sources with methylmercury production and bioavailability is evident at local (Evers et al. 2007) and landscape scales (Eagles-Smith et al. 2016a).

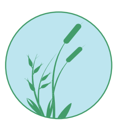
The complexity of the mercury cycle makes it challenging to predict effects levels in upper trophic level fish and wildlife from environmental mercury concentrations alone (Gustin et al. 2016, Sunderland et al. 2016). Identifying appropriate bioindicators based on their relationship with sensitive ecosystems is a critical first step in assessing risk to ecological and human health through long-term mercury monitoring.

Sensitive Habitats in New York State

The methylation of mercury is enhanced in certain terrestrial habitats (e.g., estuaries, sphagnum bogs, and high-elevation boreal forests).

In such habitats, relatively small inputs of mercury can be readily methylated by certain bacteria to create areas of high concern for fish, wildlife, and people—known as biological mercury hotspots (Evers et al. 2007).

Examples (right) of mercury sensitive habitats identified in New York State based on existing mercury exposure data in birds through recent papers include:



Estuaries – Mercury concentrations in blood and feather tissue from the Saltmarsh Sparrow (*Ammospiza caudacuta*) on Long Island indicate mercury exposure regularly exceeds levels that cause lower reproductive success in songbirds. Saltmarsh and Seaside Sparrows (*A. maritima*) are at particular risk because they often feed on spiders. Estuaries sampled were in Southampton and on North Cinder Island and North Green Sedge Islands.

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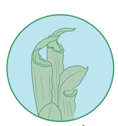

***Sphagnum* bogs** – In the Adirondack Park and elsewhere in northern New York, sphagnum bogs generate elevated levels of methylmercury. The transfer of methylmercury within and between aquatic and terrestrial food webs are important pathways for biomagnification and create risk for invertivorous wildlife such as Palm Warblers (*Setophaga palmarum*).

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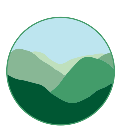

High-elevation boreal forests – These habitats generally receive higher rates of atmospheric mercury deposition due to increased precipitation rates and cloud cover, which enhance methylmercury bioavailability. A gradient of increasing mercury exposure was found in songbirds including Swainson's (*Catharus ustulatus*), Hermit's (*C. guttatus*), and Bicknell's (*C. bicknelli*) Thrush on Whiteface Mountain in the Adirondack Park.

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Mercury Emission Sources Affecting New York State

Initial regulatory efforts in the 1970s focused on large industrial sources of mercury, such as chlor-alkali plants. These point sources discharged mercury directly or indirectly into the Great Lakes and their tributaries. Today, many of these sources have been controlled, leading to a partial recovery from point-source mercury pollution (Evers and Clair 2005, Cain et al. 2011, Henry and Driscoll 2018; Figures 8 and 10).

Atmospheric emissions and deposition are the largest source of mercury to New York State. Large, stationary sources (e.g., fossil fuel burning plants and waste incinerators) emit mercury into the air as gases and particles. Once emitted, mercury may travel thousands of kilometers before it is deposited back to the Earth's surface, depending on its form. For this reason, mercury deposition to New York State can originate from sources that are local, regional, national, or global.

Mercury, a natural element in the Earth's crust, is released into the environment through human activities such as burning coal.

Global and U.S. Mercury Emissions

In the U.S., approximately 50 tons of mercury are annually emitted from anthropogenic sources. Between 1990 and 2015, total U.S. anthropogenic emissions declined more than four-fold, with the largest decreases occurring from hospital and municipal incinerators (95-99 percent decrease) and chlor-alkali facilities (97 percent decrease; Schmeltz et al. 2011). Global inventories suggest that during the same period, anthropogenic emissions increased (UN Environment 2019). Asia continues to be a dominant contributor to mercury emissions, due largely to expanding energy production from coal-fired power plants (Figure 7).

Mercury Emissions in the Great Lakes Region and New York State

The Great Lakes basin has served as the industrial engine for North America since the Industrial Revolution. The Great Lakes region accounts for an estimated 56 percent of all raw steel production and 40 percent of electric arc furnace production capacity in the United States (GLRC 2010). Therefore, it is not surprising that a large fraction of the total U.S. and Canadian atmospheric mercury emissions originate from the Great Lakes basin (Denkenberger et al. 2012).

In 2014, coal-fired power plants remained the largest source of anthropogenic atmospheric mercury emissions in the U.S., accounting for more than half of total anthropogenic emissions (Figure 8). Among the Great Lakes states, Pennsylvania has the highest annual emissions of mercury followed by Illinois, Ohio, and Indiana. However, the mapping of sources indicates that there are anthropogenic mercury emission sources across New York State, although total emissions are relatively low (Figures 9 and 10). Total mercury emissions

Mercury Emissions Sources—Worldwide

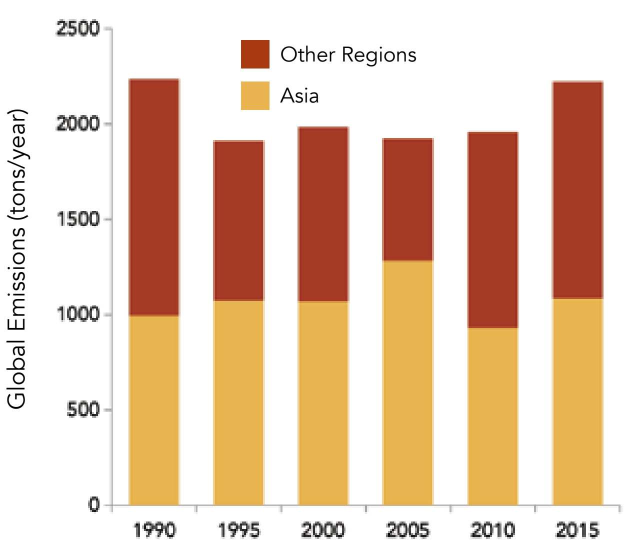


Figure 7: Global Hg emissions to air from anthropogenic sources, including the proportion of global emissions originating from Asian sources (UN Enironment 2019).

Mercury Emission Sources—United States

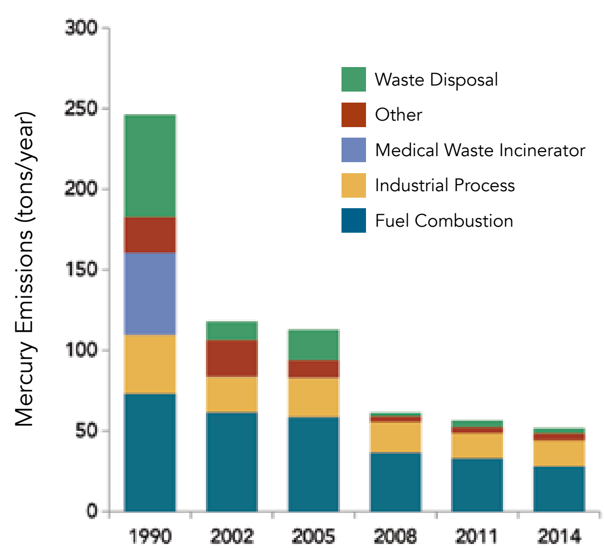


Figure 8: US EPA National Emissions Inventory (NEI) estimates of Hg emitted to the air by major source in the United States. Coal-fired power plants remained the largest source of mercury emissions in the U.S. (NEI 2014).

Sources of Mercury in New York State

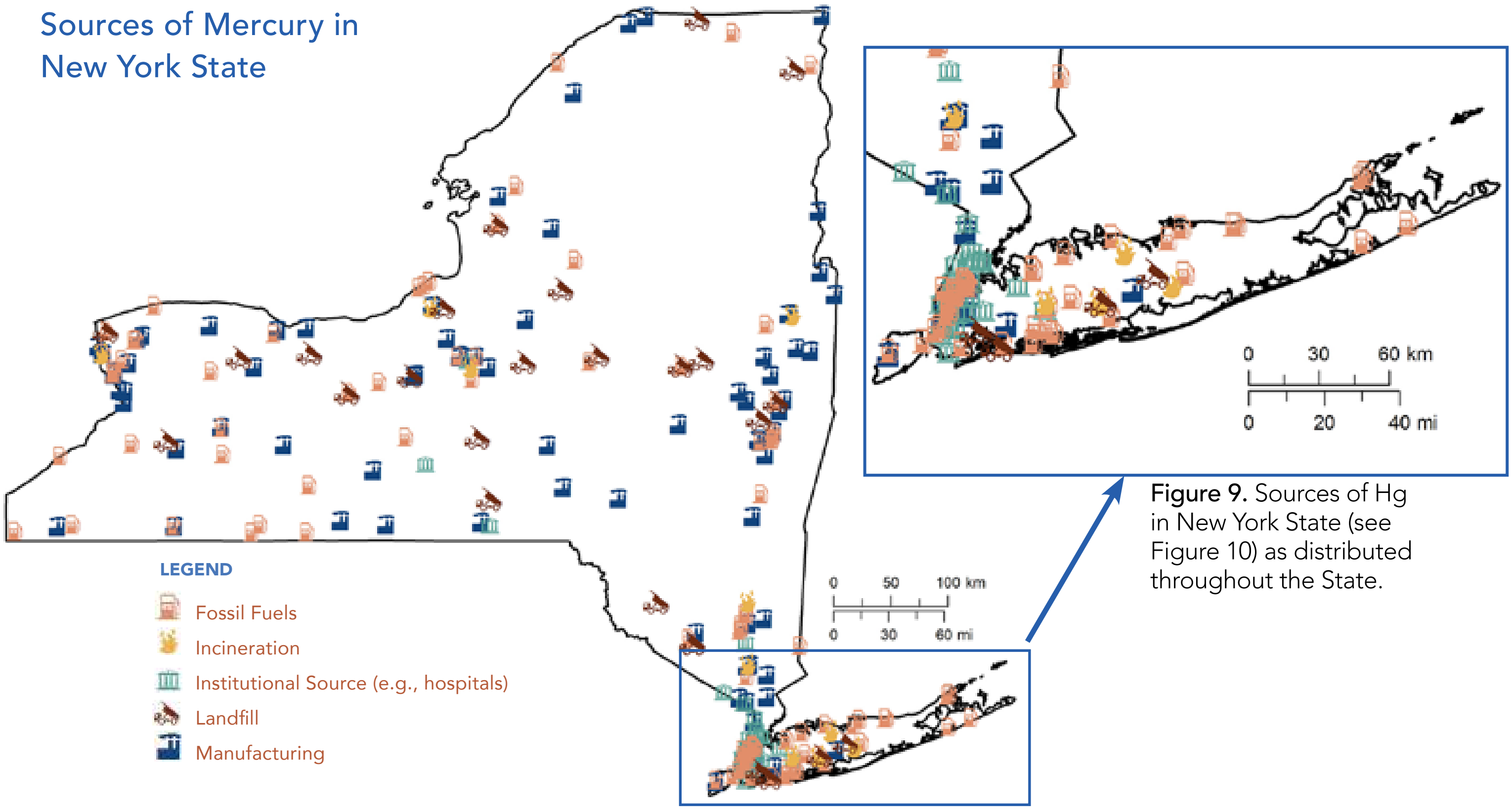


Figure 9. Sources of Hg in New York State (see Figure 10) as distributed throughout the State.

anthropogenic

The term anthropogenic designates an effect or object resulting from human activity. The term is sometimes used in the context of pollution emissions that are produced from human activity but also applies broadly to all major human impacts on the environment.

Air monitoring equipment installed at Huntington Wildlife Forest AMNet site in New York.

Mercury Emission Sources—New York State

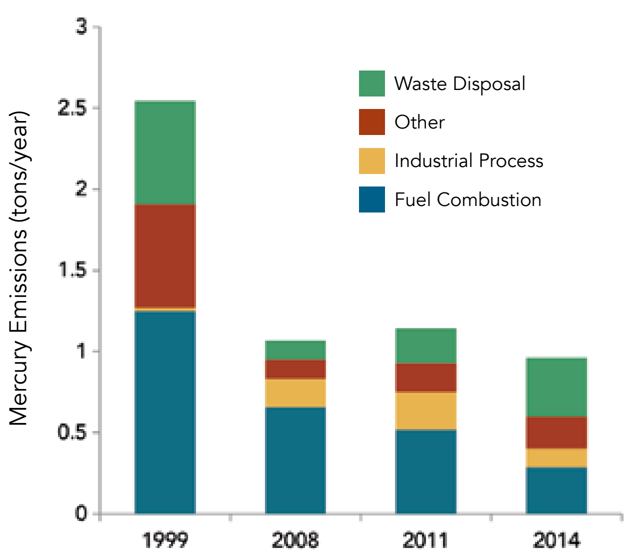


Figure 10: US EPA National Emissions Inventory (NEI) estimates of Hg emitted to the air by major source in New York State (NEI 2014).

to the atmosphere from anthropogenic sources in the Great Lakes states declined by more than 50 percent between 1990 and 2014. This decline reflects the leadership the region has demonstrated in controlling mercury emissions (Cain et al. 2011).

Nearly half of anthropogenic emissions from sources in the Great Lakes basin are gaseous oxidized mercury (GOM) or particulate-bound mercury (PBM). These forms are likely to be deposited within the region (Denkenberger et al. 2012). This emissions profile suggests that regional and local scale mercury emissions are important to mercury deposition and effects in the Great Lakes basin (Denkenberger et al. 2012).The remaining form of mercury emitted is elemental mercury (Hg^0), which has a long atmospheric residence time as a global pollutant.

Atmospheric Deposition of Mercury

After mercury is emitted into the atmosphere, it eventually returns to the Earth's surface via a process called atmospheric deposition. There are several pathways of deposition:

- **Wet deposition** occurs when mercury is deposited with precipitation;
- **Dry deposition** occurs when mercury is deposited as mercury GOM, PBM, or Hg^0 (see page 13); and
- **Litterfall** occurs when plant needles and leaves absorb mercury from the atmosphere, then fall to the ground.

Wet deposition can be measured directly by collecting precipitation such as rain or snow. Litterfall mercury can be quantified by the collection of leaf litter. Dry deposition is much more challenging to measure directly. Therefore, models are often used to characterize dry mercury deposition.

Atmospheric Mercury Monitoring Networks

There are three national networks that are operated by the National Atmospheric Deposition Program to track patterns and trends in atmospheric mercury concentrations and deposition. The Mercury Deposition Network (MDN) measures wet mercury deposition with five sites in New York State. The Atmospheric Mercury Network (AMNet) monitors concentrations of mercury forms in air, with three sites in New York State. Finally litter mercury deposition is measured at Huntington Wildlife Forest (Adirondacks) and at Biscuit Brook (Catskills) in New York State. Atmospheric mercury monitoring in New York State is supported by NYSERDA and others.

Temporal Trends in Deposition

While source emissions of mercury have decreased in North America in recent years (Zhang et al. 2016), measurements from monitoring networks in Canada and the United States show that the average annual input of mercury in wet deposition between 2002 and 2014 did not change appreciably (NADP 2019).

In the Adirondacks from 2000-2015, concentrations of total mercury in wet deposition have significantly decreased. However, patterns of total mercury in wet deposition were largely driven by variation in precipitation amount (Mao et at. 2017; Figure 11).

Spatial Patterns in Deposition

A modeling study of mercury deposition across New York State examined how local emissions and environmental variables contribute to spatial patterns of mercury deposition and found considerable spatial variation in the quantity of mercury deposited (Figure 12; Ye et al. In Review). By modeling different emissions scenarios, ranging from zero to the current levels in New York State, it is possible to understand how emissions

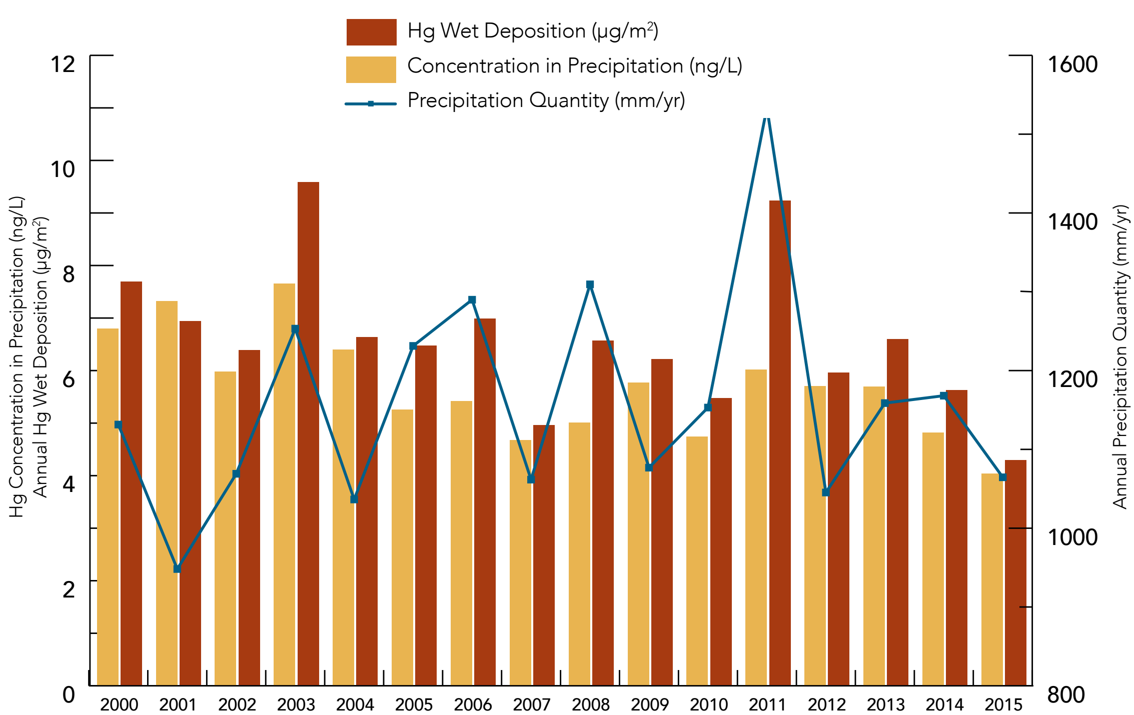
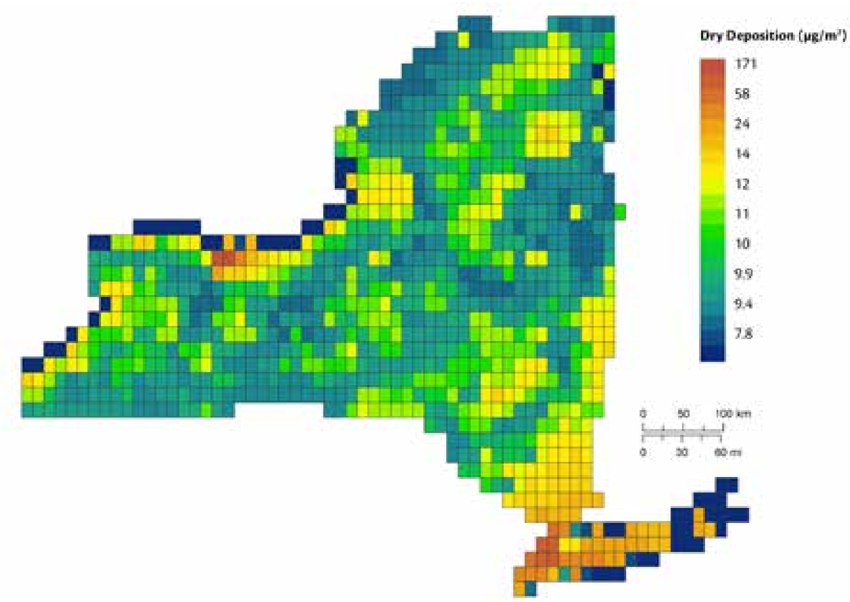


Figure 11: Patterns of wet mercury deposition and precipitation for Huntington Wildlife Forest in the Adirondack Mountains between 2000-2015, adapted from Mao et al. (2017). Total annual mercury deposition decreased by 2% per year, while mercury precipitation concentrations decreased by 2.5% per year.

Mercury Deposition in New York State

(a) Dry Deposition



(b) Wet Deposition

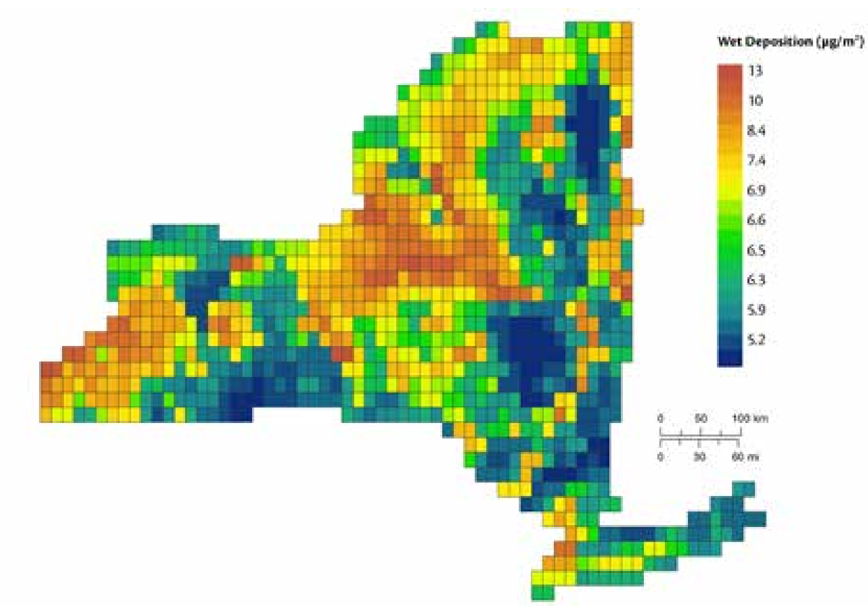


Figure 12: Simulated spatial patterns of dry and wet mercury deposition across New York State based on modeling work from Ye et al. (2018), at the scale of a 1/8 by 1/8 degree grid. Patterns of dry (a) and wet (b) mercury deposition vary considerably across the State due to emissions point sources, precipitation, wind speed, heat flux, and land cover. The z-axes for dry and wet deposition are shown on different scales.

interact with environmental variables to define the spatial distribution of mercury deposition. Different environmental factors cause different spatial patterns in wet and dry deposition.

Dry Deposition: Local, anthropogenic mercury sources increase deposition rates over water and land within 50 km of the point source. For example, there are point sources near Rochester, in Manhattan, and on Long Island, which explain elevated deposition in those areas, creating hotspots (Figure 12a).

Environmental factors such as wind speed and heat flux (changes in temperature across the surface of water and land) drive spatial patterns of deposition in aquatic habitats, while increased canopy cover correlates to greater deposition in terrestrial landscapes.

Wet Deposition: The amount of precipitation is the main driver of wet mercury deposition to aquatic and terrestrial habitats. Statewide variation in precipitation leads to increased deposition in the central and western regions, and in the New York City area (Figure 12b).

Climate Change and Mercury Deposition

The results of these studies suggest ways in which climate change could potentially affect future mercury deposition. For example, climate predictions for the northeastern United States anticipate increased precipitation amounts and increased temperature, which may in turn drive increases in mercury deposition. This forecast underscores the importance of further reduction of anthropogenic mercury emissions in order to address the potential influence climate change may have on mercury deposition.

27

Different environmental factors cause different spatial patterns in wet and dry deposition.

2 What Risks Does Mercury Pollution Pose in New York State?

The extent and magnitude of the impact of mercury on fish and wildlife in New York State is much greater than previously recognized. Mercury concentrations exceed human and ecological risk thresholds in many areas, including inland waters and marine coastal areas.

at a glance

1. Mercury pollution is ubiquitous across New York State. Elevated mercury concentrations have been detected in many animal groups (e.g., fish, birds, mammals), and across many different habitat types (e.g., marine coastal areas, lakes, wetlands, streams, forests) throughout the State.
2. Food webs in both aquatic (zooplankton to small fish to larger fish) and terrestrial (beetles to spiders to songbirds) ecosystems have the ability to biomagnify methylmercury to levels of concern for piscivorous and invertivorous wildlife.
3. During recent decades, research on the toxicological impacts of mercury pollution has demonstrated that adverse effects on fish and wildlife occur at lower mercury concentrations than previously reported.
4. A screening analysis for mercury using currently accepted thresholds (Table 3) illustrates that risks to fish, wildlife, and people who consume fish can be substantial, specifically:
   - Average mercury concentrations in fish species commonly consumed exceeded human health criterion (0.22 ppm, ww) used by the Great Lakes Commission for: 9 of 15 (60 percent) game fish for the Great Lakes; 11 of 15 (73 percent) for inland lakes and rivers; and 5 of 15 species (33 percent) in nearshore marine areas (Table 2, Figure 14);
   - Average mercury concentrations in six top predator fish exceeded the adverse effects threshold for fish reproductive success (set at 0.30 ppm, ww of total mercury measured as whole body); and
   - Wildlife have exceeded known thresholds for reproductive harm in the Adirondack Mountains (Common Loons and Palm Warblers), Catskill Mountains (Bald Eagles), Long Island Sound (Saltmarsh and Seaside Sparrows), and statewide (bats, river otter, and mink).

Biomagnification of Mercury and Its Toxicity

Mercury in its organic form, methylmercury, is classified as a persistent bioaccumulative toxin. Once ingested, methylmercury can bioaccumulate over time, especially when intake exceeds the physiological abilities of animals to either demethylate (e.g., in the liver or kidney) or depurate (e.g., release through feathers and fur).

Trophic Levels and Biomagnification

Methylmercury that bioaccumulates within individuals can pass from prey to predator, becoming more concentrated as it moves through trophic levels of the food web—a process called biomagnification.

Due to biomagnification, even small quantities of methylmercury in water can result in concentrations that are up to 10 million times higher in upper trophic level species. Each trophic level or step generally results in an increase of methylmercury of an order of magnitude. In freshwater aquatic and marine ecosystems, organisms in trophic level 4 and 5 are optimal bioindicators for mercury monitoring programs (Figure 13).

Human Risk

Populations most at risk of methylmercury exposure include: (1) sensitive individuals (e.g., women of childbearing age, pregnant women, and children); and (2) people whose diets include large amounts of high trophic level fish (e.g., recreational anglers and subsistence fish consumers).

The greatest risk to humans from the dietary uptake of methylmercury increases with increased consumption of higher trophic level species. For example, primary consumers (e.g., shellfish such as mussels) at trophic level 2 have relatively low methylmercury concentrations and are considered safe for consumption. Secondary consumers (e.g., salmon, herring) are a trophic step higher, but still remain safe to eat.

Biomagnification is an important process in creating risk.

For tertiary consumers in trophic level 4, which include predatory fish (e.g., bass, tuna), methylmercury concentrations can be elevated to levels that cause health concerns for humans. The variability of concentrations in trophic level 4 fish can be related to size and species—young yellowfin tuna (in canned tuna) are safe to eat, but larger and older fish, such as Pacific bluefin tuna (used for tuna steaks) are not as safe.

Therefore, large trophic level 4 and 5 fish are the best bioindicators to monitor for human and ecosystem health. Trophic level 5 animals have the highest body burdens of methylmercury.

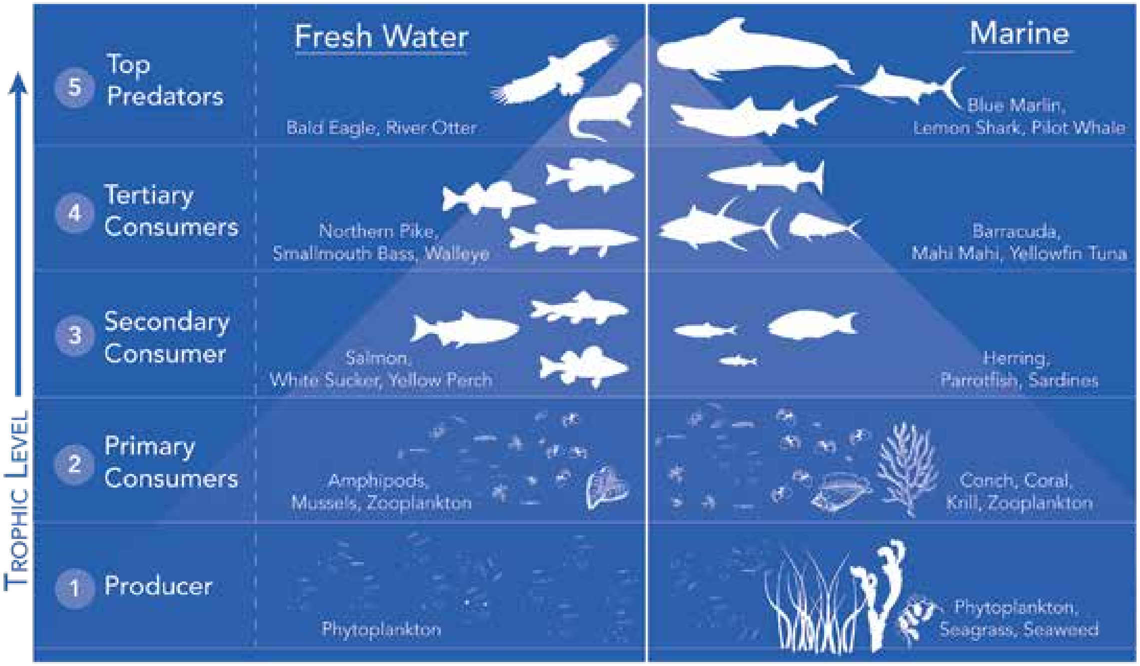


Figure 13: Trophic levels are the feeding positions within the food web and are an important metric to track and understand human and ecological health concerns of methylmercury in biota. Concerns are greatest at trophic levels 4 and 5.

Mercury Exposure: Risks to Humans

The common pathway for human exposure to methylmercury is through the consumption of contaminated fish.

New York State DOH Fish Consumption Advisories

Fish consumption advisories are issued by the New York State DOH and are based on a risk management approach and guidelines. If there is no specific advice for a waterbody, a general statewide advisory that recommends limiting sport fish consumption to up to four meals per month applies (because fish from all waters have not been tested, and fish may contain contaminants other than those that are routinely tested).

In most cases, if a water body has a specific consumption advisory for the general population (men and older women), the sensitive population (women under 50 and children under 15) are advised not to eat any fish from that water body.

Women under 50 and children under 15 are also advised to avoid consuming predator fish species from all water bodies in the high mercury regions of the Catskills and Adirondacks.

For more information:

www.health.ny.gov/environmental/outdoors/fish/health_advisories/background.htm

Mercury concentrations in 15 species of fish in different aquatic systems in the State are shown in Figure 14. The summary below lists average fish fillet mercury concentrations in frequently consumed fish species that are above the GLC guideline of 0.22 ppm (Table 2):

- Inland waters (rivers and lakes) 11 out of 15 species (73 percent).
- Great Lakes (Ontario and Erie) 9 out of 15 species (60 percent).
- Nearshore marine waters 5 out of 15 species (33 percent).

Interpreting Mercury Concentrations and Risks of Exposure

Mercury concentrations are interpreted in the context of the number of fish meals that could be consumed to stay within the US EPA health-based reference dose for methylmercury (see Table 2 for the fish meal limits by methylmercury concentration and US EPA 2001 for details on how meal limits were calculated). For further reference, the World Health Organization (WHO) and the European Commission (EC) general guidance level for fish mercury concentrations is 0.5 ppm with an "exemption" for larger, predatory fish species (e.g., swordfish, shark, some tuna species) of up to 1.0 ppm, which is used for the "no consumption" level by New York State DOH for sensitive populations.

Table 2: Fish mercury concentrations and meal frequency guidelines.

Guideline or Criterion by Agency/Entity[1]	Mercury in Fish (ppm wet weight)	Fish Consumption Guideline
New York State Department of Health	<1.0 ppm: general and sensitive population	4 meals per month
	≥1.0 – <2.0 ppm: sensitive population	No consumption
	≥1.0 – <2.0 ppm: general population	1 meal per month
	>2.0 ppm: general and sensitive populations	No consumption
Great Lakes Consortium for Fish Consumption Advisories (for both sensitive and general populations)	0 – ≤0.05	Unrestricted
	>0.05 – ≤0.11	2 meals per week
	>0.11 – ≤0.22	1 meal per week
	>0.22 – ≤0.95	1 meal per month
	>0.95	No consumption

[1]Overall guidance is based on the US EPA reference dose of 1×10^{-4} mg of Hg/kg of body weight/day, a body weight of 132 pounds (60 kg) for an adult female person, and a fish meal size of about 6 ounces (170 gm). These guidelines, with further interpretation by the Great Lakes Consortium for Fish Consumption Advisories (GLC; Great Lakes Fish Advisory Workgroup. 2007), are based on 95% of the muscle Hg concentrations being in the methyl form.

Mercury in Fish Species in New York State Waters

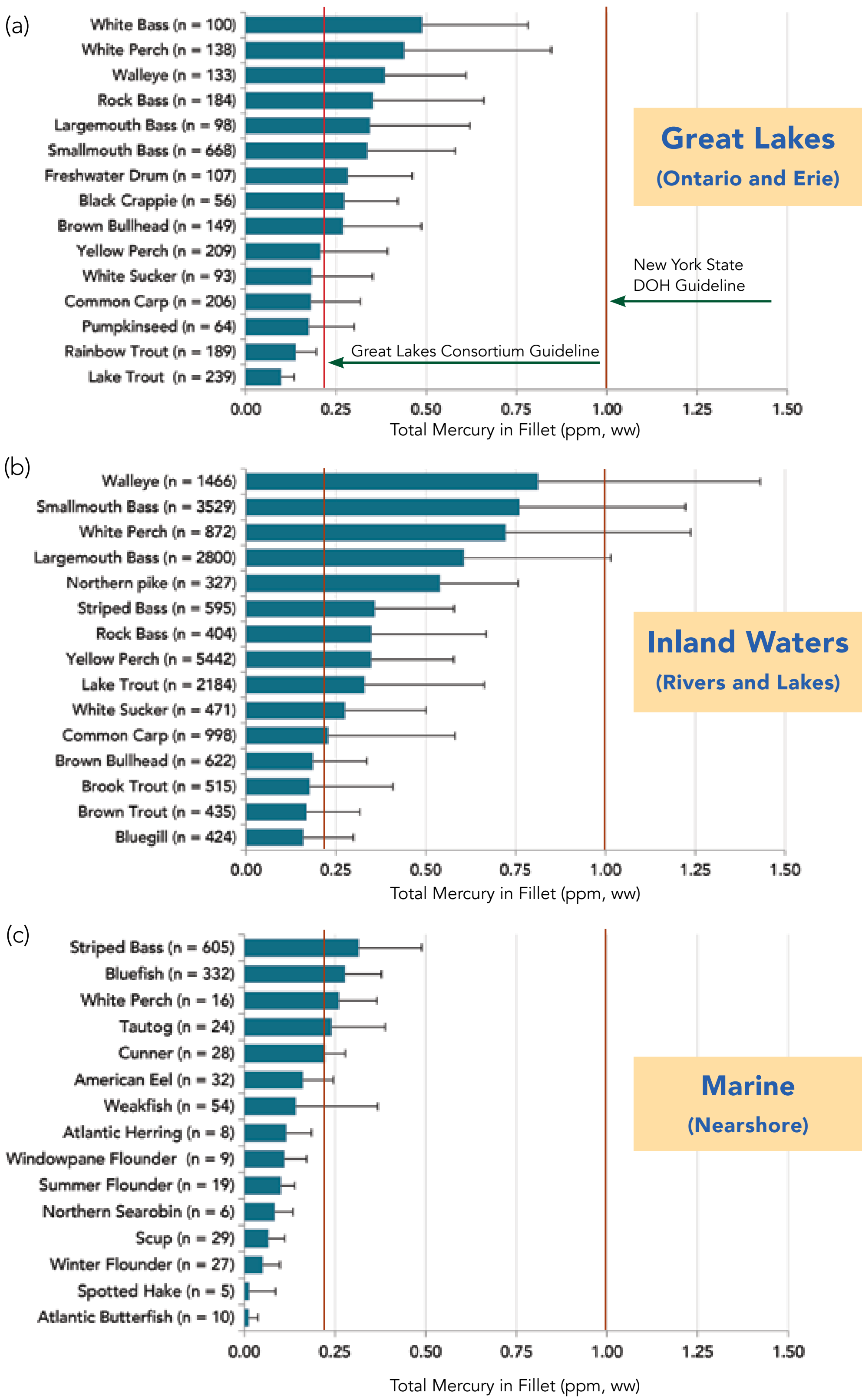


Figure 14: Each bar chart displays the mean and standard deviation of fillet mercury concentration on a wet weight (ww) basis collected from 2000 to 2017 from inland water bodies, the two Great Lakes that border New York, and nearshore marine waters. Samples were collected by a variety of State and other fish monitoring programs (39,110 fish samples from inland water bodies, 6,572 from the Great Lakes, and 1,272 from nearshore marine). Species shown are regularly consumed by humans in the region. See Table 2 for consumption guidelines.

6 10 12 17

Mercury Exposure: Risks to Fish and Wildlife

Since the 1970s, mercury (as methylmercury) exposure has been documented for 101 fish, 126 bird, and 25 mammal species across New York State. Understanding how mercury exposure varies relative to time, space, different taxa, and tissue types is critical for interpreting risks. Risks are generally assessed by applying known thresholds, which are relative to various endpoints (Table 3).

Choice of bioindicators is guided by habitat availability, species' range, and the health of local breeding populations. Statewide exposure is assessed using multiple bioindicators that represent major taxonomic groups (e.g., fish, birds, mammals) and foraging guilds (e.g., piscivores, invertivores); this is a typical approach used by recent NYSERDA-funded projects.

Fish

The impacts of methylmercury on fish are not as well understood as they are for birds and mammals. Yet, understanding methylmercury exposure and risks to fish is critical to identifying impacts to ecosystem health and human recreational opportunities. Sandheinrich and Wiener (2011) concluded that damage to cells and tissues and reduced reproduction begin to occur at concentrations of approximately 0.5 ppm, ww in muscle (>90 percent of mercury in muscle is methylmercury). Dillon et al. (2010) estimated a LOAEL of about 0.3 ppm, ww in the whole body of fish (equivalent to 0.5 ppm, ww in the muscle). Depew et al. (2013) found that dietary uptake of 0.04 ppm, ww of fish significantly reduced reproductive success in predatory fish species. While further studies may identify variations in methylmercury impacts across fish species, these generic thresholds for dietary uptake of mercury (0.04 ppm, ww) and body burdens (0.30 ppm, ww) provide interpretive guidance (Table 3).

Commonly sampled fish species in New York State include: white perch, walleye, smallmouth bass, and lake trout in the Great Lakes; northern pike and yellow perch in the Adirondack Mountains; largemouth bass, rainbow trout, and brown trout in the Catskill Mountains; and striped bass and bluefish in nearshore marine areas (Figure 15).

Birds

More species of birds have been sampled to assess mercury exposure in New York State than any other taxa. Thresholds have been developed for two major terrestrial avian foraging guilds (piscivores and invertivores) using blood and feather tissues. Thresholds are established between tissue mercury concentrations and effect endpoints such as reproductive success (Table 3).

Commonly sampled bird species in New York State, by region, include: Herring Gull in the Great Lakes; Common Loon, Palm Warbler, and Bicknell's Thrush in the Adirondack Mountains; Bald Eagle and Hermit Thrush in the Catskill Mountains; and Saltmarsh Sparrow, Red-eyed Vireo, and Osprey on Long Island (Figure 15).

Mammals

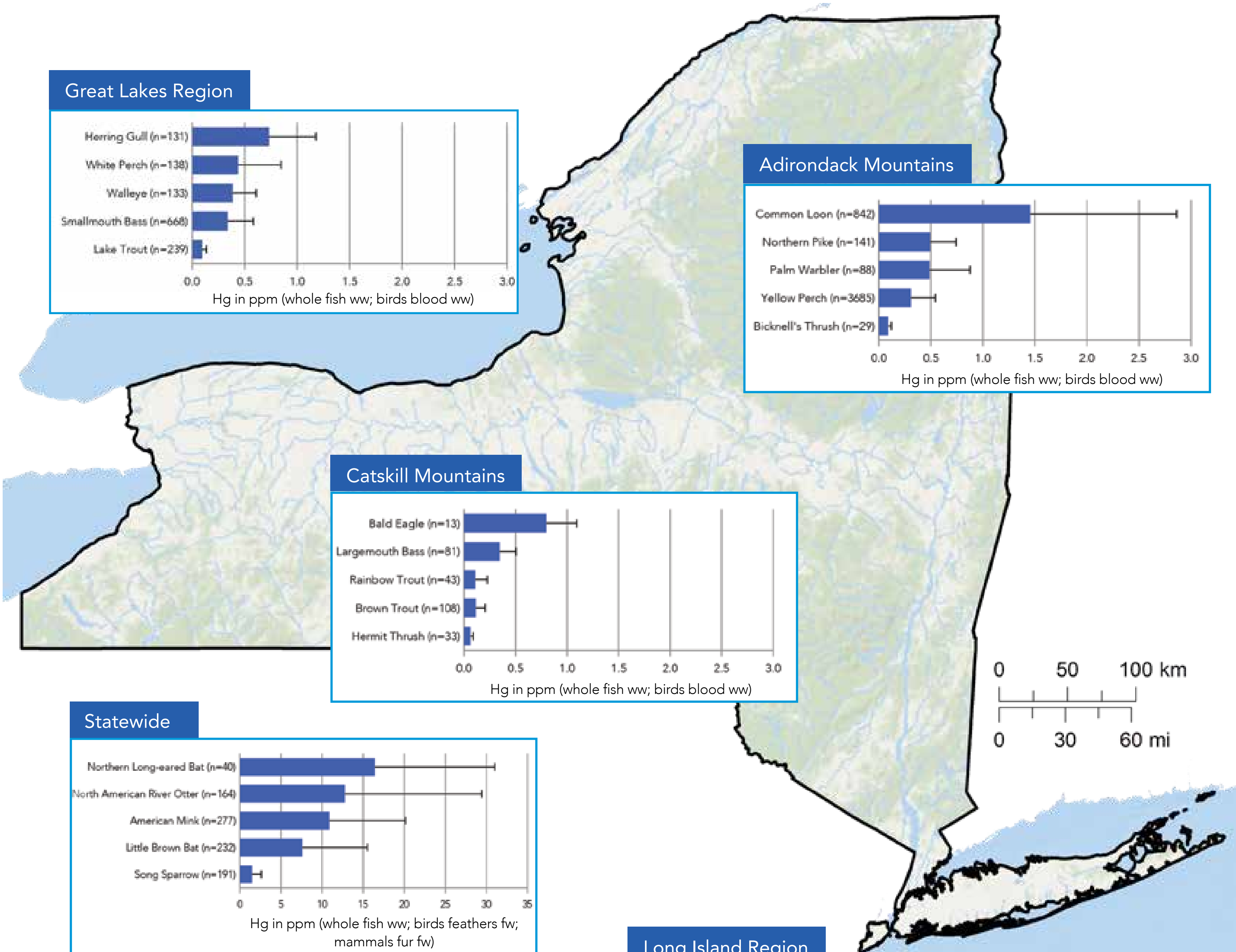
Mercury thresholds are known for both piscivore (river otter and mink) and invertivore (bats) mammals, and are linked with significant biochemical changes in the brain (Basu et al. 2005, Nam et al. 2012; Table 3). Mercury exposure to these and other mammal species is elevated in the State, but more sampling is needed to gauge the extent and magnitude of risk. Preliminary statewide risk assessments are available (Figure 15).

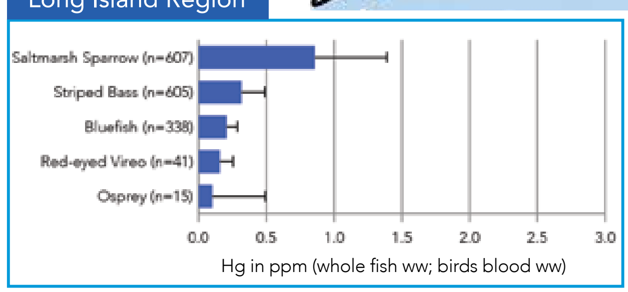
Table 3: Mercury effects on taxonomic groups

One of the most useful interpretive endpoints for ecological effects of mercury is reproductive success, as it is meaningful and scalable. For example, in the Common Loon, a 10% reduction in fledged chicks per territorial pair occurs with blood mercury concentrations at 1.5 ppm, 20% at 2.0 ppm, 30% at 2.5 ppm, and a significant population level impact of 40% at 3.0 ppm (Evers 2018). The thresholds to avian invertivores are lower for reproductive loss than avian piscivores. To assess risk to mammals, a LOAEL based on fur is used: for bats (10 ppm, fw), mink (35 ppm, fw) and river otter (45 ppm, fw; Evers 2018).

Taxonomic Group	Tissue Type	Effect	MeHg Exposure	Threshold (ppm)
All Fish	Whole (ppm, ww)	significant reproductive success	diet	0.04
			body burden	0.30
Avian Piscivore Bioindicators: Common Loon; Bald Eagle	Blood (ppm, ww)	fewer fledged young	body burden	1.5 (10%) 2.0 (20%) 2.5 (30%) 3.0 (40%)
Avian Invertivore Bioindicators: Carolina Wren	Blood (ppm, ww)	lowered nesting	body burden	0.7 (10%) 1.2 (20%) 1.7 (30%) 2.2 (40%)
Mammal Piscivore Bioindicators: Mink/River Otter	Fur (ppm, fw)	brain biochemical changes	body burden	35.0
Mammal Invertivore Bioindicators: Bats	Fur (ppm, fw)	brain biochemical changes	body burden	10.0

Mercury Levels in Selected Bioindicators by Region





Field researchers collect blood and tissue samples for toxicology assessment.

Figure 15. In New York State, bioindicators that include a mix of targeted fish, birds, and mammal species are important to characterize potential risk. High trophic level species (levels 4-5; see page 15) are best used to determine potential risk.

Lake George, Adirondack Mountains

3 Where Are Mercury Levels Highest in New York State?

The Adirondack and Catskill regions of New York State are particularly sensitive to mercury pollution. The impact of mercury emissions and deposition is exacerbated by watershed and lake characteristics in areas with abundant forests and wetlands—areas that enhance mercury inputs, transport, methylation, and uptake to elevated concentrations in aquatic food webs.

at a glance

1. The forests in the Adirondack and Catskill Mountains receive higher dry deposition of mercury and include landscape features and biochemical conditions that cause these areas to be sensitive to mercury inputs.
2. Consistent with broad geographic patterns of fish mercury concentrations in New York State, areas of high mercury concentrations in fish are positively correlated with wetlands in the Adirondacks and with reservoirs in the Catskill Mountains.
3. Largemouth and smallmouth bass sampled from water bodies in New York State show highest mercury concentrations in the northeastern highlands (Adirondack and Catskill Mountains).
4. Mercury concentrations in walleye and largemouth bass are 53 and 32 percent lower, respectively, in the Great Lakes than in nearby inland lakes, which may reflect differences in the food web structure, land-water linkages, and methylation potential.
5. Avian piscivores have elevated levels of mercury exposure in the Adirondack (Common Loons) and Catskill (Bald Eagles) Mountains that may reduce reproductive success.
6. Avian invertivores have elevated levels of mercury exposure in the Adirondack Mountains (Palm Warbler), Long Island Sound (Saltmarsh Sparrow), and the Montezuma wetland complexes in central New York (Marsh Wren) that may reduce reproductive success.

Bald Eagle

Mercury Sensitive Areas in New York State

The Adirondack and Catskill Mountains are biological mercury hotspots, areas where mercury inputs from atmospheric emissions and deposition are readily transported, converted to methylmercury, and biomagnified through food webs. The mercury sensitivity of an area is determined by characteristics that influence the inputs, transport, and bioavailability (i.e., methylation trophic transfer) of mercury in aquatic food webs (Figure 16).

The Adirondacks and Catskills feature extensive high elevation forests, which enhance mercury dry deposition from throughfall and litterfall and limit evasion losses. The Adirondacks also contain abundant wetlands—sites conducive to methylmercury production—and provide sources of methylmercury for surface waters located down gradient (Branfireun et al. 2005, Brigham et al. 2009). Concentrations of methylmercury are typically elevated in fish and wildlife inhabiting lower-pH waters (Wiener et al. 2003, Burgess and Meyer 2008)—areas abundant and widespread in these parts of New York State (Eilers et al. 1988, Clair et al. 1995).

Mercury Cycling in Sensitive Watersheds

In New York State, mercury-sensitive areas with abundant forests receive elevated mercury inputs in throughfall and litterfall from atmospheric emissions and dry deposition to the forest canopy. New York State and much of the Great Lakes basin is a net sink for mercury inputs (Denkenberger et al. 2012) with more mercury entering the basin through emissions and deposition than leaving through re-emission to the atmosphere or drainage losses. As a result, mercury deposited to the region accumulates in soils, some of which will gradually leach to surface waters. Also note that mercury recently deposited to the landscape tends to be more bioavailable than mercury long buried in soils and sediments. Mercury in soils can be mobilized rapidly by disturbances, such as floods and fires, for centuries to come.

Hotspots are areas where mercury is more readily converted to methylmercury and biomagnified through food webs.

A fraction of the mercury deposited to sensitive landscapes is converted to methylmercury in wetlands, sediments, and other favorable environments. This conversion process is amplified under conditions of high organic matter, low oxygen, low pH, and high sulfate concentrations that are common in northern forest landscapes.

In addition to differences in watershed sensitivity throughout the region, there are climatic differences within the region that could affect spatial patterns of fish mercury concentrations. Many studies report that slower growth rates allow bioaccumulation of methylmercury in fish (e.g., Harris and Bodaly 1998; Simoneau et al. 2005). Fish growth rates tend to be lower in cooler waters, and because water temperatures tend to decrease with latitude (Jobling 1981), mercury concentrations are negatively correlated to latitude in gamefish bioindicators such as largemouth bass and walleye (Helser and Lai 2004, Simoneau et al. 2005).

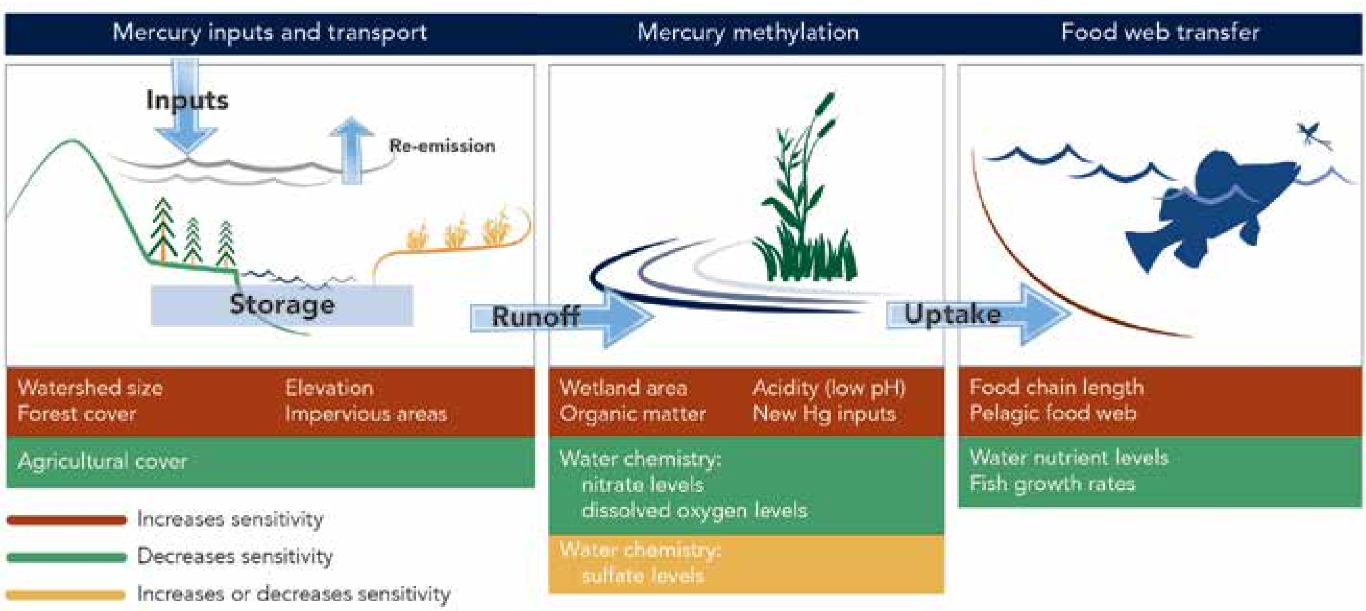


Figure 16. Watershed mercury sensitivity connects landscape features related to mercury input and transport, methylation potential, and food web transfer.

4 13 16 19 23 25

Spatial Patterns: Fish Mercury Levels across New York State

All Fish Species

Fish are some of the best bioindicators of mercury inputs and sensitivity (Figure 17) and can be used to address multiple questions and needs:

- Young fish (<1 year) reflect rapid changes in the availability of methylmercury and local conditions;
- Mid-sized fish are important for assessing impacts to fish-eating wildlife such as Common Loons, Bald Eagles, Osprey, and river otter; while
- Large fish that are at high trophic levels (i.e., gamefish) are of particular concern for human health.

The impacts on fish health and reproductive welfare are not well established, but those data that are available have been compiled and published (Depew et al. 2012b). While fish mercury concentrations are commonly examined for their impacts on humans (i.e., muscle tissue) or for wildlife exposure (i.e., whole body), the methylmercury concentrations in fish tissues also impact behavior, reproduction, and overall health.

The impacts of mercury exposure on fish health and reproductive success are not well established.

Fish that feed on other fish with mercury levels greater than 0.04 ppm, ww exhibit impaired reproductive success (Depew et al. 2012b), and fish with body burdens of 0.30 ppm, ww or higher have reduced reproductive success (Scheuhammer et al. 2015). Lower reproductive success reduces the size of healthy fish populations, which can have adverse impacts on associated populations of piscivores and human recreational and commercial interests.

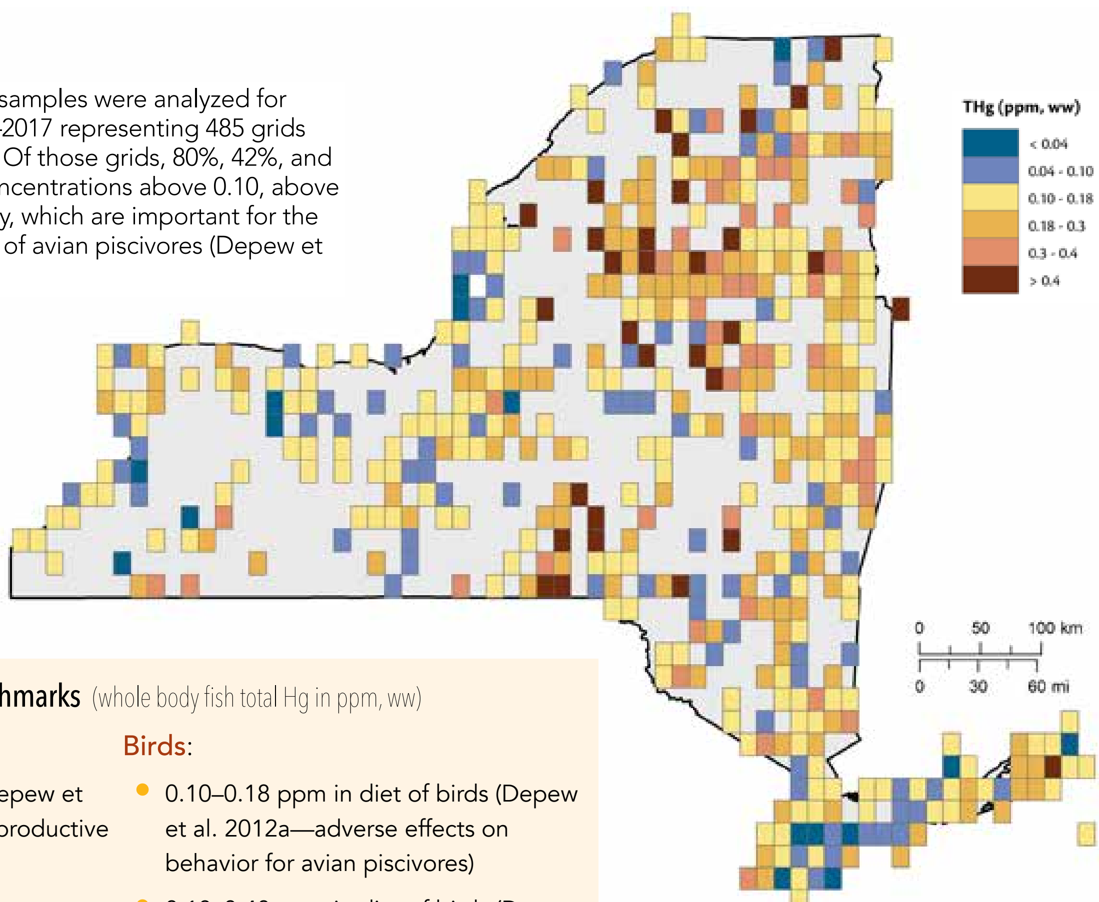


Figure 17. A total of 33,502 fish samples were analyzed for mercury in New York from 1969–2017 representing 485 grids for the State (47% represented). Of those grids, 80%, 42%, and 6% had average fish mercury concentrations above 0.10, above 0.18 and above 0.40, respectively, which are important for the health and reproductive welfare of avian piscivores (Depew et al. 2012a).

7 12 16 18

Screening Benchmarks (whole body fish total Hg in ppm, ww)

Fish:

- >0.04 ppm in diet of fish (Depew et al. 2012b—effects to fish reproductive success)
- >0.30 ppm in diet of fish (Scheuhammer et al. 2015—reduces reproductive success in fish)

Birds:

- 0.10–0.18 ppm in diet of birds (Depew et al. 2012a—adverse effects on behavior for avian piscivores)
- 0.18–0.40 ppm in diet of birds (Depew et al. 2012a—significant reproductive impairment for avian piscivores)
- >0.40 ppm in diet of birds (Depew et al. 2012a—reproductive failure for avian piscivores)

Game Fish Species

Game fish are predatory fish that tend to be at high trophic levels (i.e., trophic levels 4 or 5—see page 15) and therefore represent the biomagnification extensions of methylmercury. Human consumption of game fish in New York State usually includes species such as: walleye from Lakes Erie and Ontario; smallmouth and largemouth bass from inland lakes and rivers; and bluefish and striped bass from nearshore marine areas (Figure 18).

Fishing is a popular sport for all ages.

Long-term mercury monitoring of freshwater fish is common for many places in the United States, including New York State. Such efforts allow for spatial and temporal changes to be observed and compared across regions (Kamman et al. 2005, Monson et al. 2011, Eagles-Smith et al. 2016b).

Monitoring of selected game fish in the Great Lakes is another long-term effort that is important for tracking species' mercury concentrations, such as walleye, which average higher in Lake Ontario compared to Lake Erie. Zhou et al. (2017) found decreasing mercury trends in lake trout and walleye across the Great Lakes for the past four decades, except in the past decade when increases were observed in Lake Erie and Lake Ontario. Long-term tracking is also conducted in nearshore marine areas around Long Island, where 67 percent of the 15 fish species sampled average over 0.22 ppm.

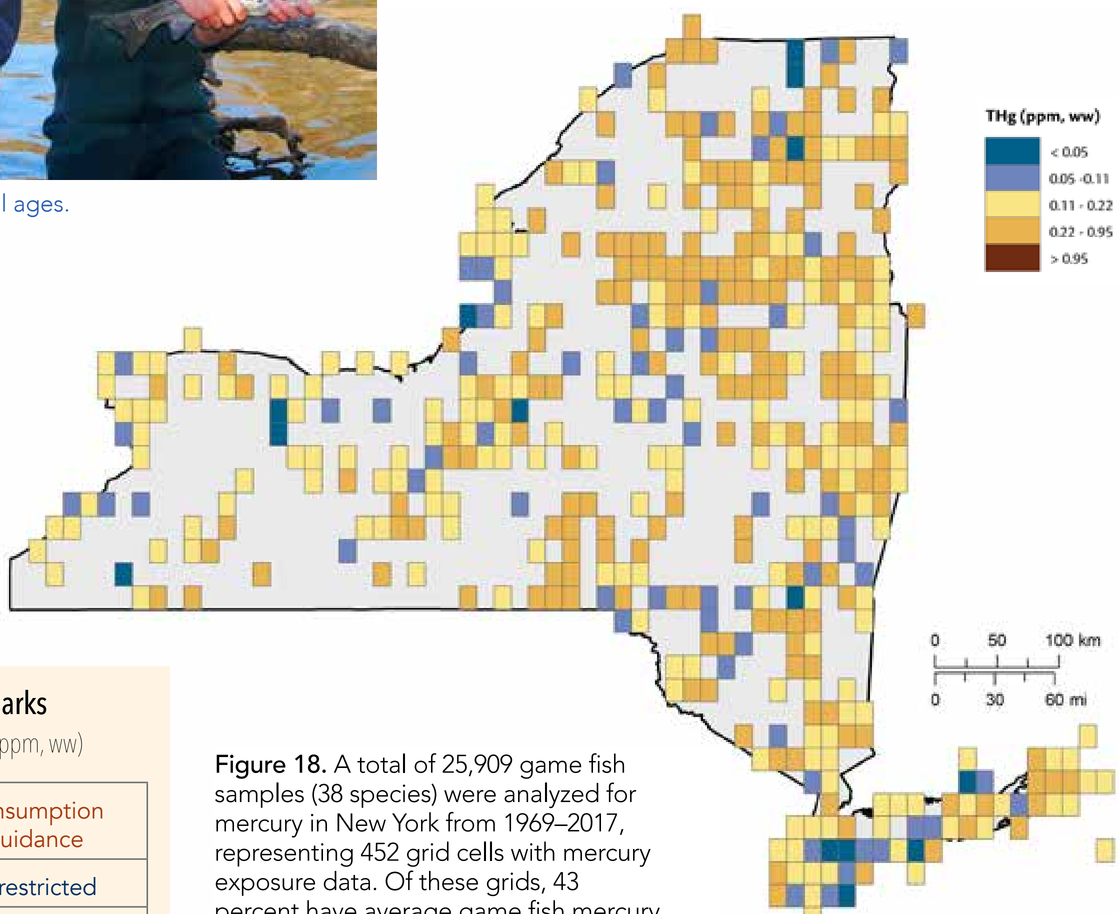


Figure 18. A total of 25,909 game fish samples (38 species) were analyzed for mercury in New York from 1969–2017, representing 452 grid cells with mercury exposure data. Of these grids, 43 percent have average game fish mercury concentrations over 0.22 ppm, with the Adirondack and Catskill Mountain regions and upper Susquehanna River Valley regularly having grids with elevated game fish mercury concentrations.

Screening Benchmarks

(whole body fish total Hg in ppm, ww)

Total Hg Concentrations	Consumption Guidance
≤ 0.05	Unrestricted
0.05-0.11	2 meals per week
0.11-0.22	1 meal per week
0.22-0.95	1 meal per month
> 0.95	No Consumption

Source: Great Lakes Consortium

Spatial Patterns: Avian Mercury Levels across New York State

Bald Eagles inhabit a variety of aquatic ecosystems (e.g., the Great Lakes, inland lakes, rivers, and nearshore marine), and often forage on high trophic level prey. Characteristics of high trophic level feeding habits and diverse habitat preferences for nesting make these raptors good contaminant bioindicators throughout New York State.

Avian Piscivores

Birds that regularly forage on fish (piscivores) are often at risk from environmental mercury loads. In New York State, larger avian piscivores (e.g., Common Loon, Bald Eagle, Osprey) tend to have greater mercury body burdens than smaller avian piscivores (e.g., Common Merganser, Belted Kingfisher, Roseate Tern).

The highest risk recorded in New York State were for some Common Loons in the Adirondack Mountains, and for Bald Eagles foraging in the Catskill Mountains and major rivers (e.g., Saint Lawrence, Hudson, Allegheny, and Susquehanna Rivers; Figure 19).

5 22

Fish-eating birds are important bioindicators for mercury contamination in aquatic ecosystems.

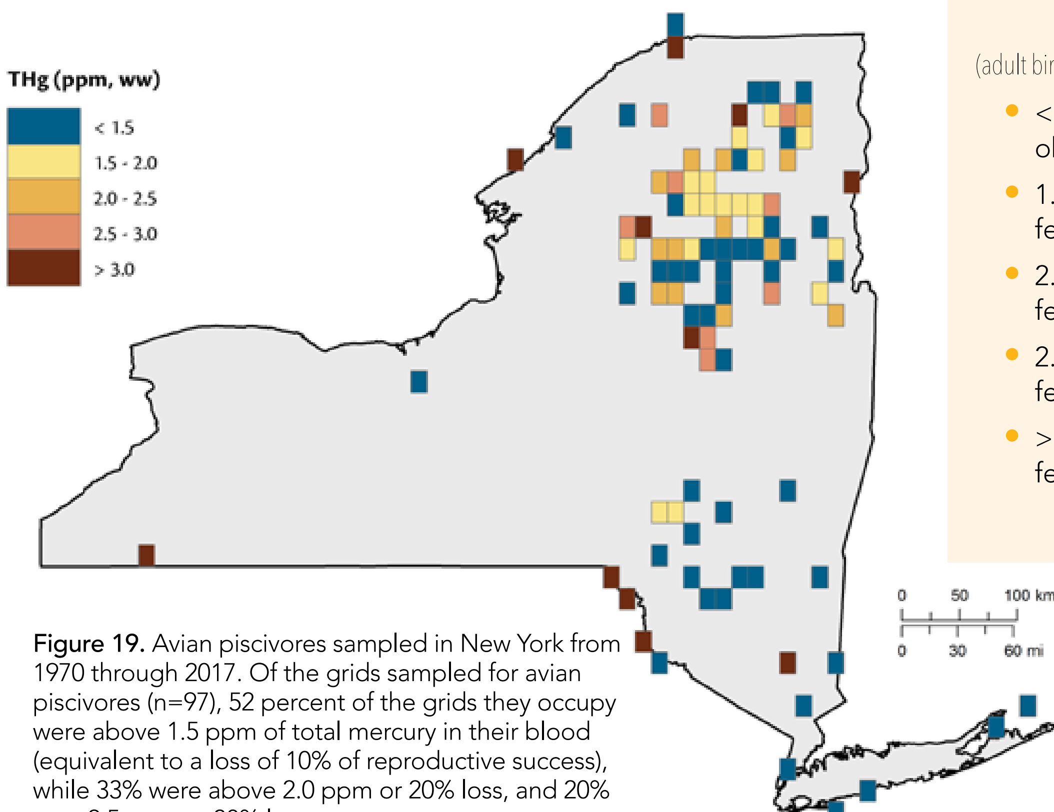


Figure 19. Avian piscivores sampled in New York from 1970 through 2017. Of the grids sampled for avian piscivores (n=97), 52 percent of the grids they occupy were above 1.5 ppm of total mercury in their blood (equivalent to a loss of 10% of reproductive success), while 33% were above 2.0 ppm or 20% loss, and 20% over 2.5 ppm or 30% loss.

Screening Benchmarks

Avian Piscivores*

(adult bird blood in Total Hg ppm, ww)

- <1.5 ppm—no observed effect level
- 1.5–2.0 ppm—10% fewer fledged young
- 2.0–2.5 ppm—20% fewer fledged young
- 2.5–3.0 ppm—30% fewer fledged young
- >3.0 ppm—>40% fewer fledged young

*Evers 2018

Avian Invertivores

Methylmercury from aquatic ecosystems can enter terrestrial food webs via predatory invertebrates, such as dragonflies and spiders. Consumers of these species include avian invertivores, which have been identified as species of concern due to methylmercury exposure (Evers et al. 2005, Jackson et al. 2011, 2015).

NYSERDA-funded sampling efforts in New York State over the past eight years have resulted in mercury data for target species that include flycatchers, warblers, wrens, sparrows, and blackbirds (Figure 20).

Songbirds that are sensitive to mercury exposure were identified in every region of New York.

The highest risk data recorded in the State included: individual Saltmarsh and Seaside Sparrows in the estuaries of Long Island; Palm Warblers and Yellow-rumped Warblers in the Adirondack Mountains; and Swamp Sparrows and Eastern Towhees in the Catskill Mountains. Mercury body burdens for these species may cause adverse reproductive impacts at a scale of concern.

11 20

Palm Warblers occupy particularly sensitive ecosystems, such as bogs, where conditions are favorable for high rates of methylation.

Wetland size dictates methylmercury concentrations. In small wetlands, prey items reflect methylmercury concentrations from a combination of wetland and terrestrial habitats where methylation production is far lower. In large wetlands, prey are weighted more heavily toward wetland-produced invertebrates (i.e., prey with high methylmercury concentrations).

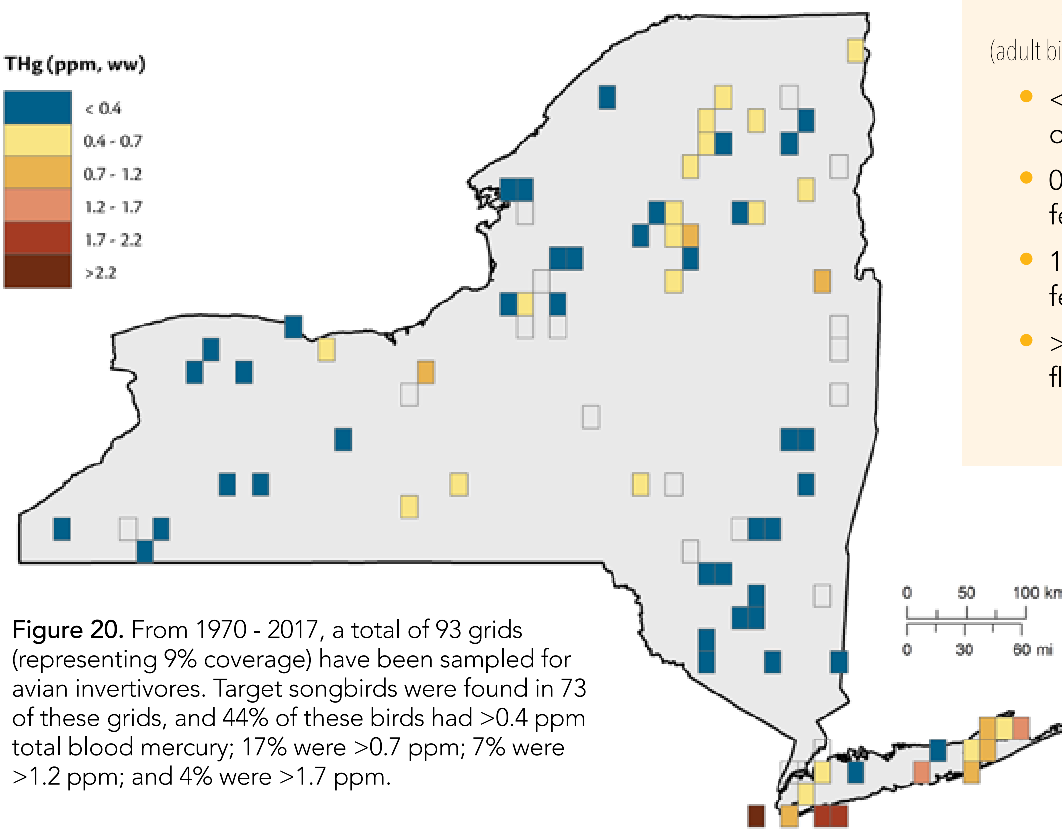


Figure 20. From 1970 - 2017, a total of 93 grids (representing 9% coverage) have been sampled for avian invertivores. Target songbirds were found in 73 of these grids, and 44% of these birds had >0.4 ppm total blood mercury; 17% were >0.7 ppm; 7% were >1.2 ppm; and 4% were >1.7 ppm.

Screening Benchmarks
Avian Invertivores*

(adult bird blood in Total Hg ppm, ww)

- <0.40 ppm—no observed effect level
- 0.7-1.2 ppm—10% fewer fledged young
- 1.2–1.7 ppm—20% fewer fledged young
- >1.7 ppm—30% fewer fledged young

*Evers 2018

Common Loons

4 How Is Mercury Contamination Changing over Time in New York State?

Mercury concentrations in biota of New York State have declined or remained the same over the last four decades, concurrent with decreased air emissions from regional and U.S. sources. After initial declines, however, concentrations of mercury in some fishes and birds from certain locations have increased in recent years, revealing the complexities of trajectories of mercury recovery.

at a glance

1. Sediment cores from inland lakes within the Great Lakes region indicate that declines in local and regional mercury emissions have decreased mercury delivery to inland lakes across the Great Lakes region by about 20 percent since the mid-1980s.
2. Mercury concentrations showed significant downward trends in several species (e.g., largemouth bass, yellow perch) that had 40-50 years of sampling in an ecoregion. Species in the Eastern Great Lake Lowlands, in particular, showed downward trends since the 1970s (pages 28-29).
3. The majority of well-studied species, including all avian piscivores, in New York State did not exhibit significant ecoregion-level declines. In certain areas within New York State, mercury concentrations in some fish and wildlife species have been trending upward—for example, northern pike in the Northeastern Highlands and Red-eyed Vireo in the Atlantic Coastal Pine Barrens (pages 28-29).
4. The challenge of interpreting patterns and change in mercury contamination and methylmercury in fish and wildlife underscores the need for comprehensive mercury monitoring at multiregional or national scales and over decadal time scales.

Walleye

Mercury Changes over Time

Ecosystem response to changes in deposition and releases of mercury are challenging to monitor. While datasets are gathered over time and are useful for analyzing temporal trends, they are often disparate because the objectives underlying their collection vary by study and program. NYSERDA is now playing a lead role in designing long-term mercury monitoring programs that can produce standardized and comparable data that objectively reflect the state of mercury loads in aquatic and terrestrial environments. Representative matrices include air, water, invertebrates, fish (both river and lake taxa), and birds (both invertivores and piscivores).

Atmospheric Deposition

Atmospheric mercury deposition is measured by the National Atmospheric Deposition Program's Mercury Deposition Network. From one to six stations have tracked mercury deposition and concentrations since 2000, representing multiple areas of New York State. Annual volume-weighted concentrations of mercury in wet deposition varies from 4 to nearly 12 μg/m^2, and many of the collecting stations exhibit an

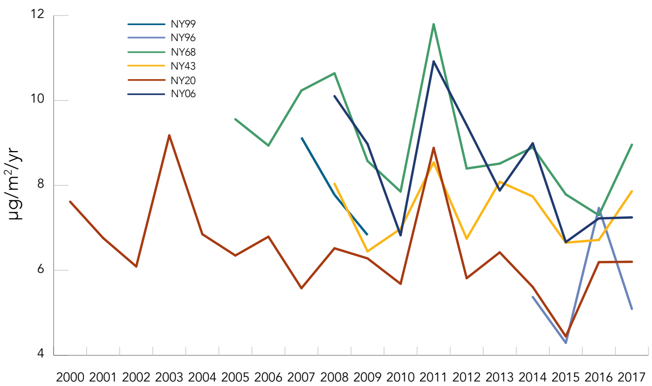


Figure 21. Changes through time in annual wet mercury deposition (μg/m^2/yr) at six sites in New York State, five of which are active today (NADP 2019).

overall declining trend (Figure 21). Litter mercury is also measured at Huntington Forest in the Adirondacks and at Biscuit Brook in the Catskills.

Birds

Because there is not a direct relationship between atmospheric mercury deposition and biotic uptake, mercury monitoring efforts in biota is of ongoing importance. Multiple bioindicators are needed to confidently track changes. For some biota, such as songbirds, long-term trends in mercury exposure can be tracked with museum specimens and compared with recent sampling.

There is strong evidence that long-term trends in environmental mercury loads and subsequent effects have increased significantly since the mid-1800s (Figure 22). To understand mercury trends it is necessary to develop long-term datasets (see pages 30-31).

5 8 15

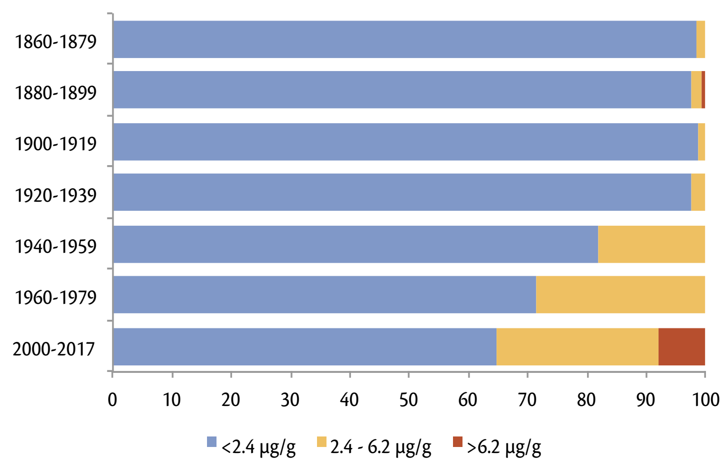


Figure 22. Percentage of individual songbirds from seven species (Northern Waterthrush, Olive-sided Flycatcher, Palm Warbler, Red-eyed Vireo, Rusty Blackbird, Saltmarsh Sparrow, Wood Thrush; n=838) analyzed from museum specimens with feather Hg concentrations falling within risk categories for adverse effects of MeHg exposure. Risk categories based on body feather concentrations: 1) <2.4 μg/g, low risk; 2) 2.4 to 6.2 μg/g, moderate risk; 3) >6.2 μg/g, high risk, adapted from Jackson et al. (2011) .

15

> *A monitoring network would help policymakers, the EPA, scientists, physicians, and the public to better understand the sources, consequences, and trends in mercury pollution in the United States.*
>
> *Senator Susan Collins, Co-author*
> *Comprehensive National Mercury Monitoring Act*

Tracking Mercury across Ecoregions

Across the nine ecoregions of New York State, landscapes exhibit varying abilities to transport and methylate atmospheric mercury deposition. Although the amount of mercury deposited across the State is relatively uniform, the sensitivity of the ecosystems to mercury deposition varies with landscape attributes.

Variables that may play a role in ecosystem mercury sensitivity include: physical (e.g., elevation, topography of catchment); hydrological (e.g., water level fluctuations affecting wet-dry cycles); chemical (e.g., pH, sulfur concentrations); ecological (e.g., forest versus agriculture); and biological (e.g., food web biomagnification).

Because standard bioindicators are challenging to identify statewide and across many of the ecoregions, choice of bioindicators by ecoregion is important for proper tracking and interpretation.

Figure 23 highlights examples of fish and bird bioindicators for three of New York State's ecoregions. For the three fish species, more than 50 years of mercury data are available, and are especially robust for the yellow perch and largemouth bass, where there are statistically significant declines. The increasing mercury levels in the northern pike are counter to other fish trends and may be related to inadequate sample size.

For birds, the temporal data set varies from six to more than 20 years. The Common Loon data shows a slight increase in mercury concentrations. The Red-eyed Vireo sampled in Long Island's forests shows an increasing trend, yet in nearby estuaries, the Saltmarsh Sparrow shows a declining trend.

Ultimately, ecoregions may respond differently to changes in environmental mercury loads, as will taxa. Therefore, it is important to use fish and bird bioindicators for multiple ecoregions to understand and track the availability of methylmercury across New York State.

2 7 10 11 17 26

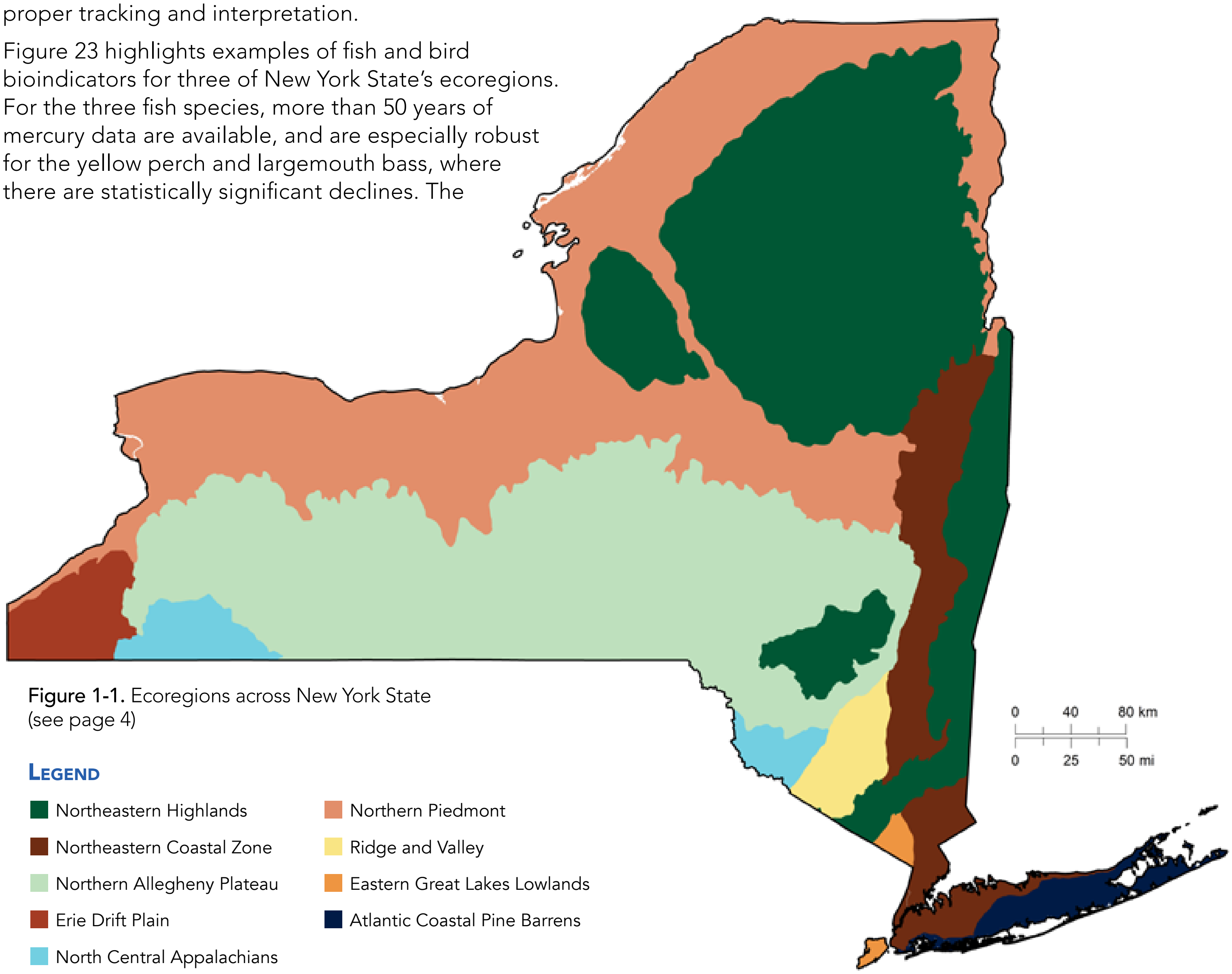


Figure 1-1. Ecoregions across New York State (see page 4)

Mercury Concentration Trends in Selected Taxa across New York State

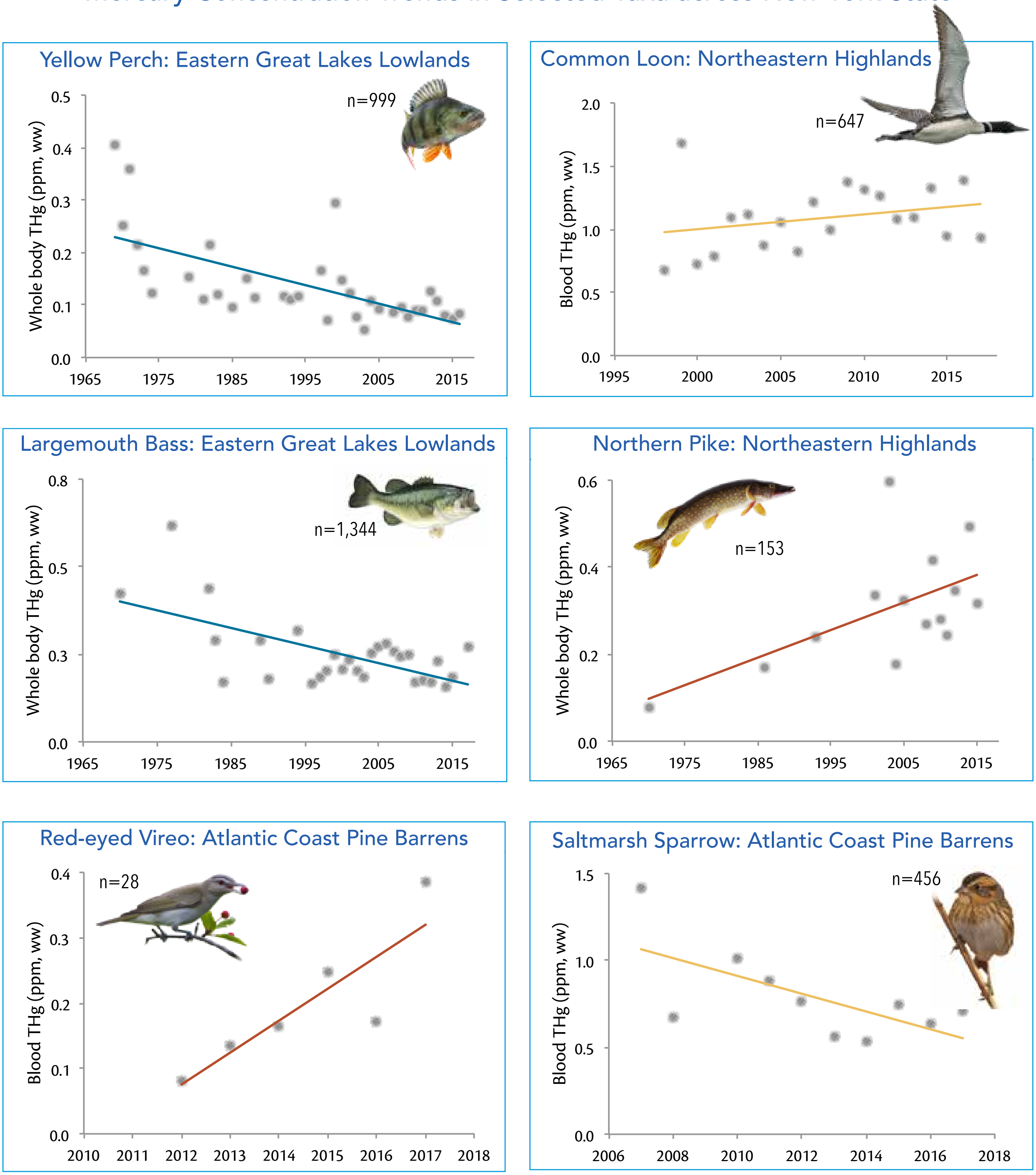


Figure 23. Six key bioindicators representing three ecoregions and respective temporal trends of mercury concentrations.

Legend

- Red line indicates a statistically significant increase in Hg concentrations through time.
- Blue line indicates a statistically significant decrease in Hg concentrations through time.
- Orange line indicates **no** statistically significant trend in Hg concentrations through time.

Past Mercury Exposure and Future Climate Effects — Case Studies

Mercury Trends in Fish of New York's Great Lakes

A Quarter Century of Near Stability

Game fish have been monitored for mercury in New York's Great Lakes for almost 50 years (1970–2019). Over this period, many environmental factors influencing mercury bioavailability have changed, including mercury deposition rates, climate, lake stage, and surrounding terrestrial habitat, and food webs.

These factors can influence the risk of mercury exposure to game fish species and in turn change human risk from consumption of fish from these waters.

Using fillet mercury concentrations, mercury exposure levels were tracked in 16 fish species over a 40-year period. The study helped to determine annual changes in fish exposure risk and human risk from consumption.

Key Findings:

- Most declines in mercury exposure occurred from the 1970s–80s.
- From the 1980s onward, fish mercury concentrations have been stable across two Great Lakes and many species.

[17]

Spatial Patterns and Temporal Trends in Common Loons in the Adirondack Park

Effects of Mercury Emission Controls

Since 1998, Common Loons have been monitored for mercury exposure in the Adirondack Park. Mercury was found to be elevated in the fish that loons consume, which may affect loon populations.

As the top predator in montane lake ecosystems, loons show mercury concentrations that are indicative of exposure risk throughout their habitat.

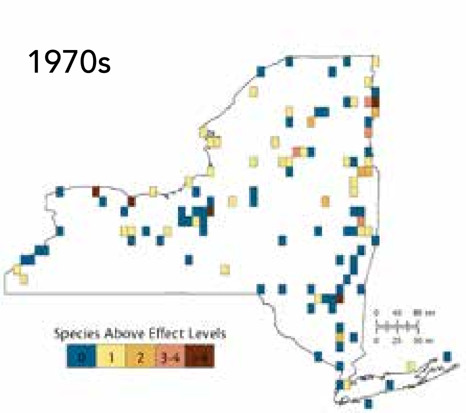
Using mercury in blood and egg samples from breeding loons from 116 lakes throughout the Park from 1998-2016, researchers have tracked aquatic ecosystem mercury availability and evaluated risk to piscivorous wildlife.

Key Findings:

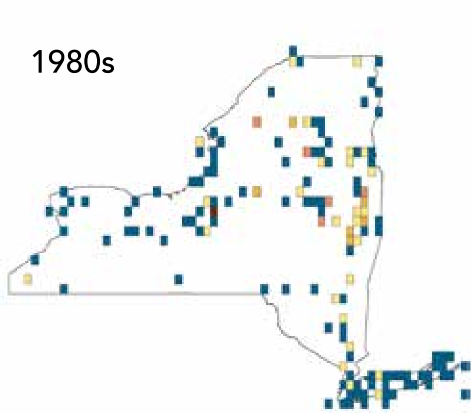
- Concentrations of mercury in Adirondack loons increased 5.7 percent per year from 1998 to 2010, and then stabilized from 2010 to 2016.
- Recovery of mercury concentrations in loons was delayed compared to trends in local atmospheric deposition of mercury.

[3] [22]

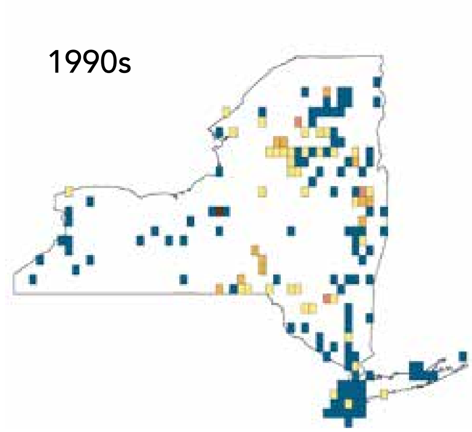
Spatio-Temporal Trends in Aquatic Species



- 11% total grids sampled
- 42% of grid cells with species above effect thresholds



- 14% total grids sampled
- 26% of grid cells with species above effect thresholds



- 16% total grids sampled
- 32% of grid cells with species above effect thresholds

Long-term Monitoring of Saltmarsh Sparrows

Monitoring Breeding Adults in New York, Maine, and Massachusetts

After the discovery of elevated mercury concentrations in aquatic fish and birds, monitoring efforts expanded to species in aquatic edge habitats. Mercury exposure high enough to cause reproductive impacts was discovered in Saltmarsh Sparrows, a species classified as endangered on the International Union for Conservation of Nature (IUCN) Red List. Since 2000, monitoring projects have tracked mercury exposure in Saltmarsh Sparrow blood to understand how the risk of mercury effects has changed over time across Long Island.

Key Findings:

- Mercury exposure risk is stable across New York marshes.
- There is considerable variation in blood mercury concentrations within the breeding season. Concentrations peak in mid-July and such patterns need to be considered for long-term monitoring.
- Most marshes have cyclical patterns of annual mercury exposure, which may relate to annual variation in local mercury deposition, tidal marsh flooding, and variation in food availability.

11

Where Are We Headed?

Forecasting the future of mercury exposure in biota is challenging. Regulatory changes have already decreased mercury emissions, and climate change will influence both mercury deposition and methylation.

Factors Affecting Mercury Deposition:

- Regulatory changes that reduce the use of fossil fuels (particularly coal) will continue to decrease emissions and deposition.
- Wet mercury deposition is driven by precipitation quantity; current climate change models project increases in precipitation for the northeastern U.S.
- Forests experience high dry mercury deposition—as climate change alters the distribution of forests in the region, dry mercury deposition will change.

Factors Affecting Mercury Methylation:

- Increases in rainfall amount and variability create wet-dry cycles that increase methylation.
- High water temperatures are associated with higher mercury methylation rates.
- Wetland habitats are key for mercury methylation and their location will change with climate.

Recent evidence suggests that climate-related factors influence patterns of mercury exposure in aquatic and terrestrial biota. Increasing temperature and rainfall, combined with shifting habitat distributions, will shape future mercury deposition and methylation, and in turn, exposure risk. Understanding how these large-scale factors will play out on smaller spatial and temporal scales will require continued research and monitoring.

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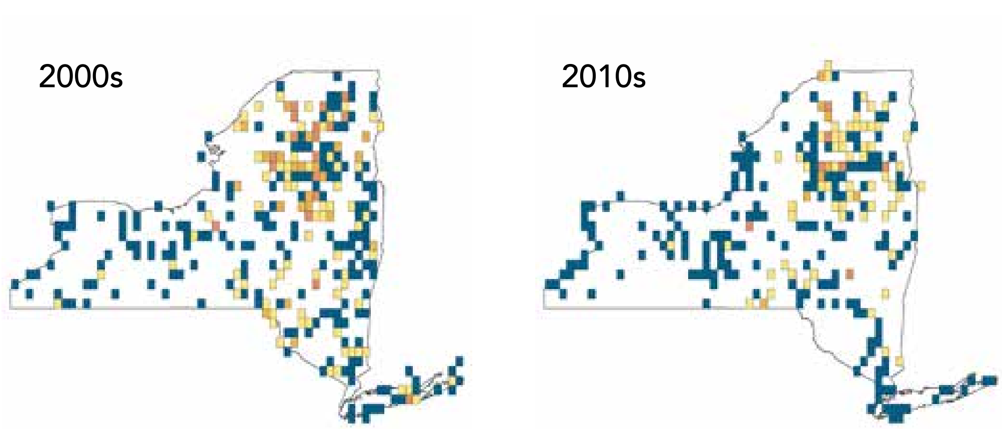


- 28% total grids sampled
- 37% of grid cells with species above effect thresholds

- 26% total grids sampled
- 29% of grid cells with species above effect thresholds

Figure 24. Number of aquatic species in New York State with median THg above mercury effect levels in each grid cell sampled during the last five decades. Comparisons between maps highlight changes in number of species above effect levels through time.

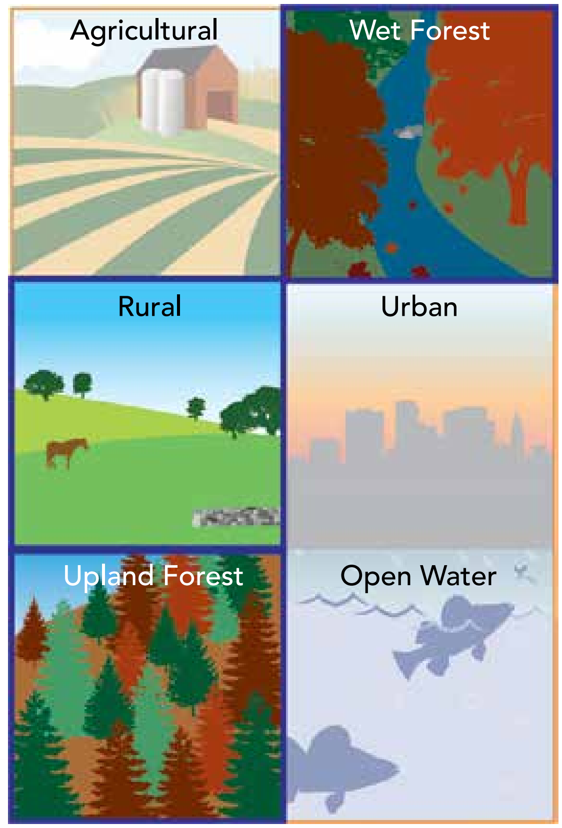
Mercury Connections Between Aquatic and Terrestrial Habitats

Mercury and Habitat Relationships

Connections between aquatic and terrestrial ecosystems are critical to understanding mercury exposure in fish and wildlife. Most mercury methylation occurs in aquatic habitats, and the surrounding terrestrial habitat supplies mercury to the adjacent aquatic habitat.

Methylmercury is taken up by insects that emerge from the aquatic ecosystem and then transport this methylmercury back into the terrestrial ecosystem, increasing mercury risk throughout those habitats. The New York State mercury synthesis study emphasizes the large-scale importance of this interplay between aquatic and terrestrial habitats.

Major New York State Landscapes with Elevated Mercury Concentrations *(identified by blue boxes)*



AQUATIC

Aquatic species such as fish and avian piscivores living and foraging in lakes and rivers surrounded by rural, upland forest that is interspersed with open water were found to be at greater risk of mercury exposure.

Forested terrestrial habitats can both capture atmospheric mercury and promote mercury methylation in the wetlands where they connect to aquatic ecosystems. In New York State, areas with these habitat characteristics are located in the Adirondacks and in other rural, mountainous areas (Figure 25).

Spatial Patterns of Mercury Concentrations in Aquatic Species

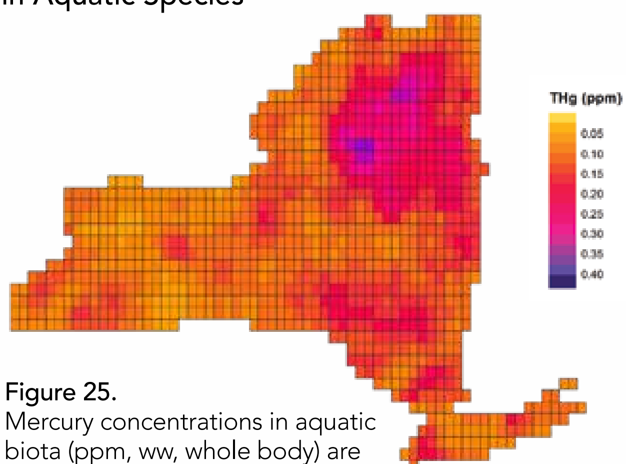
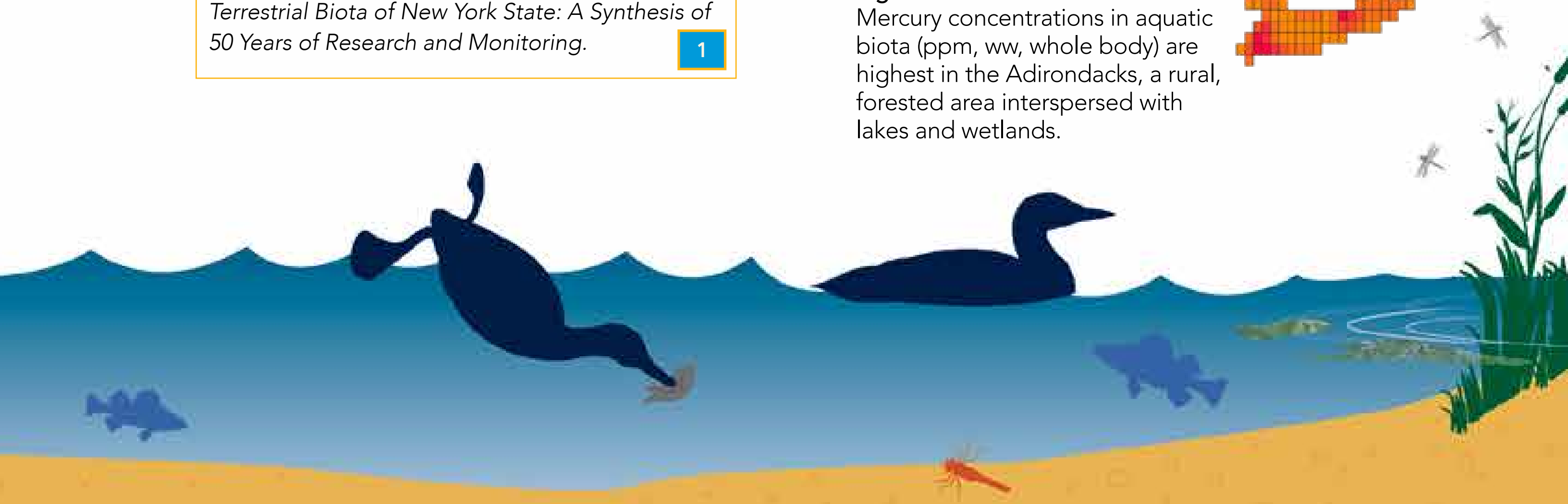
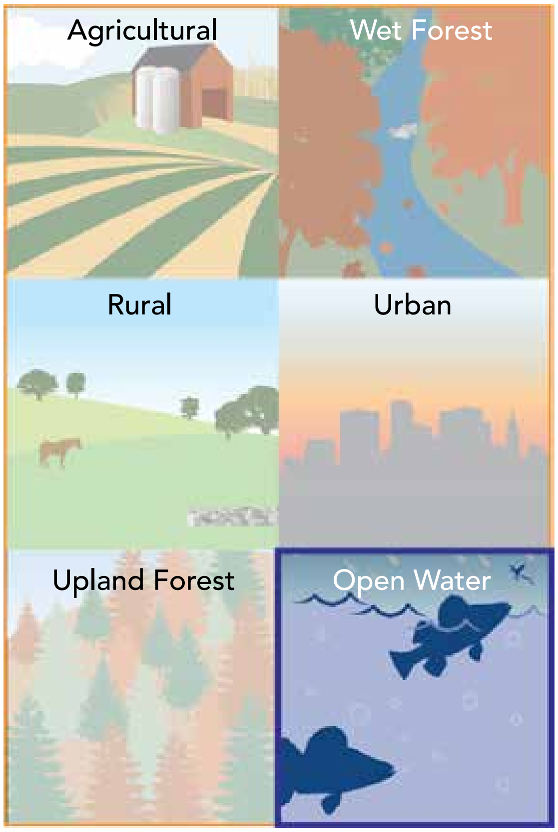


Figure 25.
Mercury concentrations in aquatic biota (ppm, ww, whole body) are highest in the Adirondacks, a rural, forested area interspersed with lakes and wetlands.



Major New York State Landscapes
with Elevated Mercury Concentrations
(identified by blue box)



Synthesizing 50 Years of Mercury Data

The *New York State Mercury Connections* study is the first comprehensive project to review five decades of mercury data that crosses species, habitats, and time.

The knowledge gained from this study provides the basis for understanding how mercury relates to the State's landscapes and how we can best understand and anticipate changes over the next 50 years.

TERRESTRIAL

Terrestrial species such as songbirds and bats living and foraging in proximity to open water habitat were found to be at greater risk of mercury exposure.Open water habitat includes wetlands, which are areas of high mercury methylation.

Terrestrial species prey on insects and spiders from aquatic habitats; these prey provide a mercury pathway to terrestrial ecosystems. In New York State, areas with these habitat characteristics are located in the tidal marshes on Long Island and freshwater wetlands in the Adirondacks and Finger Lakes (Figure 26).

Spatial Patterns of Mercury Concentrations in Terrestrial Species

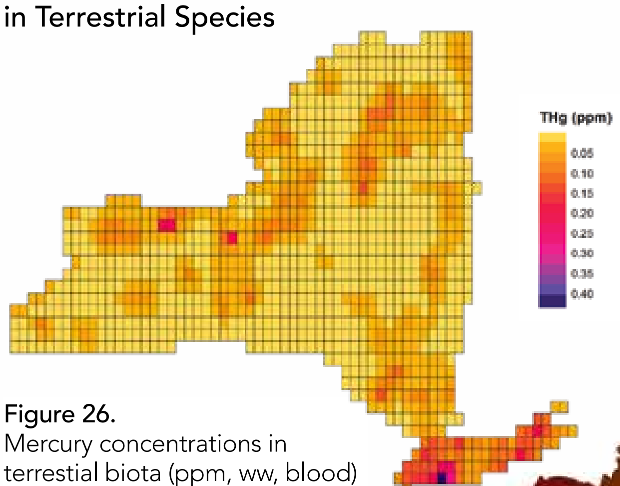


Figure 26.
Mercury concentrations in terrestial biota (ppm, ww, blood) are highest in Long Island, an area with many aquatic habitats including tidal marshes.

New York State Capitol, Albany, New York

5 What Are Key Mercury Policy Connections in New York State and Beyond?

While the timing and magnitude of the response will vary, further controls on mercury emission sources are expected to lower mercury concentrations in food webs, yielding multiple benefits to fish, wildlife, and people in New York State and surrounding states. It is anticipated that improvements will be greatest for inland lakes and will be roughly proportional to declines in mercury deposition, which most closely track trends in regional and U.S. air emissions.

at a glance

The scientific synthesis of mercury in air, water, sediments, fish, and wildlife has shed important new light on the status and effects of mercury pollution across New York State. Information from existing data and mercury monitoring programs can inform many of the regional, national, and global policy initiatives currently implemented or in process. Science-based policy actions have successfully been responsible for decreasing sulfate, nitrate, and acidification in New York State. Therefore, policy efforts related to the reduction of mercury emissions and releases can also be successful. Such policy monitoring actions include:

1. Recommendations by the Great Lakes Regional Collaboration to decrease mercury loading to the environment—the implementation of these recommendations appears to be working, but more needs to be done;
2. The US EPA Mercury Air Toxics Standards—these standards have met the goal of 91 percent reduction in mercury emissions from coal-fired power plants;
3. The Minamata Convention on Mercury—this legally binding global mercury treaty in force through the United Nations does not yet influence mercury emissions and releases, however, models indicate near-term reductions. A committee to evaluate its effectiveness is now in place; and
4. State programs—designs for long-term mercury monitoring are currently being evaluated by New York State.

Great Lakes Emission Reduction Strategy

Under the Great Lakes Water Quality Agreement, Environment Canada and the US EPA signed the Great Lakes Binational Toxics Strategy in 1997 calling for virtual elimination of mercury emissions originating from human activities in the Great Lakes region (US EPA 1997). The Great Lakes Regional Collaboration (GLRC), established in 2004 by executive order to restore ecosystem health in the Great Lakes, built on this effort and in 2010 produced the Great Lakes Mercury Emission Reduction Strategy (GLRC 2010). The strategy includes more than 34 recommended regulatory and voluntary actions to further control mercury pollution. The following three policy recommendations are particularly pertinent:

- **Lower Regulatory Thresholds for Major Mercury Emission Sources:**
  The GLRC strategy recommends that the US EPA lower the current major source category threshold for mercury emission sources.
- **Require Best Available Control Technology for New and Modified Sources:**
  The GLRC strategy also recommends that all states require Best Available Control Technology for new and modified sources if they annually emit 10 pounds of mercury (or fewer, at the state's discretion).
- **Mandate Mercury Emissions Reporting:**
  The GLRC strategy further recommends that states implement mandatory reporting requirements of new and existing mercury air emissions sources (with a recommended threshold of five pounds or fewer per year).

U.S. Mercury Regulations

Mercury pollution in the U.S. is regulated by an array of state and federal regulations (see: http://www.epa.gov/hg/). There have recently been substantial advances in regulatory efforts to decrease mercury emissions from major source categories.

Specifically, the US EPA has: (1) finalized maximum standards for mercury from coal-fired power plants; (2) created national emissions standards for hazardous air pollutants for gold ore processing and production facilities; (3) finalized rules to control mercury emissions from Portland cement manufacturing facilities; and (4) proposed new source performance standards and emissions guidelines for new and existing sewage sludge incinerators.

Mercury Air Toxics Standards (MATS Rule)

Coal-fired power plants are the largest source of mercury emissions in the U.S., accounting for approximately 48 percent in 2015. The MATS rule was finalized in 2015 to regulate emissions of mercury, acid gases, and other hazardous air pollutants from U.S. electric utilities. The MATS rule has reduced mercury emissions from the power sector by more than 90 percent and is integral to meeting U.S. commitments under the international Minamata Convention on Mercury.

Comprehensive National Mercury Monitoring Act

In April 2018, U.S. Senators Susan Collins (R-ME) and Tom Carper (D-DE) introduced the Comprehensive National Mercury Monitoring Act, a bipartisan bill that would establish a national mercury monitoring network to protect human health, safeguard fisheries, and track the environmental effects of emissions reductions.

Minamata Convention on Mercury

The Minamata Convention on Mercury is a global treaty designed to protect human health and the environment from anthropogenic emissions and releases of mercury. The Convention is the product of extensive international meetings and negotiations. On January 19, 2013, the text of the Convention was approved by delegates representing close to 140 countries. The Convention was adopted and signed on October 10, 2013 at a Diplomatic Conference in Kumamoto, Japan. The Convention entered into force on August 16, 2017. More than 100 countries have ratified or accessioned the Convention, including the United States (see www.mercuryconvention.org).

Pursuant to Article 23 of the Minamata Convention, a governing body called the Conference of the Parties (COP) was established. The COP is responsible for advancing implementation of the Convention and for keeping the Convention under continuous review and evaluation. Decisions relevant to these responsibilities are made during meetings of the COP. The third COP meeting will occur in November 2019. Subsequent meetings will be held every two years thereafter.

Science Informs Policy: A Mercury Policy Timeline

The strides taken for regulating mercury use, emissions, and releases have been extensive over the past two decades. The scientific understanding of mercury's ability to cause harm to human health and the environment grew in the 1980s and 1990s, when U.S. policies to control mercury trade, its use in products and industry, and its release in waste streams began to be instilled at state and regional levels (e.g., the Great Lakes and New England).

In parallel, local policymaking and national decisions on the costs of mercury were being developed that would eventually result in the Mercury Air Toxic Standards (MATS) rule in 2015. The MATS Rule was important for establishing a science-based policy for the United States to participate in a leadership role for creating the Minamata Convention on Mercury, a global mercury reduction treaty that entered into force in 2017.

Next Steps for Mercury Monitoring

Tracking mercury in the environment and its impact on human health is an important next step in the control of mercury use, emissions, and releases. The relationships among key compartments such as air, biota, and humans are complex and often not linear.

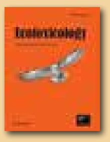
Great Lakes and/or New York State Milestones

1997

Great Lakes Binational Toxics Strategy signed.

2001-2005

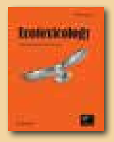
Northeast Regional Mercury Synthesis



(Lead by BRI, Environment Canada, and NSRC)

2008–2011

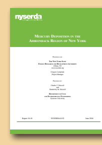
Great Lakes Regional Mercury Synthesis



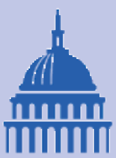
(Lead by BRI, University of Wisconsin, and Great Lakes Commission)

2010

Great Lakes Mercury Emissions Reduction Strategy



NYSERDA Mercury Deposition in the Adirondack Region of New York



National Milestones

2005

The Clean Air Mercury Rule (CAMR), issued under George W. Bush, marks the first time the US EPA requires coal-fired power plants to reduce mercury emissions, through a cap and trade approach.

2006

US EPA Office of Inspector General issues report on mercury "hotspots."

2009

Senators Susan Collins (R-ME) and Carper (D-DE) introduce legislation that will create MercNet, a new program to measure and monitor mercury levels across the U.S.

(Bill re-introduced in nearly every Congress.)

2011

The US EPA proposes Mercury and Air Toxics Standards (MATS) to limit mercury, acid gases, and other toxic pollution from power plants.

International Milestones

Februrary 2009

The Governing Council of UN Environment decides to develop a global legally binding instrument on mercury.

June 2010

The first session of the Intergovernmental Negotiating Committee (INC) to prepare a global legally binding instrument on mercury in Stockholm, Sweden.

January 2011

INC2
Chiba, Japan

October 2011

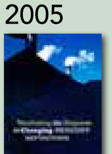
INC3
Nairobi, Kenya

June 2012

INC4
Punta del Este
Uruguay

BRI Science/Policy Publications

2005

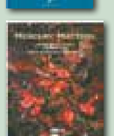


Monitoring the Response to Changing Mercury Deposition

Mercury Connections: The Extent and Effects of Mercury Pollution in Northeastern North America

2007

Ecosystem Responses to Mercury Contamination

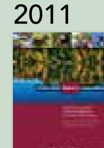


Mercury Matters: Linking Mercury Science with Public Policy in the Northeastern United States

2008

MercNet: Establishing A Comprehensive National Mercury Monitoring Network

2011



Great Lakes Mercury Connections: The Extent and Effects of Mercury Pollution in the Great Lakes Region

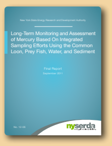
The complexity and interactions of the drivers behind the transport of mercury, methylation, and subsequent movement through the food web requires monitoring of each of these three processes to understand and evaluate the success of the MATS rule and the Minamata Convention.

Tracking mercury over time also requires carefully designed sampling approaches that can generate standardized and comparable data over time. NYSERDA began such a process in 2013 and intends to continue and refine tracking mercury over time in New York State for the foreseeable future.

The vision of NYSERDA's approach is one to be replicated in other locations in the U.S. and the world while regional and global mercury monitoring plans are being developed.

Tracking mercury in the environment and its impact on human health is an important next step in the control of mercury use, emissions, and releases.

2011



Long-Term Monitoring and Assessment of Mercury Based on Integrated Sampling Efforts Using the Common Loon, Prey Fish, Water, and Sediment

2013

NYSERDA-led mercury monitoring in fish and birds. *(Through 2017).*

2016

Mercury in Fish and Macroinvertebrates from New York's Streams and Rivers: A Compendium of Data Sources

2017

2018-2019

New York State Mercury Synthesis

(Lead by BRI, Syracuse University, and NYSERDA)

2013

The U.S. is the first country to ratify the Minamata Convention on Mercury.

2015

MATS rule reductions go into effect.

2016

U.S. Supreme Court blocks challenges to MATS rule. US EPA issues a final finding in response.

2017

MATS rule emissions reporting in effect.

August 2018

Senators Collins and Carper introduce the Comprehensive National Mercury Monitoring Act.

December 2018

US EPA proposes revised cost finding for MATS rule after new risk and technology review.

2019

Senator Collins joins bipartisan group in urging administration to keep the MATS rule untouched.

January 2013

INC5
Geneva, Switzerland

October 2013

The Minamata Convention on Mercury opened for signature.

November 2014

INC6
Bangkok, Thailand.

March 2016

INC7
Dead Sea, Jordan

August 2017

The Minamata Convention on Mercury enters into force.

November 2017

The first Council of Parties (COP) to the Minamata Convention, Geneva, Switzerland

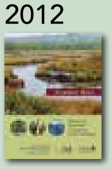
November 2018

COP2
Geneva, Switzerland

November 2019

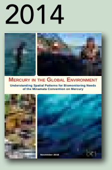
COP3
Geneva, Switzerland

2012

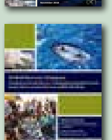


Hidden Risk: Mercury in Terrestrial Systems of the Northeast

2014



Mercury in the Global Environment: Patterns of Global Seafood Mercury Concentrations and their Relationship with Human Health and the Environment



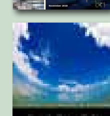
Global Mercury Hotspots: New Evidence Reveals Mercury Contamination Regularly Exceeds Health Advisory Levels in Humans and Fish Worldwide

2017

(Updated annually)

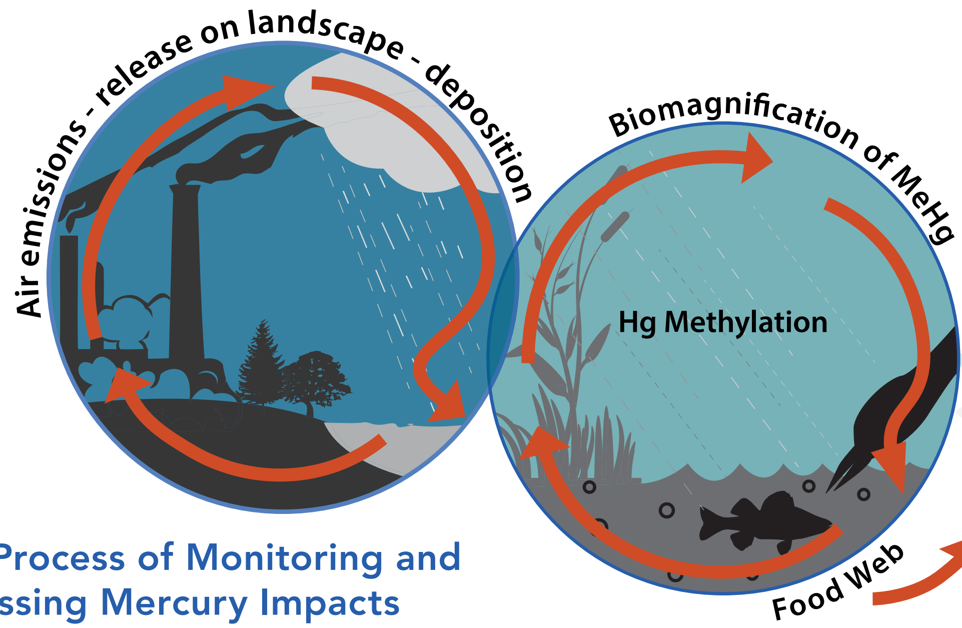
Local, Regional, and Global Biomonitoring

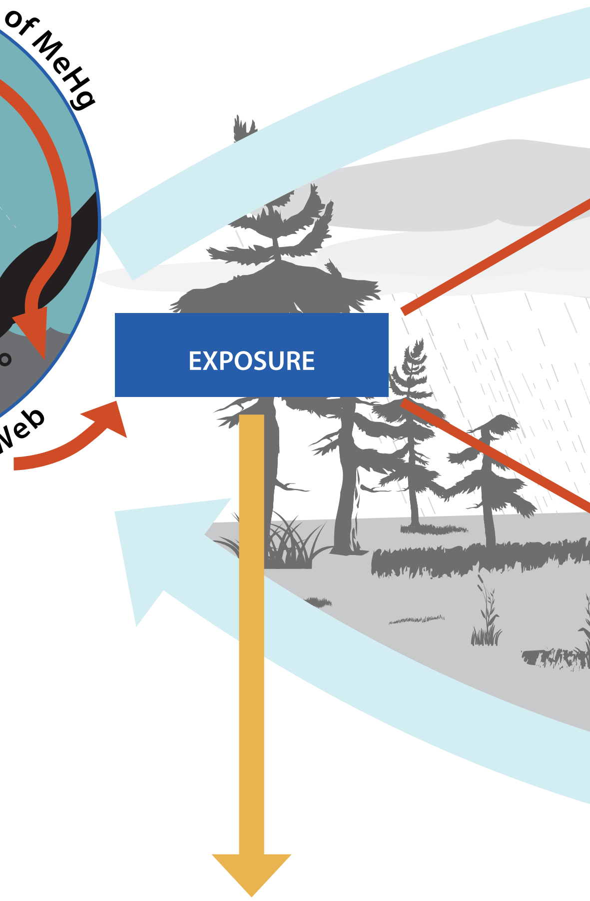
2018



Center for Mercury Studies

Monitoring Mercury Contamination in New York State and Assessing





The Process of Monitoring and Assessing Mercury Impacts

Mercury monitoring data for different habitats, ecoregions, and objectives (e.g., temporal trends) are now summarized for the past 50 years across New York State. Target bioindicators have been identified for major taxonomic groups (Step 1) and were used for established mercury monitoring by NYSERDA to quantify mercury exposure (2013-2017).

To best interpret bioindicator mercury exposure over time and space, ecosystem components sensitive to methylation rates need to be identified, collected, and interpreted. While such metadata are critical for high quality interpretation, the changing climate creates increasing urgency. With the volume of information on effects thresholds available for major biota groups, risk assessments can be more confidently generated (Step 2).

Historically, mercury monitoring and risk assessments have been endpoints. Today, further steps can be taken to either remediate or restore the impact to New York State's fish and wildlife populations. Through a formal U.S. regulatory process called Natural Resource Damage Assessment and Restoration (NRDAR), point-source pollution by responsible parties (e.g., chlor-alkali facility owners) are assessed. Regulatory practitioners use a tool called the Resource Equivalency Analyses to quantify the bioindicator-years-lost. Once the injury is assessed, it can be monetized based on precedent (Step 3).

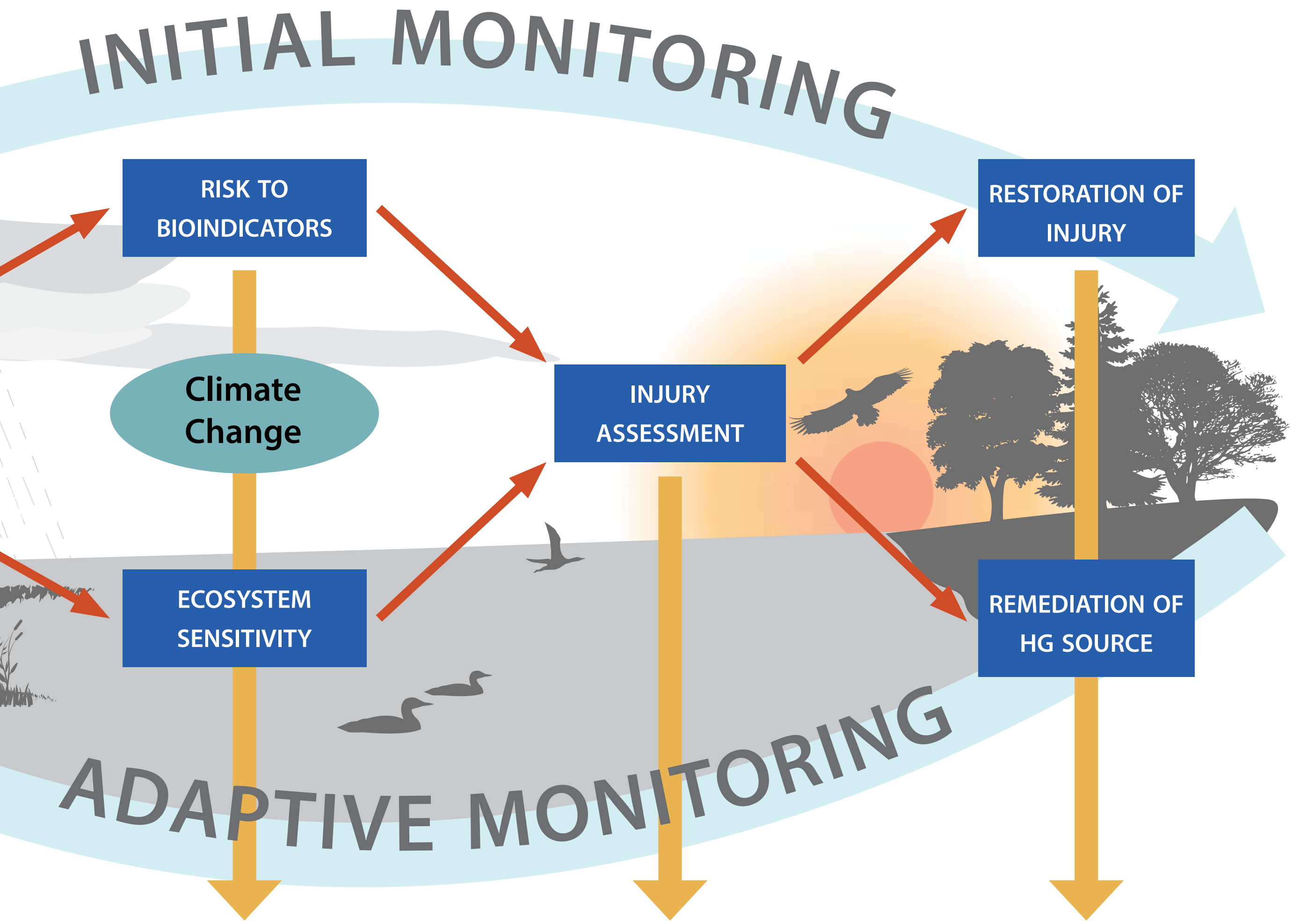
In New York State, a NRDAR injury assessment could be conducted for atmospherically-deposited mercury, as it can now be better linked to responsible parties through modeling and mercury stable isotopes (e.g., coal-fired boiler facilities). Once an injury is monetized and paid by the responsible party, a restoration plan can be developed to identify options for remediation or restoration (e.g., purchase of land, improving reproductive success). Follow-up monitoring is conducted to evaluate the success of the NRDAR process (Step 4).

Mercury Monitoring

	BIOINDICATORS
Invertebrates	• Odonates
Fish	• Great Lakes (walleye) • Lakes (bass and perch) • Nearshore Marine (bluefish and striped bass)
Birds	• Piscivores (loons/eagles) • Invertivores (saltmarsh sparrow, northern waterthrush, marsh wren)
Mammals	• Piscivores (river otter) • Invertivores (bats)

Step 1

Impact to Fish and Wildlife



Measuring Ecosystem Components

- Habitat types (e.g., wetlands)
- Water quality (e.g., pH, DOC)
- Temperature/precipitation
- Hg isotopes
- Wetting/drying cycle
- Food web length (i.e., biomagnification)

Step 2

Conducting Resource Equivalency Analyses (REA)

- Quantify bioindicator-years-lost.
- Monetize results based on type of restoration or remediation.

Step 3

Addressing the Issue

- Funds generated by the REA-based injury assessment can be used to restore bioindicator-years-lost and/or through remediation of the point source.
- Follow-up (or adaptive) monitoring is used to evaluate success.

Step 4

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2. Adams, E.M., Sauer, A.K., Lane, O., Regan, K., & Evers D.C., in review. The effects of climate, habitat, and trophic position on methylmercury bioavailability for New York songbirds. Ecotoxicology.
3. Buxton, V.L., Evers, D.C., & Schoch N., in review. The influence of biotic and abiotic factors on banded common loon (*Gavia immer*) reproductive success in a remote, mountainous region of the northeastern United States. Ecotoxicology.
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5. DeSorbo, C. R., Burgess, N.M., Nye, P., Loukmas, J.J., Brant, Burton, M.E.H., Persico, C.P., & Evers, D.C., in review. Mercury exposure differences in nestling bald eagles in New York, USA. Ecotoxicology.
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10. Grieb, T., Karimi, R., & Fisher, N., in review. Assessment of Trends in Fish Tissue Mercury Concentrations. Ecotoxicology.
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14. Nelson, S.J., Chen, C.Y., & Kahl, J.S., in review. Dragonfly larvae as biosentinels of Hg bioaccumulation in Northeastern and Adirondack lakes: relationships to abiotic factors. Ecotoxicology.
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18. Riva-Murray, K., Razavi, R., Richter, W., Cleckner, L., & Burns, D., in review. Mercury in Fish from New York's Streams and Rivers: Recent Spatial Patterns and Long-Term Trends. Ecotoxicology.
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* Papers designated with an asterisk are included in the *Ecotoxicology* special issue on *Mercury in Songbirds*.

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