The Production and Transfer of Methylmercury within Terrestrial Foodwebs across the Northeastern Landscape

Theme # 2

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The cycling and trophic transfer of mercury from prey to predator species through terrestrial food webs within the Northern Forest Region is dependent upon several factors including atmospheric mercury deposition, soil/sediment chemistry, and habitat type. Predatory invertebrate and songbird communities inhabiting sensitive coastal and wetland systems were found to have mercury concentrations that could negatively impact their population dynamics.

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http://www.nsrcforest.org

Project Summary

A potent neurotoxin, mercury (Hg) has been shown to impact the behavior, growth and reproductive success of wildlife through bioaccumulation within food webs. The detrimental effects of mercury contamination have been extensively documented in aquatic ecosystems, but it is equally important to understand the impacts of mercury deposition, methylation and bioaccumulation on biota within the adjacent, surrounding landscape. Unfortunately, relatively few studies have focused on the mechanisms of bioaccumulation of mercury in terrestrial ecosystems. However, preliminary measurements have shown blood mercury concentrations in several Northeastern songbird species are elevated to levels where adverse physiological effects are evident. It is hypothesized that mercury is transferred to top predators, such as songbirds, by invertebrate, prey species located at lower trophic levels within terrestrial systems.

The overall goal of this research was to improve understanding of the fundamental mechanisms of methylmercury (MeHg) transfer in terrestrial foodwebs. The specific objectives were to: conduct a synthesis of existing datasets on the relationships between abiotic and biotic mercury concentrations in terrestrial foodwebs; conduct stable isotope analysis to identify and evaluate trophic pathways for methylmercury bioaccumulation in terrestrial habitats; and link the results with regional ecological studies to develop a more comprehensive understanding of the effects of mercury deposition across the Northeastern landscape.

Information compiled through a collaboration between Syracuse University and BioDiversity Research Institute examined the relationship between mercury deposition across the landscape and its subsequent movement through terrestrial systems. Modeling of atmospheric mercury deposition across the Adirondack region of New York State indicated that while variation is large across the area, geographic locations in the southwest and northern part of the Park are subject to higher deposition rates. Regional mercury levels within soils were highest for the Adirondack Park and variables such as soil moisture and pH were found to influence the production of methylmercury. The cycling and availability of mercury is dependent upon habitat type and drives mercury concentrations at the base of the food chain and bioaccumulation within associated foodwebs. As a result, invertebrate and songbird communities inhabiting sensitive coastal and wetland systems were found to have mercury levels elevated to concentrations that can negatively impact reproductive success. Stable isotope analyses demonstrated the transfer and biomagnification of methylmercury from herbivores to predators within *Sphagnum* bog habitats. Ideally, the results from this project will be used as a foundation to direct future research and monitoring efforts designed to examine critical issues of air quality, environmental integrity and wildlife health in the Northern Forest region.

Background & Justification

- Mercury is a trace metal found in the Earth's crust
- A potent neurotoxin, mercury impacts the behavior, growth and reproductive success in humans & wildlife
- Mercury bioaccumulates through aquatic and terrestrial food webs
- Extensively documented in aquatic systems, few studies have focused on mercury exposure in terrestrial ecosystems

Background and Justification

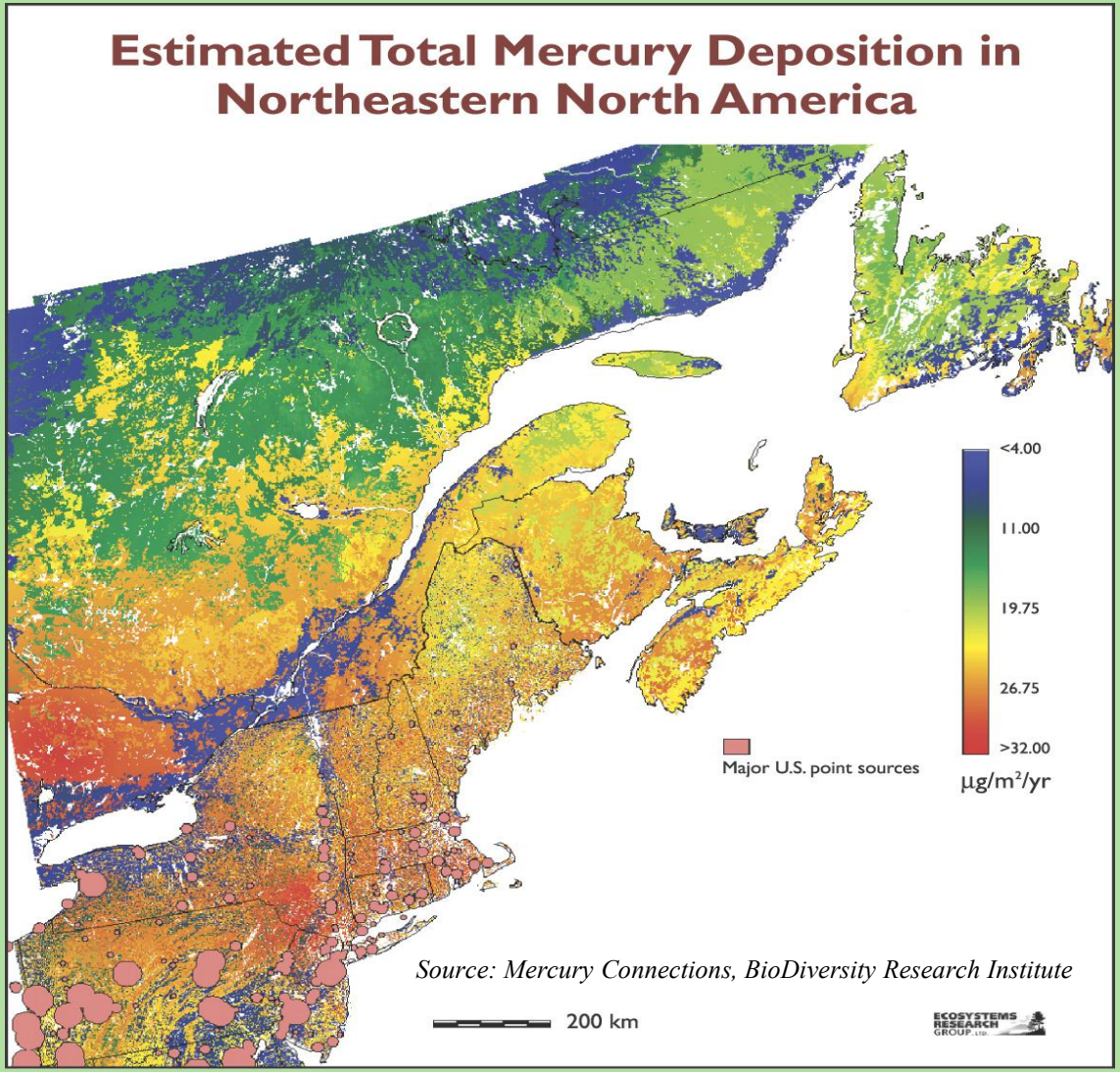
~ Mercury Deposition and Transport ~

Natural and anthropogenic sources:

- Coal-fired power plants
- Fossil fuel combustion

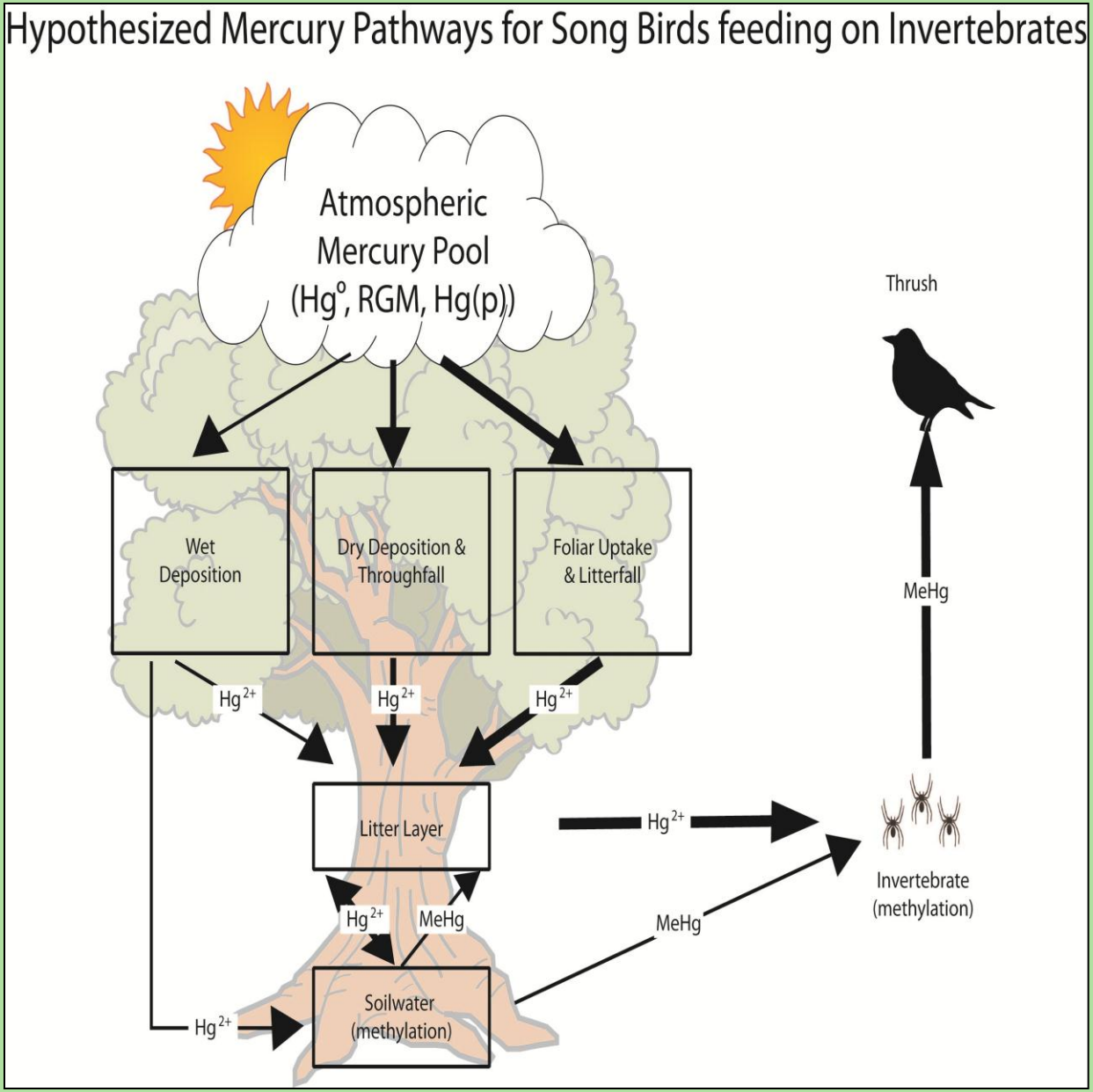
Emissions can be transported local to global distances

Deposition upon the landscape can vary by: distance from source, precipitation quantity, elevation and vegetation



Once deposited, natural processes convert inorganic mercury into methylmercury, which bioaccumulates to toxic levels as it is transferred through food webs

Background and Justification



~ Pathways for Bioaccumulation~

- Seasonally, songbirds are able to decrease concentrations of mercury in their bodies through feather growth and egg deposition

- With continued ingestion of prey species high in mercury content, individuals may accumulate mercury faster than they can rid their bodies of it through natural processes

- Insectivores are widespread across the landscape; these species may be indicative of the health of the surrounding environment

Methods

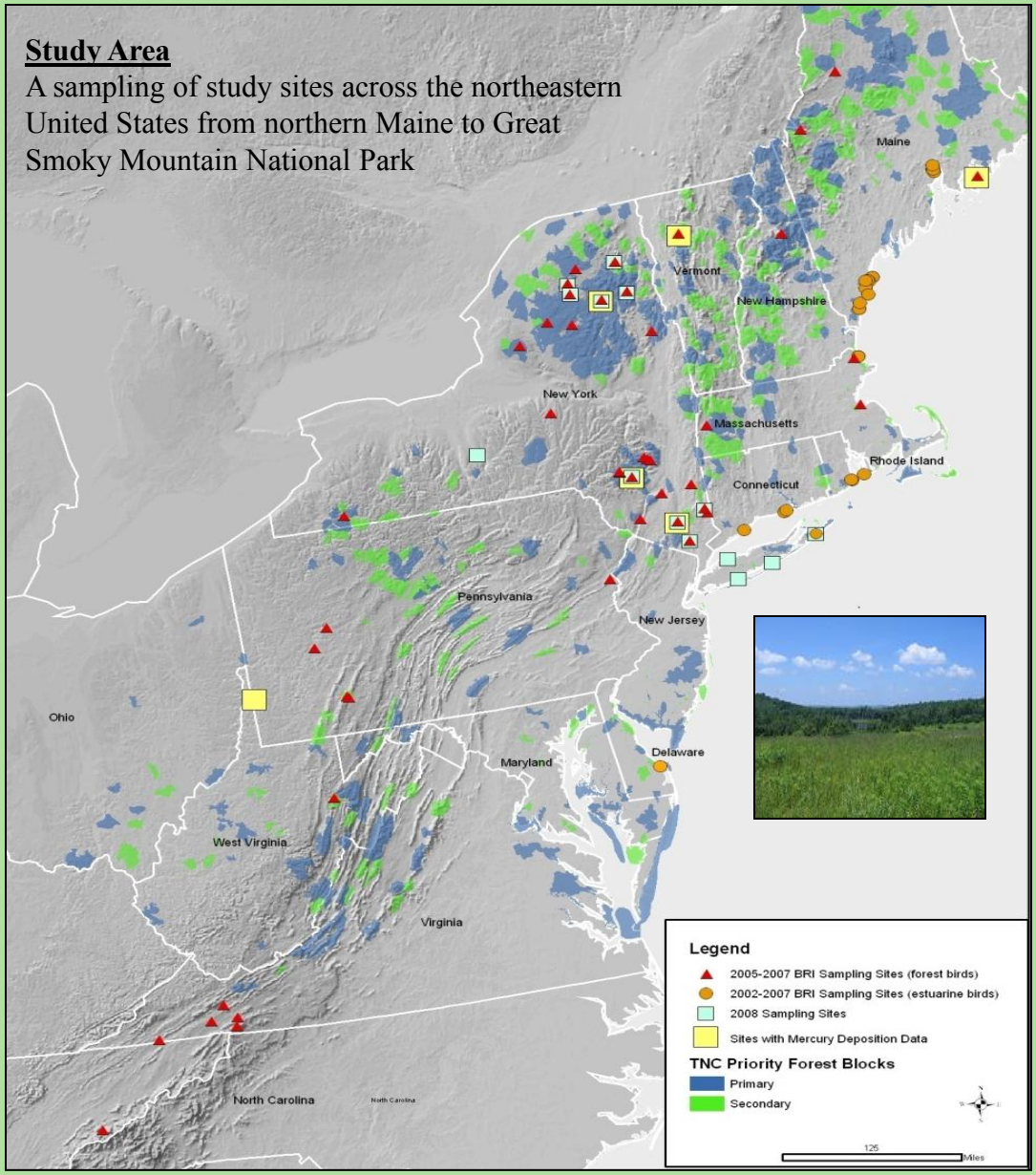
- Regional and multi-year efforts conducted by Syracuse University and BioDiversity Research Institute to assess the impacts of mercury deposition on ecosystems within the Northern Forest

- Sampling across a variety of ecosystems to identify at-risk wildlife species and sensitive habitat types

- Data collected from long-term ecological research sites; high and low elevation habitats; and forested and *Sphagnum* bog ecosystems

Study Sites Include:

- Acadia National Park, Maine
- Hubbard Brook Experimental Forest & White Mountain National Forest, NH
- Green Mountains, VT
- Harvard Forest & Berkshire Mountains, MA
- Tug Hill, Catskill & Adirondack Mountains, NY
- Powdermill Nature Preserve, PA
- Shenandoah National Park, VA
- Fernow Experimental Station, WV



Methods

- To determine the relationships among mercury deposition, exposure levels, and regional patterns of mercury contamination, samples were collected from various compartments within terrestrial foodwebs

<u>Study Site Collection</u>

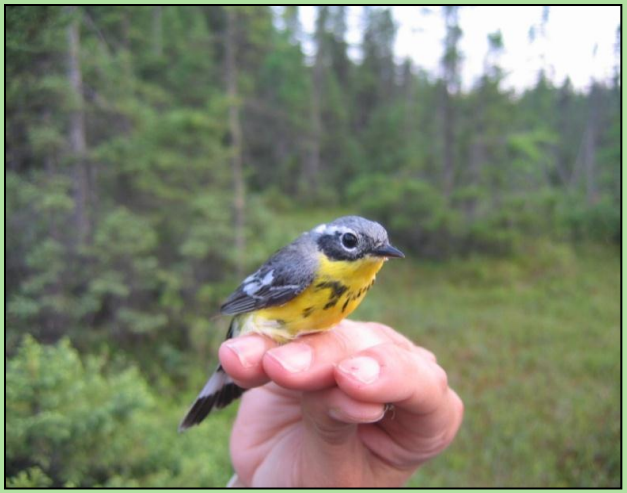
- Soil
- Leaf Litter
- Sphagnum moss
- Fresh vegetation
- Invertebrates
- Songbird blood and feathers

Methods

~ Stable Isotope Methodology~

- Identify trophic pathways for mercury bioaccumulation in terrestrial foodwebs by examining $\delta^{15}N$ and $\delta^{13}C$ values in songbird communities and invertebrate prey species

- Based on dietary selection, top predators feeding at higher trophic levels within a food chain, often have the highest $\delta^{15}N$ values, which correlates with the bioaccumulation of contaminants



- Two *Sphagnum* Bog and Northern Hardwood forest study sites analyzed in the Adirondack Mountains – a regional biological mercury hotspot

Hermit Thrush Diet

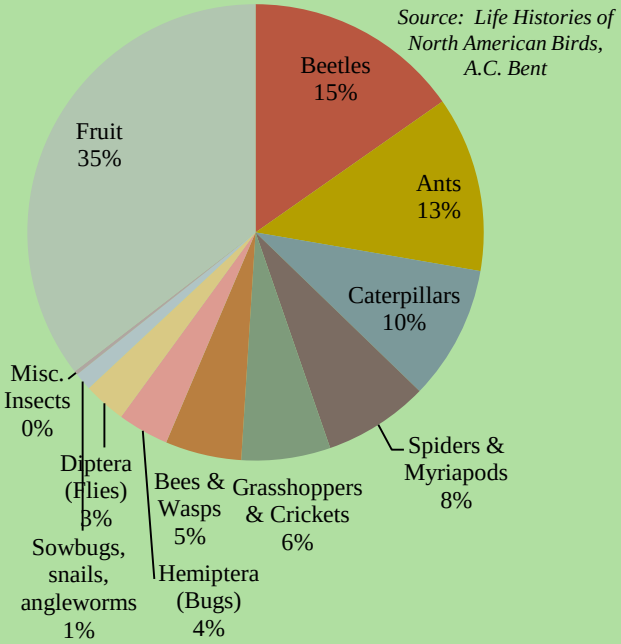


Figure 1: Stable isotopes can be used to determine where a songbird is feeding ($\delta^{13}C$) and the types of prey items comprising its diet ($\delta^{15}N$).

Results – Deposition Patterns

Atmospheric Mercury Deposition in the Adirondack Park

- 6-million acre Adirondack Park has been designated as a "biological mercury hotspot". Hotspots have high rates of mercury deposition and landscape characteristics that encourage Hg uptake into aquatic and terrestrial foodwebs

Atmospheric Mercury Deposition

- Large variation in atmospheric mercury deposition occurs across the Park
- The Adirondacks receives moderate wet mercury deposition, ranging from 6-11 µg m^{-2} yr^{-1}
- Wet mercury deposition is slightly smaller than dry deposition, with total amounts of 210 and 370 kg yr^{-1}, respectively
- Wet mercury deposition is low on open water surfaces, and greater in forests

Spatial Patterns

- Scattered areas in the eastern Adirondacks have total Hg deposition > than 30 µg m^{-2} yr^{-1}
- Southwestern and the northern areas receive higher mercury deposition ranging from 25-30 µg m^{-2} yr^{-1}.

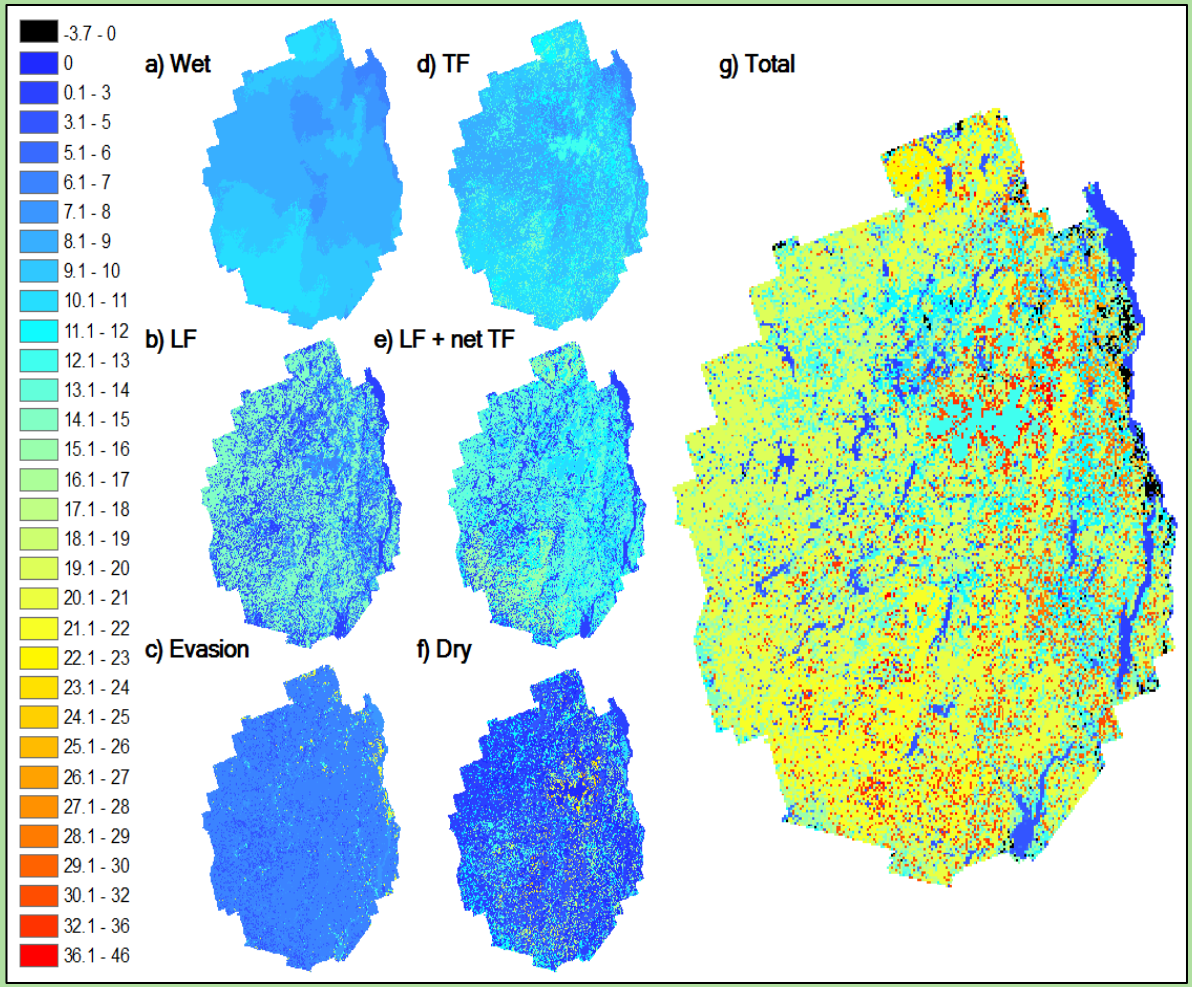
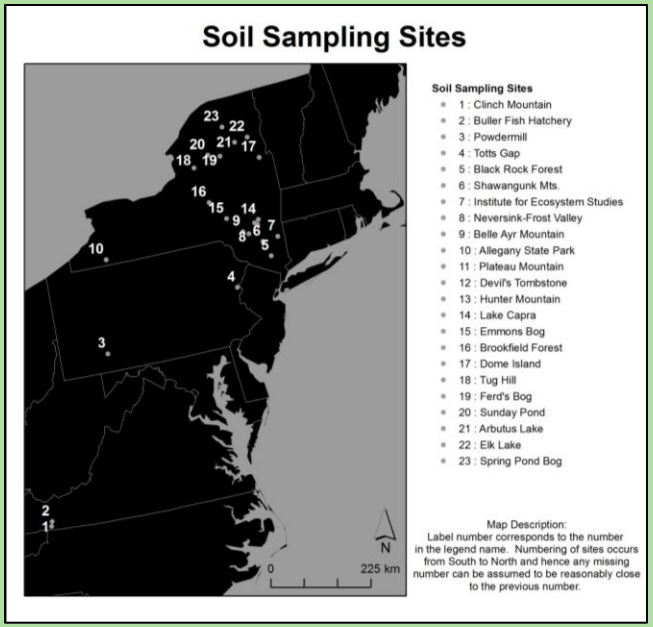


Figure 2: Spatial distribution patterns of atmospheric Hg deposition (units: µg m^{-2} yr^{-1}) to the Adirondack Park, including: a) wet deposition; b) litterfall deposition (LF); c) surface evasion; d) throughfall deposition (TF); e) the sum of LF and net TF (TF wet deposition),; f) the modeled dry deposition (sum of GEM, GOM and PBM deposition); and g) the total net Hg deposition (wet + dry - evasion).

Results – Soils

Pathways into the Food Web



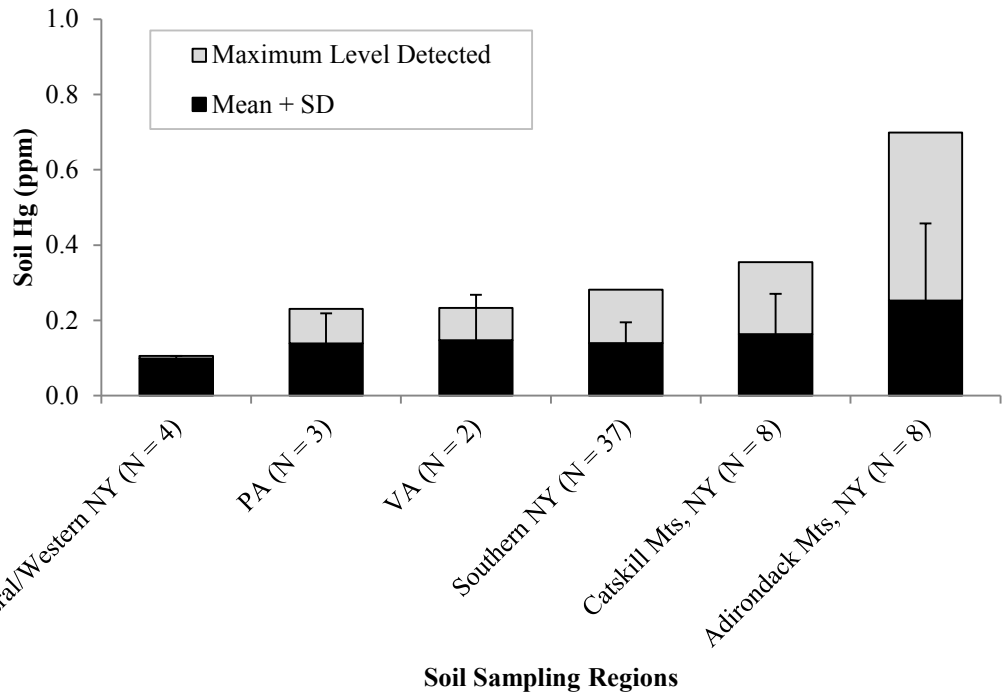


Figure 3: Mean plus standard deviation and maximum detected of mercury in soils sampled in PA, VA and four regions of NY. Small sample sizes precluded statistical comparisons.

- Mercury concentrations in soils ranged from 0.06 to 0.69 ppm
- Soils collected in the Adirondacks had the highest mean mercury, while Central/Western NY had the lowest

Catskills Case Study

- Soil mercury was found to have a significant positive relationship with soil moisture in the forest floor
- Positive relationship between soil moisture and calcium in the forest floor
- Significant correlation between low pH (<5), acidic soils and high mercury

~ Wide range of soil mercury at sites within the same geographic region likely correlates with landscape characteristics and variables related to soil chemistry ~

Results - Invertebrates

- 371 Invertebrates from 13 orders and 9 regions were sampled in New England and Mid-Atlantic States (2005 to 2010)

- Diptera, Amphipoda, and Araneae had the highest methylmercury (MeHg) concentrations (Figure 4)

- Several orders sampled in coastal systems (Diptera, Amphipoda, and Araneae – Figures 4 & 5) were found to have significantly higher mercury than those sampled in other habitat types

- Wetland and coastal habitats have characteristics that encourage the production and uptake of methylmercury into aquatic and terrestrial food webs

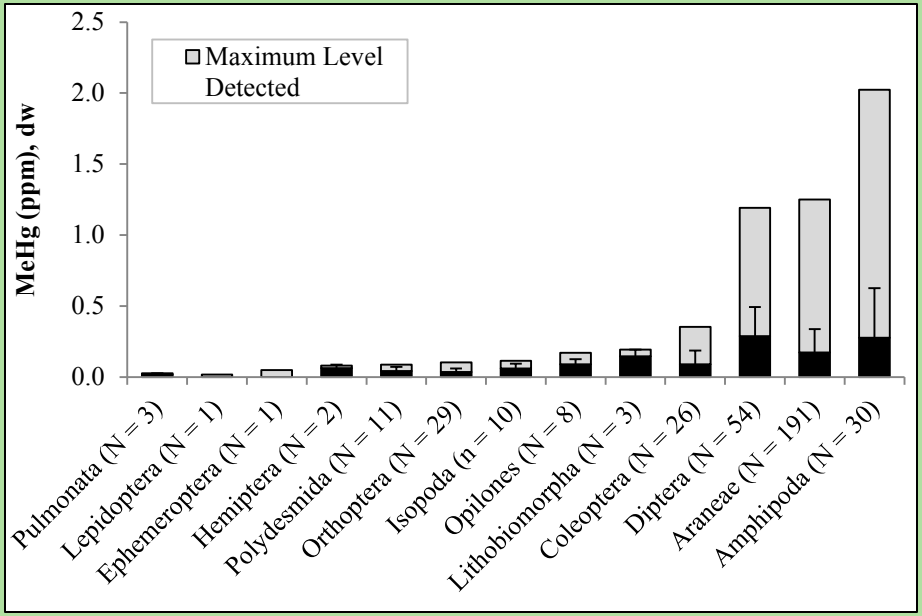


Figure 4: Mean plus standard deviation and maximum levels detected of MeHg concentrations in invertebrate orders sampled.

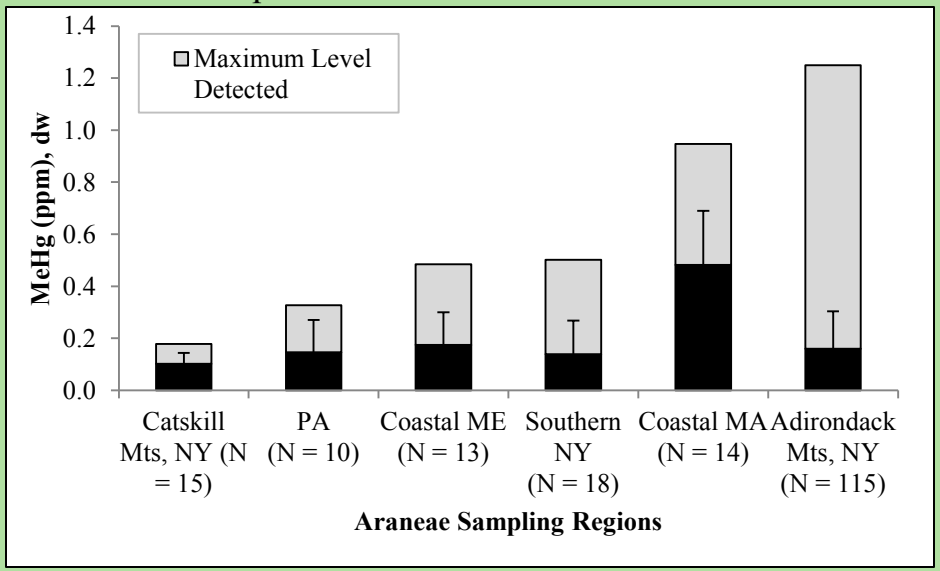
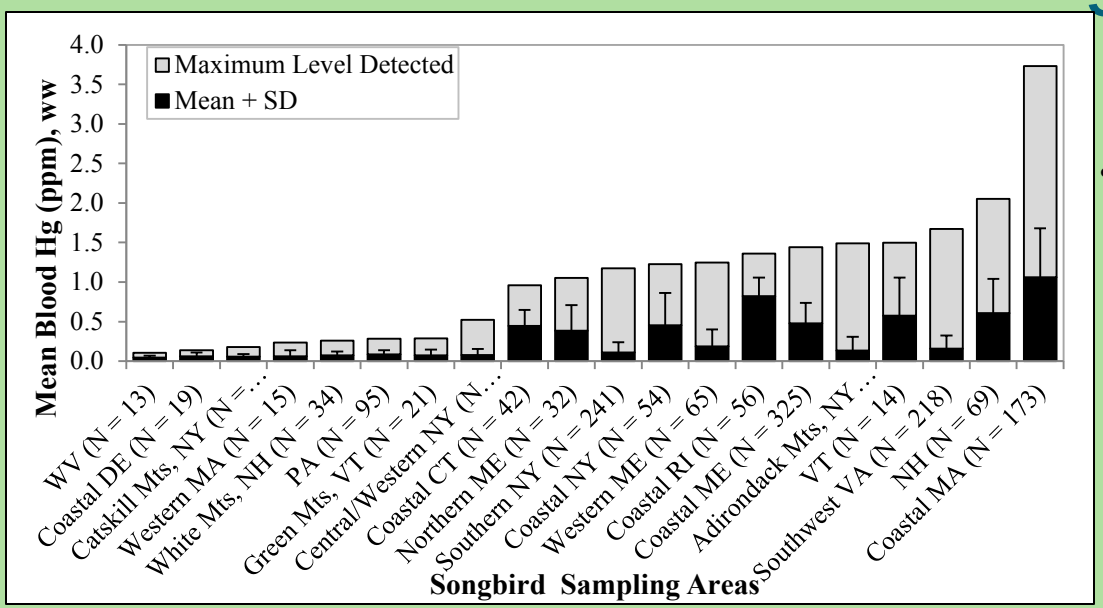


Figure 5: Regional means plus standard deviation and maximum levels detected of MeHg concentrations in Araneae species sampled.

- Predatory invertebrates, such as spiders and blood-sucking flies, were found to have higher methylmercury than other prey items within lower trophic level orders, which include herbivores or detritivores

- Soil-dwelling and predatory invertebrates constitute the foraging base and pathways for mercury bioaccumulation to top predators in a food web, such as songbirds. Therefore, variables including prey selection, seasonal availability, and habitat type are important factors contributing to exposure levels documented within wildlife communities.

Results - Songbirds



- 1,878 individuals from 165 sampling locations within New England and Mid-Atlantic States (Figure 6)
- Habitat Type: Species sampled within coastal and wetland habitats averaged the highest mean mercury concentrations
- Family Exposure: Songbird families with members inhabiting wetland systems exhibited higher mercury than those in upland forests
- Foraging Guild: Insectivores and ground-feeding species, particularly in wetlands, had higher mercury as compared to frugivorous and omnivorous, upper-canopy feeding species

Figure 6: Regional means plus standard deviation and maximum levels detected of blood mercury (ppm) in songbirds sampled from 1999-2007.

Reproductive Success

- Behavior, growth, survival, reproduction, immune response, and endocrine function have been documented to be adversely affected by elevated blood mercury found within songbird species
- 12 of the 82 species sampled were at risk of reduced nesting success based on observed blood mercury (Figure 7)

~ Trophic position, methylmercury availability, body size, habitat type, elevation, foraging guild and geographic location are variables that play important roles in mercury exposure among songbird species ~

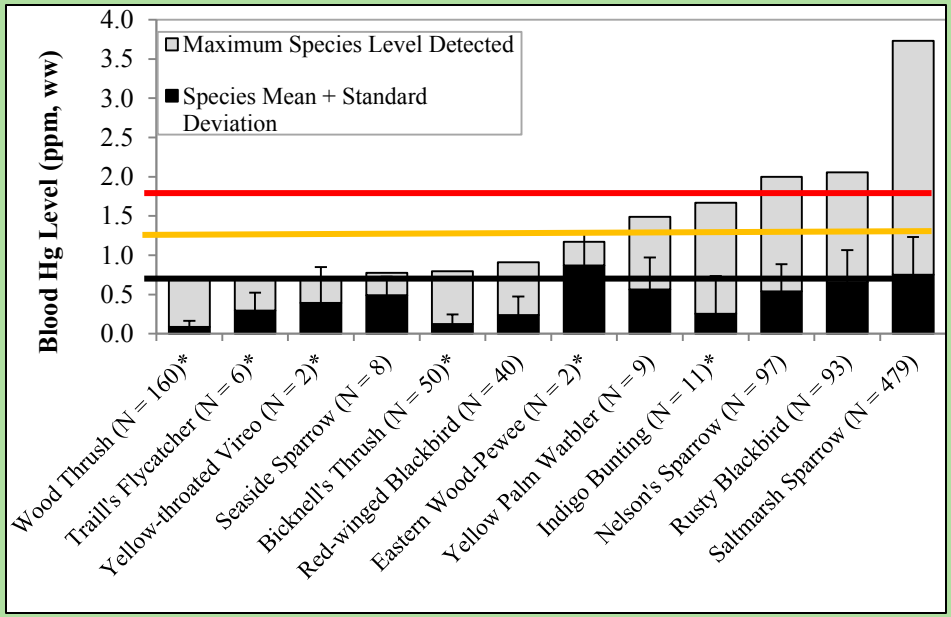
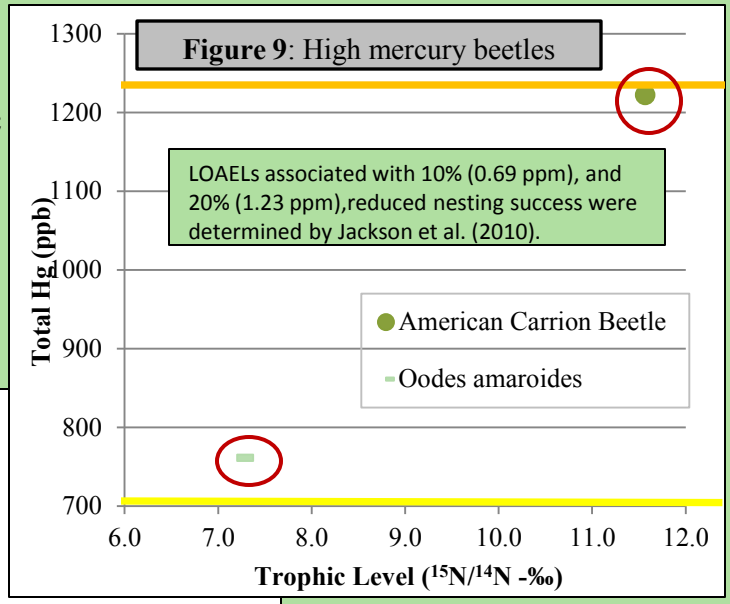
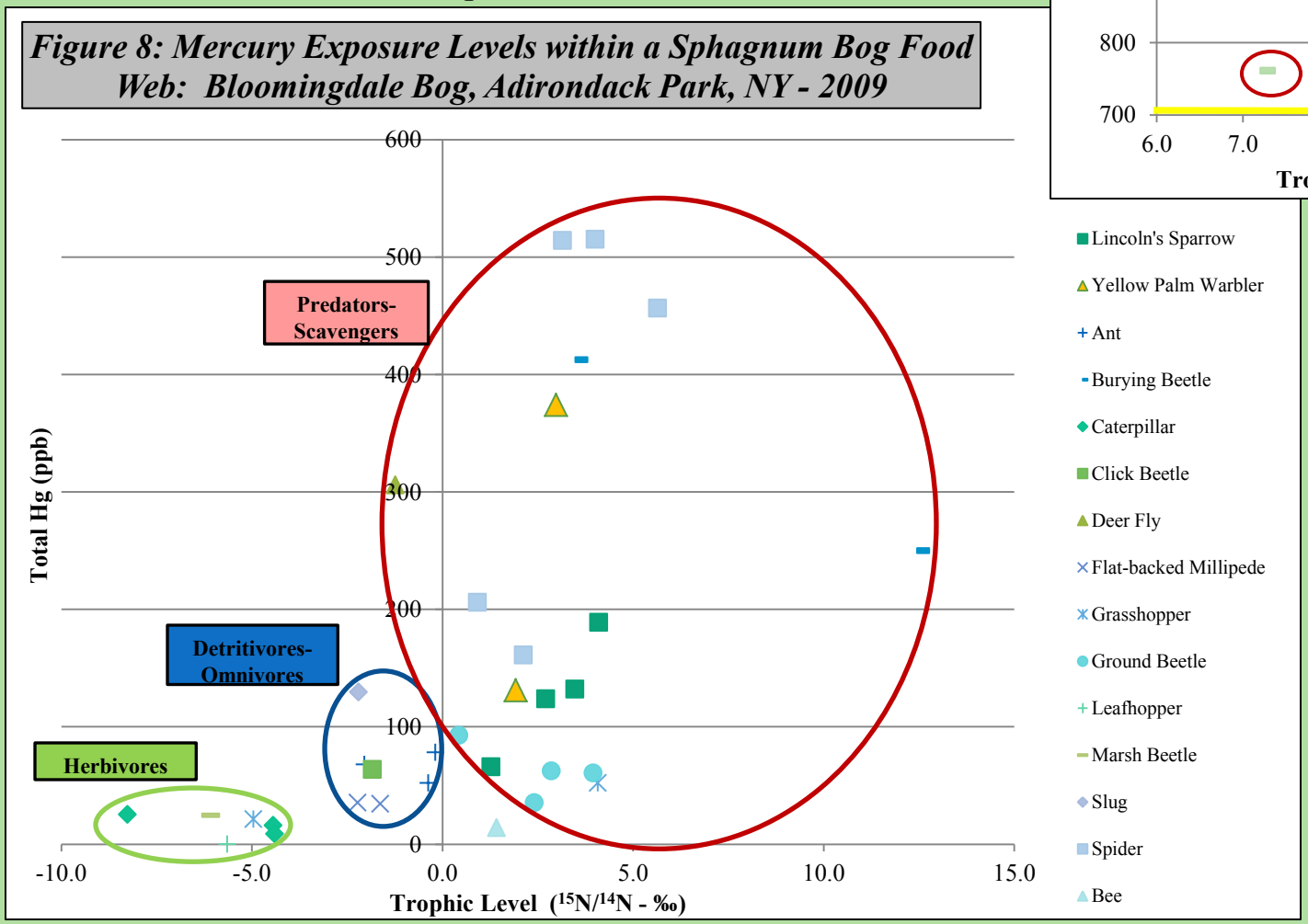


Figure 7: Mean (+ SD) and maximum blood mercury (ppm, ww) of songbird species sampled between 1999 – 2010 with blood mercury that put them at risk of reduced nesting success. LOAELs associated with 10% (0.69 ppm), 20% (1.23 ppm), 30% (1.70 ppm) reduced nesting success were determined by Jackson et al. (2010). *Denotes neotropical migrant species.

Results – Stable Isotopes

- Demonstrate transfer and biomagnification of mercury across trophic levels from herbivores at the base of the food web to predators at the top of the food chain (Figure 8)
- Carbon isotopes ($^{13}C/^{12}C$) provide evidence that songbirds from the bog and forested systems are feeding on a foraging base from within their respective habitats

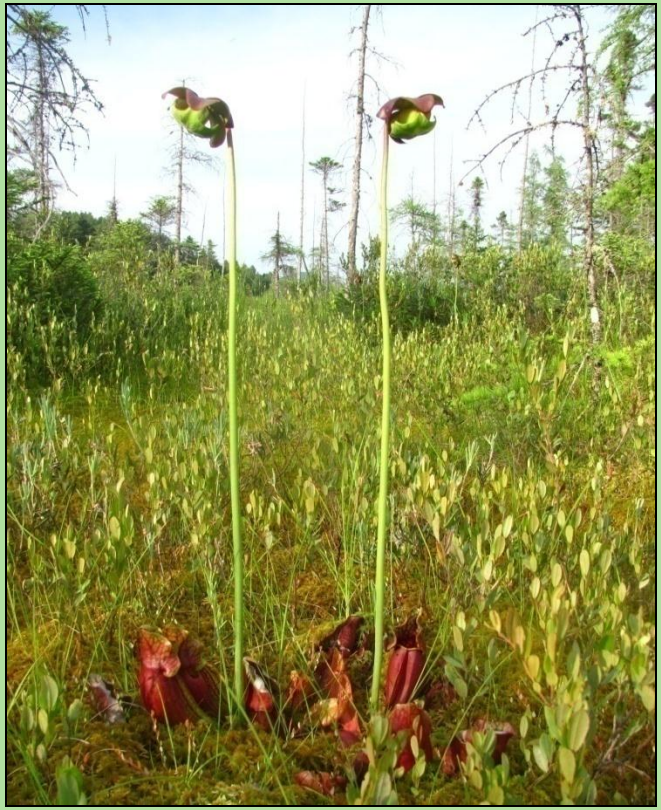




- Mercury in predatory and scavenger beetles were found to exceed levels associated with adverse reproductive impacts in songbirds (Figure 9).
- These high mercury beetles could represent strong trophic pathways for mercury bioaccumulation in songbirds consuming these prey items
- Prey selection, abundance and habitat type influence mercury and nitrogen isotopes signatures in food webs

Outreach Efforts

- Conference presentations, academic seminars and public presentations were conducted from 2008 to 2012 to educate others about the research being conducted on mercury in terrestrial ecosystems as part of this NSRC-sponsored project



- Summer internships were provided for 5 undergraduate women from SUNY-ESF, Northwestern University, Syracuse University and Princeton University in collaboration with this research investigation

Implications and applications in the Northern Forest region

- The results from this project will provide a better understanding of the connections between mercury deposition and trophic transfer through regional terrestrial ecosystems.

- Ideally, these studies can be used as a foundation to direct future research and monitoring efforts designed to examine critical issues of air quality, environmental integrity and wildlife health in the Northern Forest region.

- Considering that limited stable isotope analysis has been conducted within the context of trophic structure and mercury bioaccumulation in the Northern forest, the results from the Adirondack analysis will improve our understanding of mercury transfer through biota and forested ecosystems within the Northeastern landscape.

Future directions

- Continued collection of biotic and abiotic samples targeting sensitive habitats and avian species of concern
- Synthesis of datasets and results of analyses to identify information gaps that require further investigation

- Additional research to better characterize the mechanisms of mercury cycling through sensitive, terrestrial foodwebs
- Further isotope analyses, including mercury isotopes, to improve understanding of the complexities of food web dynamics and transfer of mercury through forested ecosystems across the Northeastern landscape

List of products

Peer-Reviewed Publications

- Yu, X., C.T. Driscoll, J. Huang, T. Holsen and B. Blackwell. 2012. Modeling and mapping of atmospheric mercury deposition in the Adirondack Park, New York. PLOS ONE. Manuscript submitted for publication.
- Sauer, A.K., C.T. Driscoll and D.C. Evers. Mercury cycling, spatial patterns of bioaccumulation, and mechanisms of trophic transfer within *Sphagnum* Bog and Northern Hardwood Forest Habitats – Adirondack Park, New York. Series of journal articles in preparation for expected completion in 2013.

Technical Reports & Publications

- Evers, D.C., A.K. Jackson, T.H. Tear and C.E. Osborne. 2012. Hidden Risk: Mercury in Terrestrial Ecosystems of the Northeast. BioDiversity Research Institute. Gorham, Maine. BRI Report 2012-07. 33 pages.
- Osborne, C. E, D. C. Evers, M. Duron, N. Schoch, D. Yates, D. Buck, O. P. Lane, and J. Franklin. 2011. Mercury Contamination within Terrestrial Ecosystems in New England and Mid-Atlantic States: Profiles of Soil, Invertebrates, Songbirds, and Bats. Report BRI 2011-09. Submitted to The Nature Conservancy – Eastern New York Chapter. BioDiversity Research Institute, Gorham, Maine.

List of products

Presentations

Presented by Charles Driscoll

- "Every Cloud Has a Quicksilver Lining: Inputs and Dynamics of Mercury in Forest Ecosystems of the Northeast" presentation given for the Atmospheric Sciences spring seminar series in the School of Engineering and Applied Sciences at Harvard University, Cambridge, MA, 28 January 2011.
- "Mercury Pollution: Impacts, Sources and Tracking" presentation given at Capitol Hill briefing, Washington, DC, 14 June 2011.
- "Mercury Pollution: Impacts, Sources and Tracking" presentation given at NGO briefing, Washington, DC, 14 June 2011.
- "Human Alteration of Hg Cycle: A Mostly "Land" Perspective" presentation given as a Plenary Speaker at the 2011 International Conference on Mercury as a Global Pollutant, Halifax World Trade and Convention Center, Halifax, NS, 23-29 July 2011.
- "Great Lakes Mercury Connections" presentation given at a press conference at the Westin Book Cadillac for the Great Lakes Mercury Connections: The Extent and Effects of Mercury Pollution in the Great Lakes Region report, Detroit, MI, 11 October 2011.

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Presentations

Presented by Charles Driscoll

- "Great Lakes Mercury Connections" presentation given at a press conference for the U.S. House of Representatives for the Great Lakes Mercury Connections: The Extent and Effects of Mercury Pollution in the Great Lakes Region report, Washington, DC, 25 October 2011.
- "Great Lakes Mercury Connections" presentation given at a press conference for the U.S. Senate for the Great Lakes Mercury Connections: The Extent and Effects of Mercury Pollution in the Great Lakes Region report, Washington, DC, 25 October 2011.
- "Mercury Science and Policy" presentation given at the annual NYSERDA conference NYSERDA Environmental, Evaluation, and Protection (EMEP) in New York: Linking Science and Policy at the Holiday Inn, Albany, NY, 15 November 2011.
- "Great Lakes Mercury Connections" presentation given to the St. James Men's Breakfast, Skaneateles, NY, 13 December 2011.
- "Every Cloud Has a Quicksilver Lining: The transport, Bioavailability and Effects of Mercury in the Environment" presentation given for the Mercury, the Environment and Public Health lecture series at Smith College, Northampton, MA, 20 April 2012.

List of products

Conference, Public and Academic Presentations

Presented by Amy Sauer

- Northeast Ecosystems Research Cooperative Conference - Durham, NH. November 2008.
- New York State Energy Research & Development Authority EMEP Conference - Albany, NY. October 2009.
- SUNY ESF Adirondack Ecological Center Speaker Series - Newcomb, NY. July 2010.
- Oswego Rotary Chapter - Oswego, NY. October 2010.
- Northeast Ecosystems Research Cooperative Conference, Saratoga Springs, NY. November 2010.
- NYS Wetland Forum, Lake Placid, NY - April 2011.
- NYSERDA EMEP Conference, Albany, NY - November 2011.
- Northeast Natural History Conference, Syracuse, NY. April 2012.
- Catskill Center for Conservation and Development, Woodstock, NY. May 2012.
- 8 Academic Seminars – Syracuse University

Acknowledgements

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