Monitoring Spatial Gradients and Temporal Trends of Mercury in Songbirds of New York State, 2013–2017

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Monitoring Spatial Gradients and Temporal Trends of Mercury in Songbirds of New York State, 2013–2017

Summary Report

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Abstract

Mercury (Hg) is a global pollutant that impacts New York State songbird populations across many different ecosystems. Currently, songbirds are recognized as critical indicators of mercury in terrestrial ecosystems, where invertivore food webs are able to biomagnify methylmercury (MeHg) to levels that can adversely affect reproductive success in a variety of habitats. To understand the current status of mercury in State songbirds, the Biodiversity Research Institute conducted a five-year study (2013–2017) with the objectives of determining (1) the songbird species, habitats, as well as regions at greatest risk to mercury exposure, (2) how mercury exposure is changing over time in sensitive habitat types, and (3) how mercury is related to habitat, climate, and trophic food webs across the State. Trends of songbird Hg bioavailability were estimated over the entire five-year study period and mercury exposure was stable at most sites sampled, although some sites showed increases—particularly in Long Island. Areas of Hg concern were identified using statewide surveys. Most of these sites were in the core areas of the Adirondacks, Catskills, and Long Island, but new areas of high exposure were observed in the Finger Lakes (e.g., North Montezuma Wildlife Management Area) and New York City regions. Temporal trends in Hg bioavailability were assessed at multiple scales for songbirds. Over the past 100–150 years, Hg exposure increased in many indicator species in the northeastern United States. Mercury in songbird feathers increased from the 1900s to the 1980s, then appears to have stabilized afterward. Mercury exposure was highly variable throughout the State at both regional and site scales. While Long Island, the Catskills, and the Adirondacks had some of the highest Hg concentrations, there was high variability within these regions. Across New York State, wetland area in proximity to the sampling site was an important predictor for songbird Hg exposure, although wetlands in some regions were observed to have a greater effect on songbird concentration levels than others. Long-term climate patterns also influenced Hg exposure concentrations—temperature was a particularly strong effect, as warmer climates tended to have higher songbird Hg. The role of trophic position and diet on Hg exposure was examined using species-level trophic estimates and carbon/nitrogen stable isotope signatures to assess individual-level diet. Species-level information was not a strong predictor of Hg exposure, while individual estimates of trophic level were. The results of this study were also used to provide recommendations for a New York State songbird mercury monitoring plan that can be used to inform future research efforts and assess the bioavailability of mercury across the State.

Keywords

Mercury, Songbirds, Bioaccumulation, Habitat, Trophic Level, Climate Change, New York State

Acknowledgments

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1 Focus

To understand the current status of mercury (Hg) in New York State songbirds, the Biodiversity Research Institute conducted a five-year study with the objectives of determining (1) the songbird species, habitats, as well as regions at greatest risk to mercury exposure, (2) how mercury exposure is changing over time in sensitive habitat types, (3) and how Hg is related to habitat, climate, and trophic food webs across the State. This project builds on previous long-term Hg monitoring studies on songbirds across the Northeast (e.g., Lane et al. 2011, Evers et al. 2012, Lane et al. in review) as well as 14 years of mercury research in the state of New York funded through several New York State Energy Research and Development Authority (NYSERDA)-Environmental Monitoring, Evaluation, and Protection (EMEP) projects. Over 4,500 blood and 2,200 tail and/or flank feather samples have been collected from songbirds in the State since 2000.

From 2013–2017, 2,425 songbirds have been assessed for Hg exposure in New York State. Blood Hg samples were collected to assess mercury exposure in 104 species across many of the State's regions. The samples were used to (1) evaluate temporal changes in Hg concentrations over the last five years in the core study areas of the Adirondack Mountains, Catskill Mountains, and Long Island and (2) develop predictive models that determine the role of habitat, climate, and trophic level in songbird Hg exposure in a spatially explicit manner. This study significantly improves the state of knowledge about Hg in regional songbird communities and assists in the development of long-term strategies for additional Hg monitoring activities in New York State.

2 Context

Mercury is a pollutant that is globally distributed, but locally variable in availability for biomagnification and bioaccumulation (Evers and Clair 2005, Driscoll et al. 2013). After being emitted to the atmosphere from natural (e.g., volcanoes) and anthropogenic (e.g., coal-fired power plants, municipal incinerators, etc.) sources, Hg can be globally transported on air currents and deposited on habitats far from the original sources (Vanarsdale et al. 2005, Driscoll et al. 2007). Additionally, Hg can enter habitats from local sources through atmospheric deposition (e.g., municipal incinerators in the Everglades or small-scale artisanal gold mining in the Amazon; Telmer and Veiga 2009, Gibb and O'Leary 2014) or via soil and/or water contamination from industrial activities (e.g., Superfund sites; Amos et al. 2013). Once deposited, microorganisms convert inorganic Hg to methylmercury (MeHg)—a more toxic, environmentally persistent form that has high potential for bioaccumulation and biomagnification in both aquatic and terrestrial ecosystems (Ullrich et al. 2001, Podar et al. 2015).

In vertebrates, and specifically avian communities, numerous neurological, immunological, and physiological effects have been documented as a result of MeHg exposure (Scheuhammer et al. 2007, Hawley et al. 2009, Wada et al. 2009) and these effects can influence life history parameters and alter demographic rates for populations (Brasso et al. 2008, Evers et al. 2008, Jackson et al. 2011, Whitney and Cristol 2017). Currently, songbirds are recognized as critical indicators of mercury in terrestrial ecosystems, where invertivore food webs are able to biomagnify methylmercury to levels that can adversely affect reproductive success in a variety of habitats (Cristol et al. 2008, Evers et al. 2012, Jackson et al. 2015). Songbirds species that are generalist invertivores, like many warblers, vireos, wrens, some sparrows, and thrushes, have been utilized in many studies to provide a representation of MeHg levels in various habitat types (Figure 1; Rimmer et al. 2005, Lane et al. 2011, Townsend et al. 2014) as birds are able to effectively integrate dietary Hg over time and are indicative of the amounts of MeHg present in the associated food chain when other indicators, like fish or amphibians, are absent.

Environmental changes are predicted over the next century in New York State, and these changes could potentially affect the bioavailability of Hg to songbirds. Mercury methylation rates are related to water quality (Miskimmin et al. 1992, Sellers et al. 1996), water temperature (Ramlal et al. 1993), and water stage dynamics (St. Louis et al. 2004) in wetland environments. All of these environmental variables are likely to be affected by the predicted changes to air temperature and precipitation over the next century (Meehl et al. 2007) and induce changes to Hg methylation rates in these systems (Schindler 2001). Moreover, the distribution and abundance of these wetlands will be altered by climate change (Craft et al. 2009, Kirwan et al. 2010, Kirwan and Megonigal 2013, Mitsch and Hernandez 2013, Schile et al. 2014), which could shift Hg hotspot locations across the northeastern United States. Finally, changes to Hg emissions rates over time (Zhang et al. 2016) and weather-dependent deposition rates (Mao et al. 2017) could also impact Hg bioavailability. The future of Hg in New York State is complex and challenging to forecast; research and monitoring programs that can refine our understanding of Hg risk to wildlife populations will be critical to understanding the Hg landscape of the future.

Figure 1. Yellow Palm Warbler, Massawepie Mire, Adirondack Park, NY

(Photo credit: A. Sauer)

3 Goals and Objectives

The project focused on the following primary objectives:

- Conduct annual monitoring at sites in the Adirondack Mountains, Catskill Mountains, and Long Island to both supplement historical Hg songbird samples and to evaluate temporal trends in songbird mercury exposure.
- Sample sites statewide to identify new areas, species, and habitats with high potential for Hg exposure.
- Relate mercury exposure with trophic position, diet, and habitat use by utilizing stable isotope signatures of carbon and nitrogen.
- Use museum specimens of songbirds to quantify trends in Hg exposure over the 20th century.
- Use data from all Hg sampling to determine (1) the role that habitat and climate play in songbird Hg exposure and (2) how changes to these environmental conditions could affect Hg risk in the future.

4 Study Area and Methods

4.1 Sampling Design and Study Areas

Sampling sites were selected across New York State based on the following criteria: (1) previous Hg sampling efforts for songbirds or other biota, (2) habitat sensitivity to MeHg bioaccumulation, and (3) proximity of Hg emission sources. Two types of sampling sites, core (n=11) and statewide (n=44), were designated to assess study objectives related to spatial and temporal trends and varied in frequency of sample collection (Figure 2). Core sites, designed to estimate temporal trends in Hg bioavailability, were locations where songbirds were sampled during all five years of the study. Four sampling sites were selected in three regions: Adirondack Mountains, Catskill Mountains, and Long Island. Core sites were located within regions that are known to have high levels of Hg in songbirds and were also selected due to the large amounts of data previously collected at these sites and strong evidence of consistently elevated tissue Hg levels (Driscoll et al. 2007, Evers et al. 2007). Each core region also has a nearby Mercury Deposition Network (MDN) atmospheric Hg monitoring station for comparative analysis with Hg levels in biota. Statewide sampling sites were visited at least once during the five-year study, as these sites were used for identifying and mapping new Hg areas of concern and species of concern. Six regions encompassed the statewide sampling sites: Western New York/Lake Ontario, Northern New York, Tug Hill Plateau, New York City, the Finger Lakes Region, and the Capital Region.

4.2 Bird Capture and Tissue Sampling

All bird capture and blood and feather sampling was conducted during periods of peak breeding activity in June and July from 2013–2017 using non-lethal, mist-netting techniques. A series of recorded conspecific vocalizations were used to elicit a territorial response from breeding birds and attract them to the net location. Our sampling scheme focused primarily on invertivorous species that are likely to be exposed to Hg, but all birds in the associated community were possible to capture. All birds were released unharmed within 10–25 minutes of capture.

Once captured, each bird was banded with a uniquely numbered United States Geological Survey (USGS) aluminum band. During processing, age, sex, reproductive status, wing chord length, tarsus length, mass, and fat score were recorded. Blood samples were collected via venipuncture of the cutaneous ulnar vein with a 27-gauge sterile disposable needle. Fifty to 75 µl of whole blood was collected into heparinized, Mylar-wrapped capillary tubes for Hg and stable isotope analysis. Two tail feathers (R6) were also collected from each bird, and one primary feather (P1) was collected from sparrows on Long Island to compare to previous monitoring efforts. Approximately 5–6 flank feathers were collected from all songbirds for comparison with archived museum feather specimens at the Harvard Museum of Comparative Zoology to evaluate current levels of Hg availability with historical Hg levels from the 19th–20th centuries.

4.3 Laboratory Analysis

All whole blood, body, and flight feather samples were analyzed for total Hg. Mercury concentrations in blood reflect recent dietary uptake. Samples were collected during the breeding period, and thus reflect a bird's Hg exposure at its breeding habitat. Methylmercury was not analyzed because approximately 95% of total Hg in songbird blood and feathers is in the form of MeHg (Rimmer et al. 2005, Edmonds et al. 2010).

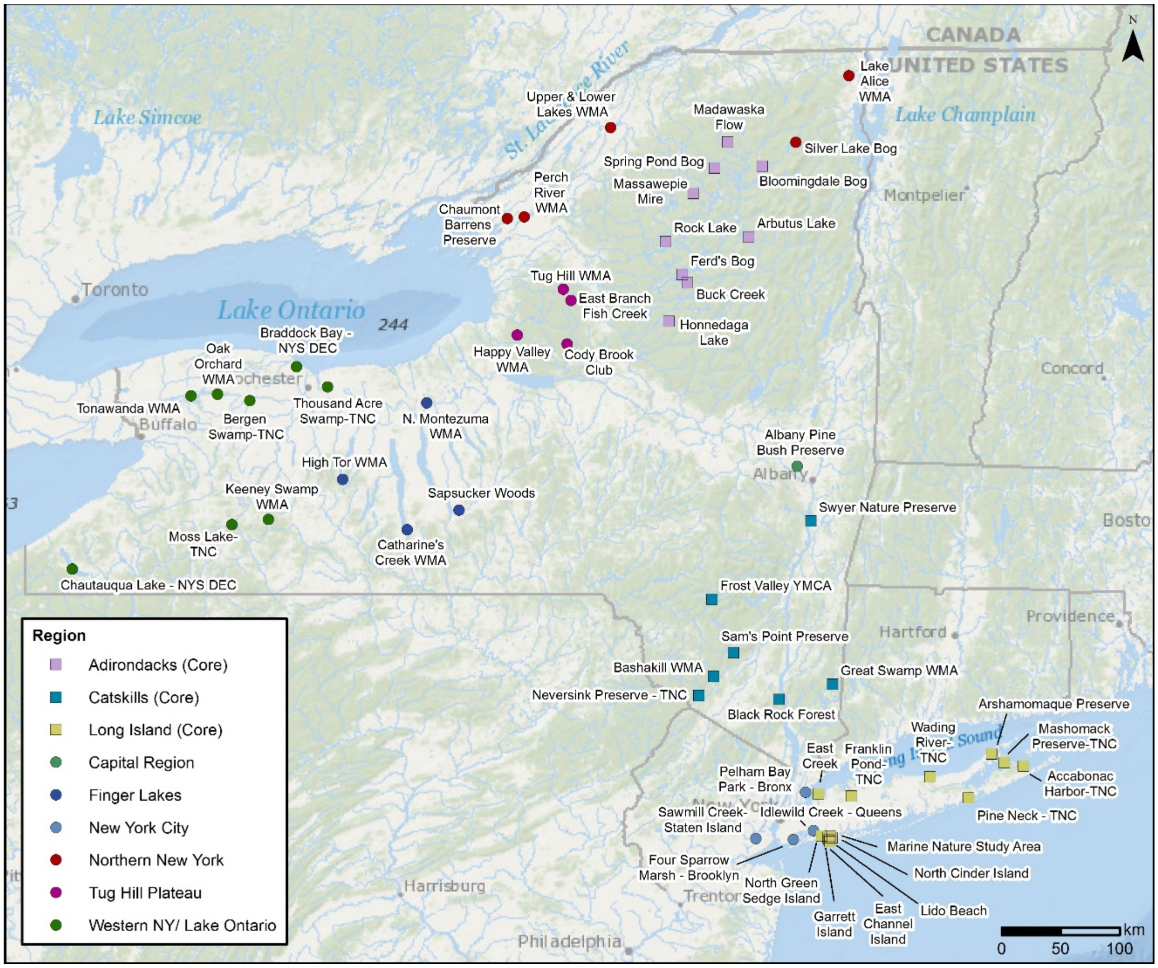
Flank feather samples, from nine species of birds collected from archived specimens at the Harvard Museum of Comparative Zoology, were analyzed for MeHg at the John A. Paulson School of Engineering & Applied Sciences Laboratory at Harvard University.

A total of 1,018 songbird blood samples were analyzed at the Boston University Stable Isotope Laboratory in Boston, Massachusetts for stable carbon and nitrogen isotope ratios. Isotopic signatures are used to provide an estimate of relative position in the food web.

4.4 Statistical Analysis

Climate and land cover (Homer et al. 2015) data were collected from publicly available databases to pair with the Hg data collected in this study. All methods for statistical analysis, including evaluation of summary statistics and general linear mixed model frameworks, are outlined in the NYSERDA final report by Biodiversity Research Institute (2020).

Figure 2. New York State Songbird Sampling Locations, 2013–2017



5 Project Findings

5.1 Avian Mercury Exposure Summary

Mercury concentrations varied widely among sites and species in the blood and feather samples analyzed from 2013–2017. The blood Hg concentrations (n=2243) ranged from a low of below the instrument detection limit in an American goldfinch at Neversink Preserve to a high of 4.1 parts per million (ppm) wet weight (ww) in a swamp sparrow from North Montezuma Wildlife Management Area. Tail feather Hg (n=1869) ranged from below the instrument detection limit in a seaside sparrow on North Cinder Island to 29.2 ppm fresh weight (fw) in a blue-gray gnatcatcher from Mashomack Preserve on Long Island. Mercury in first primary (P1) feathers (n=38) ranged from 0.5 ppm fw in a song sparrow in Accabonac Harbor to 18.6 ppm in a saltmarsh sparrow from North Cinder Island. The highest mean blood Hg levels were identified in Long Island tidal marshes at 1.4 ppm ww. Songbirds on Long Island and in New York City had the highest average blood Hg concentrations, followed by the Finger Lakes, Adirondacks and Catskills Regions (Table 1).

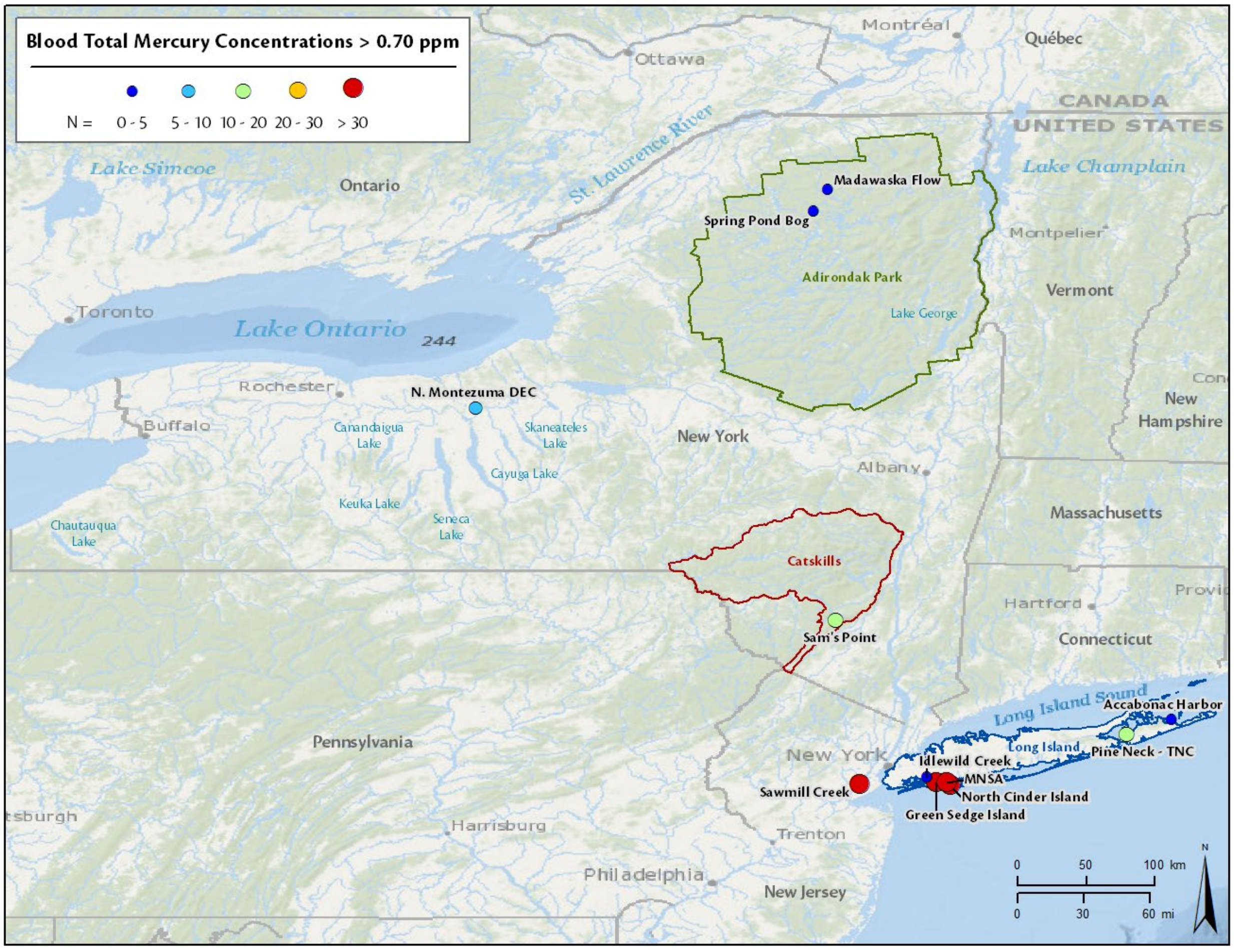
Individuals with high blood Hg tended be spatially clustered (Figure 3). Tidal marsh sites across Long Island, like North Green Sedge Island and Cinder Island, had consistently high levels of mercury in marsh-obligate species (> 0.7 blood Hg ppm ww). This mostly occurred in saltmarsh sparrows, but other sparrow species and flycatchers using habitat adjacent to the tidal marshes were also found to be high in blood Hg. Sawmill Creek, in the nearby New York City Region, also had a large proportion of high-risk individuals. The Catskills Region had moderate or greater risk individuals at Sam's Point Preserve; the Finger Lakes Region had high individuals at Montezuma National Wildlife Refuge; and Sphagnum bog sites at Spring Pond Bog and Madawaska Flow in the Adirondacks also had high-risk individuals.

Table 1. Mean Blood Mercury Concentrations, Standard Deviation (SD) and Sample Size (n) for Regions Sampled from 2013–2017

Region	Year														
	2013			2014			2015			2016			2017		
	Mean (ppm)	SD	n	Mean (ppm)	SD	n	Mean (ppm)	SD	n	Mean (ppm)	SD	n	Mean (ppm)	SD	n
Adirondacks	0.18	0.16	68	0.18	0.17	101	0.18	0.13	110	0.18	0.14	167	0.23	0.17	90
Capital Region							0.05	0.04	56						
Catskills	0.12	0.10	139	0.13	0.20	105	0.12	0.14	93	0.19	0.24	90	0.15	0.16	82
Finger Lakes							0.37	0.20	17	0.35	0.54	84			
Long Island	0.52	0.41	126	0.45	0.44	176	0.72	0.65	73	0.65	0.49	132	0.61	0.57	96
Northern New York							0.10	0.10	55	0.20	0.14	33			
New York City	0.41	0.33	75	0.49	0.51	107	0.53	0.57	62	0.50	0.55	64			
Tug Hill				0.10	0.07	38	0.17	0.13	41						
Western NY/Lake Ontario							0.14	0.11	46				0.12	0.08	98

Figure 3. Spatial Distribution of Songbirds at Moderate Risk of Mercury Effects

Map of potential hotspots based on blood total mercury (THg) concentrations in songbirds sampled in New York State in 2013–2017 (the size and color of the circle represents the number of individual birds above moderate risk). Moderate risk is defined as > 0.7 ppm ww blood Hg as defined using Jackson et al. (2011).



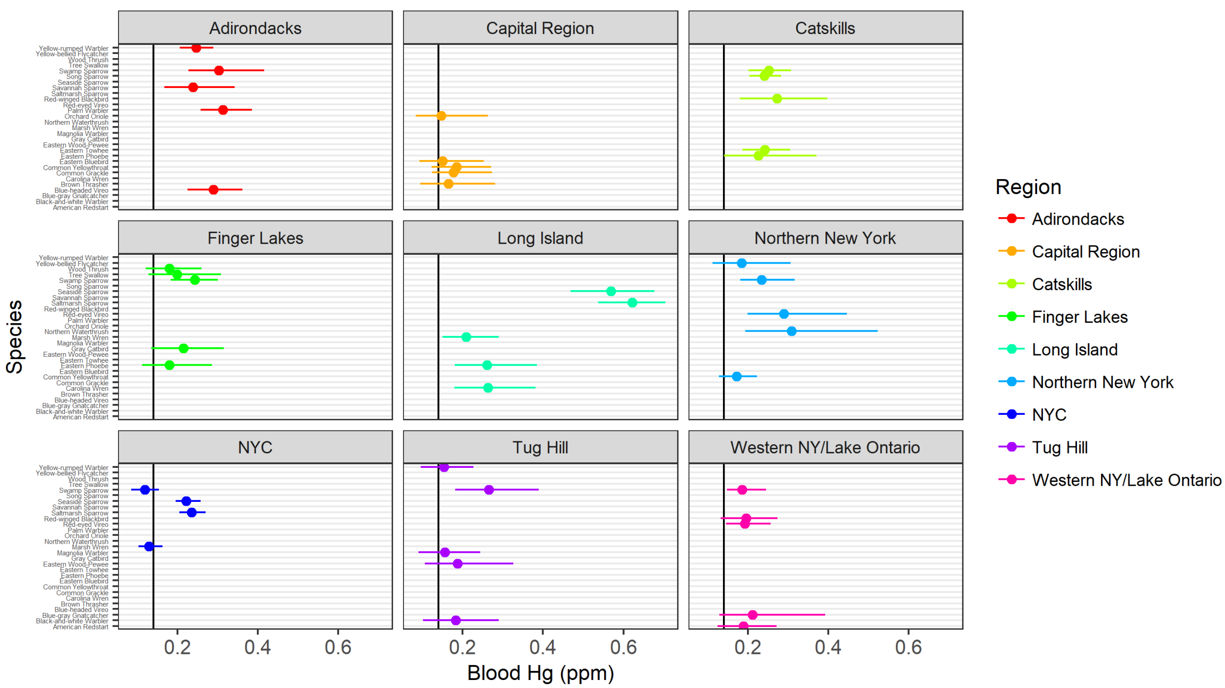
5.2 Identifying Priority Species

The large number of sites and generalist sampling approach of this project provides an opportunity to evaluate many species in their role as indicators of Hg bioavailability. Using the general linear mixed model that is focused on variation in blood Hg across species, sites, and regions, the average blood Hg was estimated for each species in the regions where they were captured. Long Island saltmarsh and seaside sparrows were the highest species/region combinations, while purple and house finches in Northern New York and Long Island were the lowest. By examining the top five Hg species per region, the most consistently observed Hg sensitive species can be identified for each region (Figure 4).

Differences in songbird blood Hg concentrations among regions likely have many potential origins. Some sites, particularly in Long Island, may be close to local sources of industrial origin while other sites may have high songbird Hg concentrations due to higher local deposition rates. But habitat-specific Hg methylation rates also can cause significant differences among sites that likely have similar Hg deposition rates. The Capital Region was found to have very low Hg concentrations across all levels of the food web, as there is limited bioavailable Hg for uptake into associated food webs. On the other hand, the Catskills and the Adirondacks have wetland habitats with high Hg methylation rates and have bioavailable Hg in multiple components of the terrestrial/aquatic food web.

Figure 4. Top Five Species by Blood Mercury for Each Region

The error bars represent the 95% confidence interval of the regional blood Hg concentration estimate for each species. The solid black line is the overall average blood Hg concentration across all sites and regions.



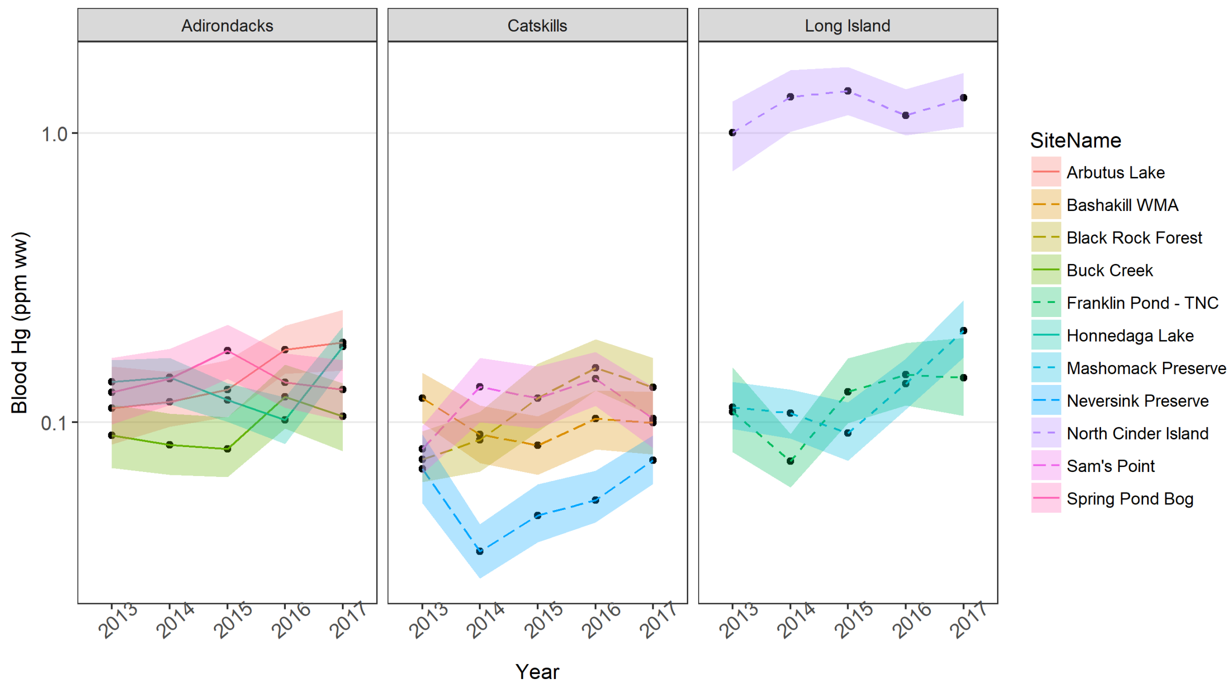
5.3 Temporal Trends in Mercury Bioavailability

Using our temporal trends general linear mixed model, it was determined that changes in Hg across sites and years were statistically important. While most core sites sampled in all five years have similar levels of songbird blood Hg over time, diversity in trends was documented across the three core regions (Figure 5). All Long Island sites showed increases over time, although Franklin Pond and Mashomack

Preserve showed the greatest increase. The Catskills showed the greatest diversity in trends among their sites. Most sites stayed close to their five-year average, while Neversink Preserve showed a significant decrease in the middle years only to increase back to 2013 levels by 2017. All Adirondack sites showed slight increases that appeared to be within the 95% confidence intervals for each estimate at a site.

Figure 5. Modeled Trends in Songbird Mercury Levels at Core Sites, 2013–2017

Average annual blood Hg concentrations in songbirds at core sites in Adirondacks, Catskills and Long Island Regions, 2013–2017. These estimates are plotted on a log-transformed scale for visual clarity. Each annual estimate for a site is for the average bird across all sites and all regions in the study. Absolute levels of blood Hg concentration can vary among sites depending on the species captured each year.



5.4 Spatial Variation in the Role of Habitat and Climate on Mercury Bioavailability

Using the habitat and climate general linear mixed model, it was determined that 50-year summer temperature averages, 50-year summer precipitation averages, and wetland habitat area were all important for predicting changes in Hg in songbirds. Moreover, there were strong regional components to these covariates—climate and habitat differences among sites had different effects in New York City than in the Adirondack Mountains.

Analyses indicated that increasing wetland area increases songbird blood Hg in almost all sites. The positive effect of wetlands on blood Hg is particularly important in the New York City and Catskills regions (and marginally less important in Long Island), while there is more uncertainty in the estimates for other regions (Figure 6). Average summer temperatures have a more complex effect. Western New York/Lake Ontario, New York City, and the Finger Lakes Regions show a positive relationship between temperature and blood Hg, while Northern New York has a negative relationship (Figure 7). Here, even though the fixed effect was not statistically significant for all regions, average temperatures are important to blood Hg concentrations in many regions. The effect of rainfall was consistently positive on songbird Hg and there was limited variation among regions.

Figure 6. The Effect of Wetland Habitat on Songbird Blood Mercury Across Regions

Regional estimates of the beta parameter describing the effect of wetland habitat acreage on songbird blood Hg concentrations. Point estimates are a combination of the overall fixed beta estimate combined with the random effect estimate for each region. The error bar represents two times the standard deviation of the combined estimate and the dotted blue line is at zero. If the error bar overlaps zero, then it is likely that the effect is not strong in that region. The standard deviation is estimated by combining the variance of the fixed and random effects using the delta method.

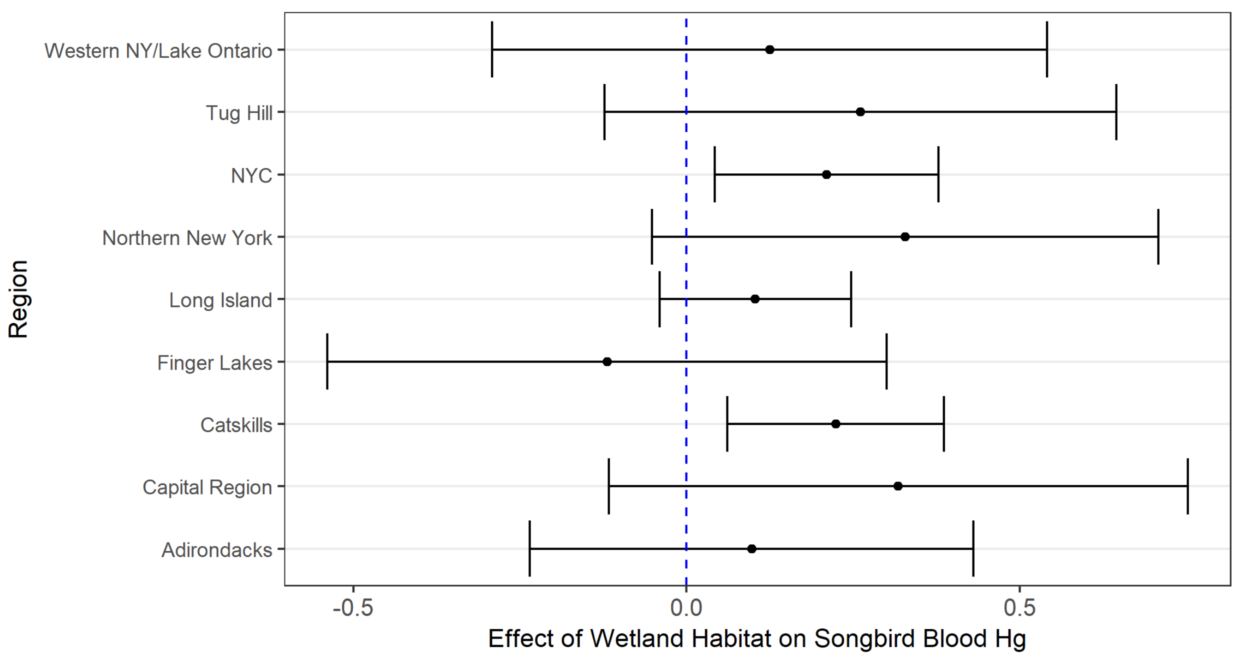
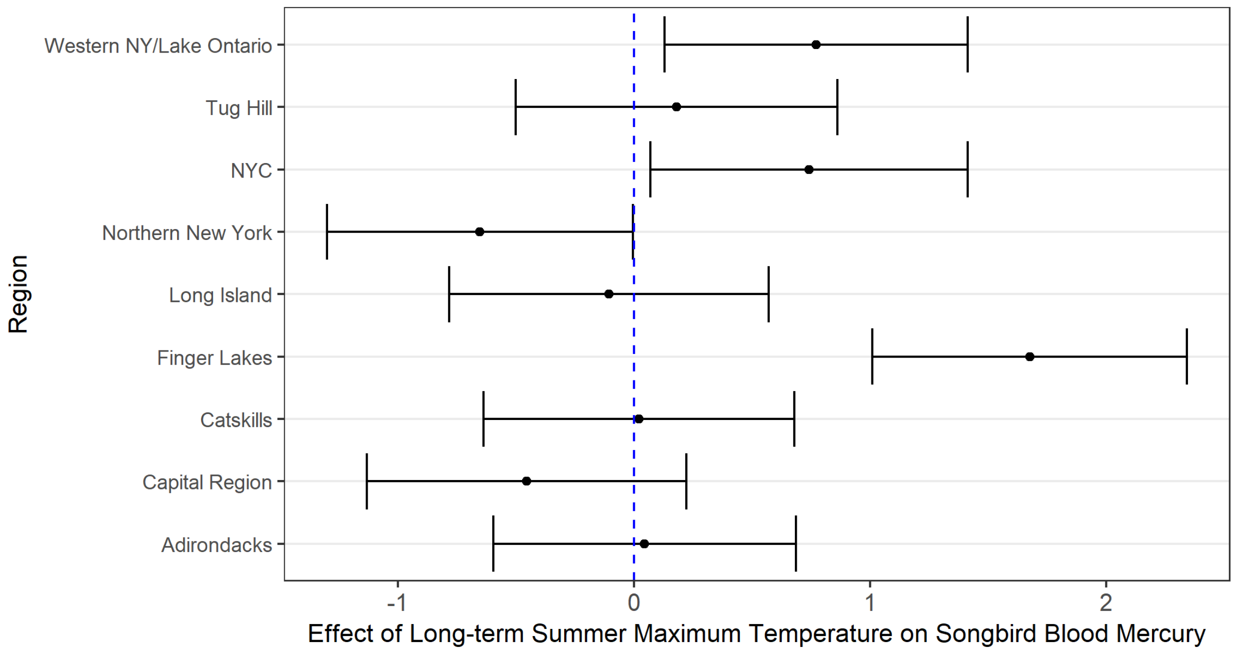


Figure 7. The Effect of Summer Maximum Temperatures on Songbird Blood Mercury Across Regions

Regional estimates of the beta parameter describing the effect of 50-year average summer maximum temperatures on songbird blood Hg concentrations. Point estimates are a combination of the overall fixed beta estimate combined with the random effect estimate for each region. The error bar represents two times the standard deviation of the combined estimate and the dotted blue line is at zero. If the error bar overlaps zero, then it is likely that the effect is not strong in that region. The standard deviation is estimated by combining the variance of the fixed and random effects using the delta method.



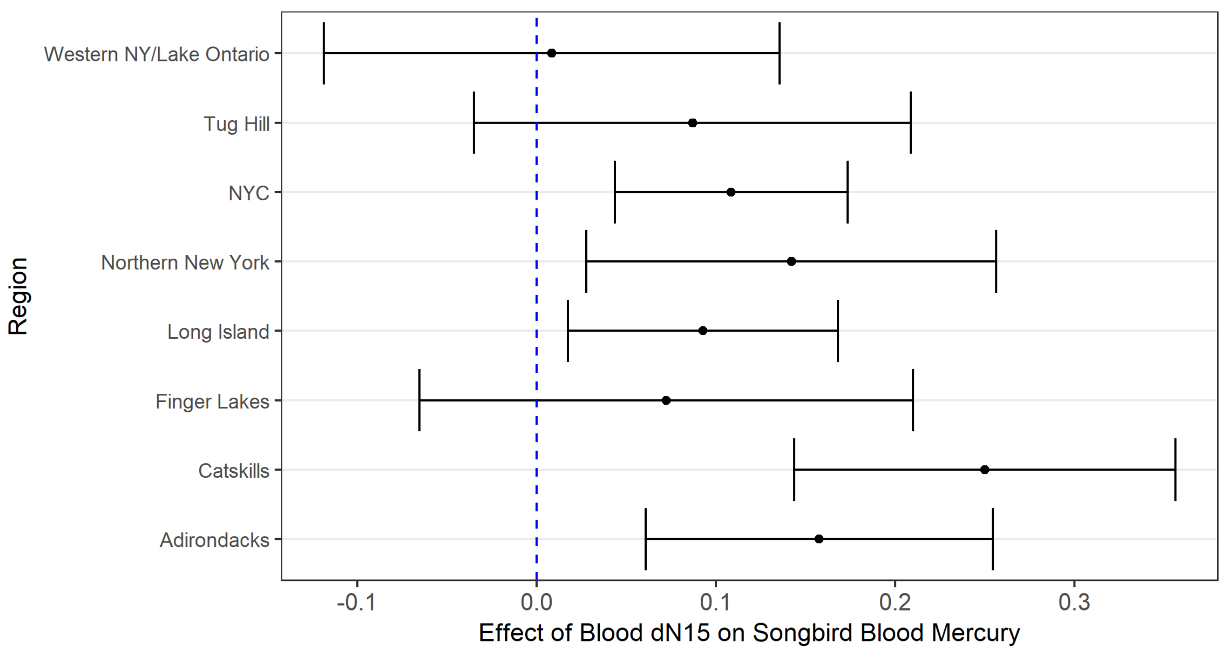
5.5 Relations Between Blood Mercury and the Food Web

Using the habitat/climate general linear mixed model, the effect of a species-level invertebrate diet on the amount of Hg found in an individual's blood was examined. Generally, this was a weak effect that showed no consistent pattern across all regions.

Using the stable isotope general linear mixed model (n=1018), the effect of individual-level $\delta^{13}C$ and $\delta^{15}N$ on blood mercury levels was explored. A marginal negative effect of $\delta^{13}C$ on blood mercury levels that was invariable among regions was documented. Depleted $\delta^{13}C$ values indicate that the animal's food is coming from wetter habitats that have higher Hg bioavailability potential, but there is high site-to-site variance in this process that likely represents variation in the types of mesic habitat the $\delta^{13}C$-depleted diet is linked to. The effect of $\delta^{15}N$ was strongly positive, and also variable by region (Figure 8). As enriched $\delta^{15}N$ values indicate an individual foraging from a higher trophic position, analysis documented that trophic level was strongly correlated with blood Hg. The effect was strongest in the Adirondacks, Catskills, New York City, Northern New York, and Long Island, and was the weakest in Western New York/Lake Ontario.

Figure 8. The Effect of Stable Nitrogen Isotopes on Songbird Blood Mercury Across Regions

Regional estimates of the beta parameter describing the effect of blood $\delta^{15}N$ (per mil) on songbird blood Hg concentrations. Point estimates are a combination of the overall fixed beta estimate combined with the random effect estimate for each region. The error bar represents two times the standard deviation of the combined estimate and the dotted blue line is at zero. If the error bar overlaps zero, then it is likely that the effect is not strong in that region. The standard deviation is estimated by combining the variance of the fixed and random effects using the delta method.



5.6 Changes in Mercury Bioavailability Over the Past 100–150 Years

Bioavailability of Hg to songbirds has been increasing for most of the 20th century and the levels currently observed appear to be a maximum for many species. Overall, species-corrected feather Hg concentrations increased from 1900 to 1980 with levels steadying past 1980. In terms of individual species, wood thrush, rusty blackbirds, and saltmarsh sparrows saw significant increases in feather Hg from the turn of 19th century until more recent times. Sometimes these differences could be on the scale of over an order of magnitude (e.g., rusty blackbird). Many of these species (e.g., saltmarsh sparrows and rusty blackbirds) are of significant conservation concern. It is unclear what role Hg exposure has played in some of these large population declines, but it is certainly a mechanism that warrants further research and an issue that should be considered when developing conservation plans.

6 Study Implications

The lessons learned during this multiyear project can be used to create monitoring recommendations to inform future efforts. First, this study was able to identify a suite of songbird indicator species for each region of New York State that increases the confidence that Hg bioavailability is detected (Figure 4). Second, a framework was provided for site selection and sample collection for future monitoring efforts that minimizes uncertainty in songbird Hg bioavailability assessments and is robust to a variety of sampling conditions. For further details, relating to the specific recommendations for the New York State songbird-mercury monitoring plan, based on the results of this study, please refer to the NYSERDA final report by Biodiversity Research Institute (2020).

The dynamics of Hg bioavailability is related to many complex ecological processes across New York State. Mercury exposure varies across species, regions, sites, trophic niches, habitats, and climate regimes. In the future, it is expected that climate change will directly alter temperature, precipitation, and other weather patterns that in turn will affect songbird communities, habitat, and trophic relationships throughout the State. Moreover, while policy changes have reduced emissions, it is unclear how deposition rates will change in the future and the extent to which deposition rates predict Hg bioavailability. National and international policies relating to controlling Hg emissions are currently under development or in flux and this uncertainty emphasizes the importance of continued monitoring of Hg availability in the State's ecosystems. Taken together with the results of this study, it is suggested that there will be considerable uncertainty in future Hg bioavailability in New York State. Continued assessments of Hg bioavailability will be important to track the potential effects of Hg and to inform management decisions. Future research on understanding the small- and large-scale effects of a changing climate on Hg bioavailability across multiple ecosystems will be critical to accurately forecast the effects of Hg on New York State ecosystems and to safeguard ecological and human health in the coming century.

7 Conclusions

From 2013–2017, this study assessed the absolute Hg exposure risk to many songbird species and sites in New York State. For areas of Hg concern, trends of songbird Hg bioavailability were estimated over the entire five-year study period. Mercury exposure was stable at most sites sampled in this survey area, although some sites showed increases—particularly in Long Island. Areas of Hg concern were identified using statewide surveys. Most of these sites were in the core areas of the Adirondacks, Catskills, and Long Island, but new areas of high exposure were observed in the Finger Lakes (e.g., North Montezuma Wildlife Management Area) and New York City regions.

Temporal trends in Hg bioavailability were assessed at multiple scales for songbirds. Over the past 100–150 years, Hg exposure increased in many indicator species in the northeastern United States. Mercury in songbird feathers increased from the 1900s to the 1980s, then appears to have stabilized afterward. This increase corresponds with a rise in industrialization and Hg emissions in North America during this time period. Over the 2013–2017 study period, generally stable patterns were observed at sites across New York State. Changes to Hg emissions regulations in the United States was likely decreasing Hg deposition across the State, but this pattern was not observed in songbirds. The lack of connection between recent changes in Hg emissions and songbird Hg exposure could be related to temporal lags between Hg deposition and subsequent bioavailability, atmospheric deposition not being the primary limiting factor in songbird Hg exposure, or Hg inputs to sites from local sources.

Mercury exposure was highly variable throughout New York State at both regional and site scales. While Long Island, the Catskills, and the Adirondacks had some of the highest Hg concentrations, there was high variability within these regions. Across the State, wetland area in proximity to the sampling site was an important predictor for songbird Hg exposure, although wetlands in some regions were observed to have a greater effect on songbird concentration levels than others. More expansive wetlands in the sampling area lead to increasing levels of Hg exposure when compared to smaller wetlands. Since methylation varies due to differences in wetland type, the regional differences were likely a reflection of these site-specific differences in wetland habitat type.

Long-term climate patterns also influenced Hg exposure concentrations—temperature was a particularly strong effect as warmer climates tended to have higher songbird Hg. Higher temperatures can influence Hg methylation rates in wetlands, so this observation may be describing regional patterns in methylation rates or climate-related wetland microhabitat differences. While the causality is uncertain, these results suggest that future increases in temperature could result in increased songbird Hg exposure; while such patterns have been theorized, this study presents evidence for their importance.

In many ecosystems trophic position can be a strong predictor of Hg exposure. In this study, it was determined that species-level quantifications of diet to better estimate trophic position were not such a predictor. Rather, individual-level trophic position estimates through stable nitrogen isotope signatures proved to be strongly correlated with blood Hg concentrations. These data suggest that while species-level behavior patterns provide the potential for examining Hg exposure, individual dietary preferences and local trophic food web complexity are what turns this potential into actual exposure.

There are many questions that remain about the causes and patterns of Hg exposure in New York State songbird species. But this project has described the locations that merit further monitoring, habitat and climate conditions that create high Hg exposure conditions, as well as the role that trophic relationships play in determining Hg sensitivity. Climate change is a source of great uncertainty in forecasting the future of many species; the effects of Hg is another in a long list of potential effects that are not well understood. Future research to better understand the impact of a changing climate on Hg bioavailability across multiple ecosystems will help reduce such uncertainty and inform conservation decision-making from emissions regulations to species listing and delisting.

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