Assessing mercury in the Delaware, Croton and Upper Hudson watersheds, 2007

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Photo caption: *Song Sparrow (Melospiza melodia). Photo provided by BRI staff.*

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(BRI 2009-06)

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1.0 EXECUTIVE SUMMARY

To understand terrestrial mercury (Hg) pathways, we sampled litterfall, soil, breeding songbirds, invertebrates, raptors and bats for Hg and analyzed a subset of songbird, soil and litterfall for calcium. We obtained 151 samples (3 raptors, 67 songbirds, 15 bats, 51 invertebrates, 8 soil and 6 litterfall samples) from five sites (Bog Brook Unique Area, Bashakill Wildlife Management Area, Great Swamp, Devil's Tombstone and Neversink-Frost Valley) within the Lower Hudson River Valley region of New York, which consisted of the Delaware, Upper Hudson (lower portion) and Croton watersheds.

Except for an Eastern Wood Pewee (Blood Hg=1.17 ww,ppm) from Great Swamp, species sampled from the sites did not reach or exceed working lowest observed adverse effect levels (LOAEL) . However, compared with national and state data points, songbirds sampled within the three watersheds had some of the highest mean blood Hg levels in the nation and the state of New York.

2.0 INTRODUCTION

Mercury (Hg) contamination in the northeastern U.S. is well-documented (Bank et al. 2007, Driscoll et al. 2007, Evers et al.2007) and continues to be a public-health issue of concern (Schober et al 2003, Mahaffey et al. 2004). Hg contamination and its potential ecotoxic effects on terrestrial invertivores including, songbirds, bats, and raptors inhabiting upland, wetland, riparian, and lotic (stream) ecosystems has received little attention, yet these species are widely distributed across watersheds, are possible vectors of mercury transport into the surrounding riparian zone and uplands, and comprise an energy base upon which higher trophic levels in riparian systems depend (Bank et al. 2006).

Although studies of Hg cycling in terrestrial ecosystems are limited, uplands soils have considerable capacity to store large quantities of atmospherically deposited Hg, particularly in the forest floor (Mason et al. 1994). In addition, new evidence connects methylmercury (MeHg) availability in upland forests with acidic soils; regressions based on spatial models of atmospheric Hg deposition across terrestrial ecosystems in the Northeast predicted 50% of the variation in Bicknell's Thrush blood Hg levels (Rimmer et al. 2005). Other recent studies suggest that accumulation in terrestrial ecosystems directly involves plants, through absorption of gaseous Hg stomatally, incorporation by foliar tissue, and subsequent release of Hg in litterfall (Ericksen et al. 2003).

While litterfall may represent the bulk of Hg input to forested ecosystems, the wash-off of dry-deposited Hg species in throughfall, direct deposition in precipitation, and uptake of dissolved Hg by roots with translocation to foliar tissue may also play roles (Rea et al. 2002). Total Hg inputs to eastern forests may largely be incorporated in the leaf-litter and forest floor, where it is available to invertebrates, such as gastropods (snails and slugs), isopods (woodlice), myriapods (millipedes), and to predators, such as centipedes (myriapods) and spiders (arachnids).

Spiders and other invertebrate top predators can have a particularly influential impact on biomagnifying MeHg in invertivore food webs. Cristol et al. (2008) found some terrestrial songbird species exceeded aquatic-based songbirds; even piscivorous species such as the Belted Kingfisher had Hg body burdens that were lower than terrestrial songbird species that regularly prey on spiders. Aside from spiders, birds consume calcium-rich prey items for egg laying and chick skeletal development (Graveland 1996; Graveland and Drent 1997). However in acidic soils, the abundances of many of the calcium (Ca)-rich prey species decline. This pattern can have important ramifications on the health of songbird populations, particularly on females laying eggs and on the growth of hatchlings.

Project goals include:

1. Elucidate patterns and relationships of abiotic and biotic Hg levels,
2. Develop a predictive model relating measured Hg levels to landscape variables that currently exist or ones that we measure, and
3. Identify biological Hg hotspots in terrestrial systems
4. Identify any adverse effect levels of bat fur exceeding 30 ppm, fresh weight (fw), songbird blood exceeding 1.18ppm wet weight (ww) and songbird blood calcium below 60 ppm.

3.0 STUDY AREA

In 2007, we sampled raptors, bats, songbirds, invertebrates, soil and litterfall at Frost Valley (near Neversink Reservoir), Bashakill Wildlife Management Area, Bog Brook Natural Area, Great Swamp and Devil's Tombstone. These sites represent the Catskill, Delaware and Croton watersheds in New York. In addition, we sampled songbirds, soil and invertebrates at Devil's Tombstone (2005 to 2007) and Frost Valley (2006 and 2007).

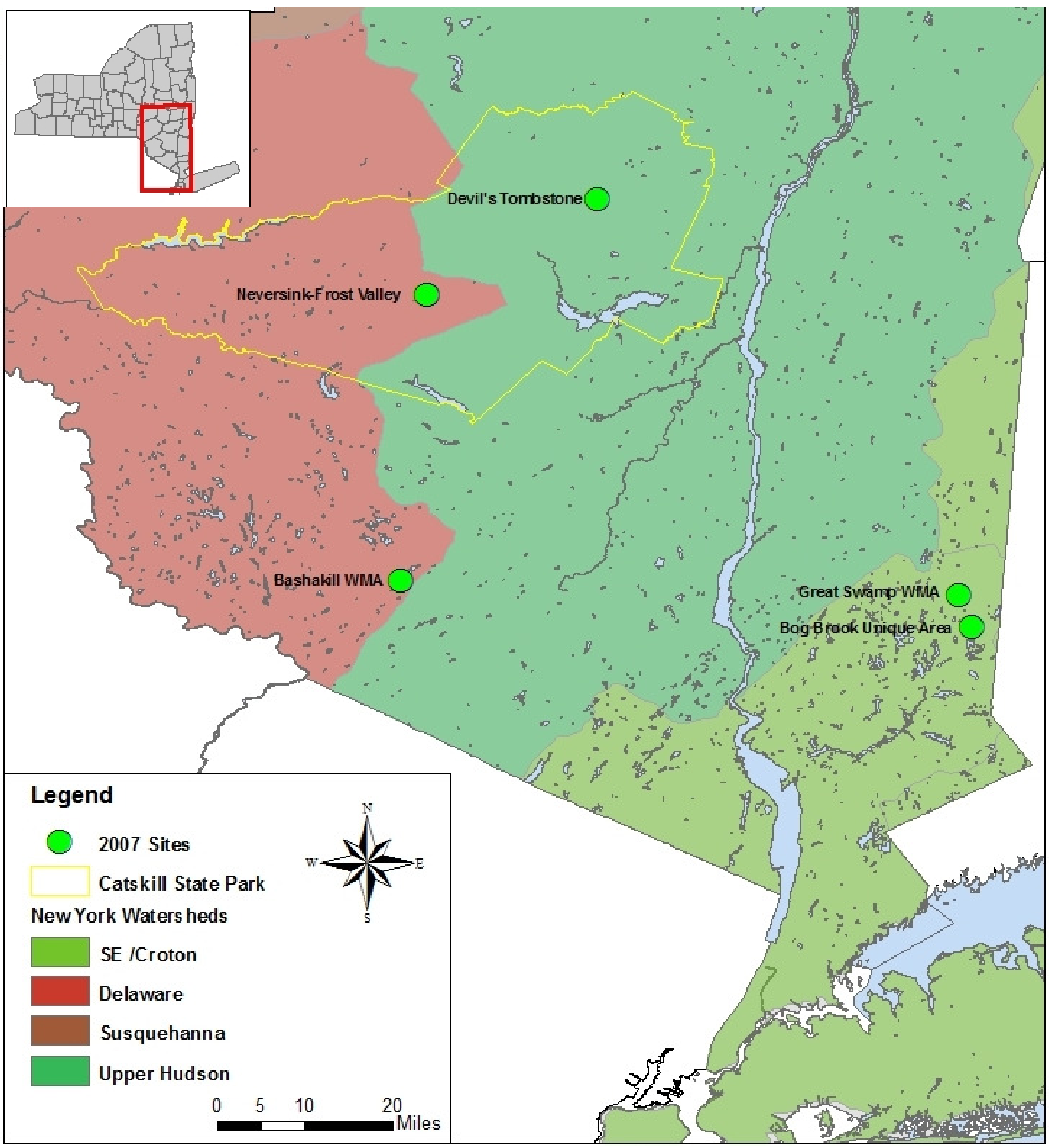

Figure 1. Sample sites, 2007

4.0 METHODS

In addition to the sampling effort shown in Table 1, we sampled songbirds and invertebrates at Devil's Tombstone in 2005 and 2006 and Neversink-Frost Valley in 2006.

Table 1. Sampling efforts for five sites in New York, 2007

Site	Lat	Long	Raptors	Songbird	Bats	Inverts	Soil	Litterfall	Grand Total
Bog Brook NA	41.44287	-73.58176		15		18	3	2	**38**
Great Swamp	41.49559	-73.60366		14	3	7	1	1	**26**
Neversink-Frost Valley	41.99313	-74.49139	1	11		8	2	1	**23**
Devil's Tombstone	42.15621	-74.20444		11		8	1	1	**21**
Bashakill WMA	41.51933	-74.53483	2	16	13	10	1	1	**43**
	Grand Total		**3**	**67**	**16**	**51**	**8**	**6**	**151**

4.1 SOIL AND LITTERFALL COLLECTION

Litterfall was collected by using a modified pin block method (Yanai et. al., 1999) that consisted of a 10 x 15cm wooden frame and a butter knife. Using the frame as a guide, we cut a rectangular hole into the litterfall layers. Whole leaves, non-decaying matter were collected as one sample referred to as litterfall layer 1. Litterfall layer 2 consisted of decaying leaves and non-soil particles. After the litterfall layers were cleared away, we used the same rectangular outline to collect 2.5cm of soil using a bulb digger (Gary Lovett, pers. comm.). If there was a noticeable division in the soil, we collected these layers (organic and mineral) into separate bags. All soil samples were double bagged in plastic bags and stored in the freezer.

Soil and litterfall samples were analyzed for pH, Hg, available calcium and total calcium at Cebam Analytical.

4.2 INVERTEBRATE SAMPLING AND COLLECTION

We focused our sampling effort on calcium-rich invertebrates found on or near the forest floor, such as isopods, predatory ground beetles and myriapods. In addition, we collected higher trophic invertebrates such as spiders. We sampled invertebrates near net lanes used for songbird capture to ensure that we were capturing prey items within the songbird territory. Invertebrates were hand searched, captured alive in PET scintillation vials and weighed as soon as possible to obtain a fresh weight. Invertebrates were euthanized by freezing and later identified to the lowest possible taxonomic level.

Wholebody invertebrates were analyzed for Hg and MeHg at Cebam Analytical and reported as dry weight (dw). A subset of leftover invertebrate material was sent to Boston University for isotope analysis.

4.3 BIRD CAPTURE AND SAMPLE COLLECTION

We emphasized capture on common species found in wetlands and in adjacent forests (if available). We captured thrushes and other songbirds using mist nets in concert with decoys, playback of conspecific territorial vocalization, and playback of a flock of songbirds mobbing a small owl (Gunn et al. 2000). Both playbacks elicit a strong response from territorial breeding birds, allowing reliable capture. Sampling efforts were timed for June and July to allow time for depuration of Hg body burdens that could reflect winter and/or migratory MeHg uptake (as indicated in Bicknell's Thrush; Rimmer et al. 2005).

We used 8-10, 12m mist nets with a 36mm mesh size designed to harmlessly catch songbirds. Nets were placed on 6 m bamboo and/or metal poles. The nets were checked every 20-40 minutes. Captured birds were removed and placed in cotton holding bags until processing. All birds were released unharmed 15-45 minutes after capture. Birds were captured during both dawn and dusk periods. All birds were measured using standard wing, tail, tarsi, bill, and mass measurements, and banded with United States Fish and Wildlife Service (USFWS) bands. We also collected information on age, sex, and body condition, which is indicated by the external thickness and extent of fat.

For all birds we used 28 gauge disposable needles to puncture a cutaneous ulnar vein in the wing to collect a small blood sample. We also collected outer retrices (tail feathers) from adults. Each blood sample was collected in a 75 mm capillary tube, which was then sealed on both ends with Critocaps ® and placed in a labeled plastic 7 cc vacutainer. Generally, 2-4 capillary tubes half-filled with blood were taken from each bird. The feathers were placed in a labeled plastic bag. All samples were stored in a field cooler with ice, and samples were later transferred for temporary storage (blood in the freezer, feathers in the refrigerator) until shipment to the lab.

Songbird blood and a subset of feathers were analyzed for Hg and MeHg at CebamAnalytical. Another subset of songbird blood samples were analyzed for isotopes at Boston University and calcium was analyzed at the University of Connecticut.

4.4 RAPTOR CAPTURE AND SAMPLING

We conducted surveys at night using barred owl and eastern-screech owl territorial calls as described by Jacobs (2007) and McGarigal (1985). We surveyed diurnal raptors using techniques established by Mosher et al. (1990, 1996), in which great-horned owls or conspecfic calls played from a speaker and playback unit were used to elicit a response from nesting territories. We used a range of capture techniques such as mist nets and bal chatri traps (Jacobs, 2007; Bloom 1987,1986).

Five to ten mL of blood were sampled from the left brachial vein using 25 butterfly needles attached to heparinized evacuated test tubes. Samples were placed into protective cases and frozen within 10 hours. In addition, three to six breast feathers were collected for Hg analysis. Morphometrics consisting of bill length, culmen, footpad length, tarsus width and tail length were taken from each individual following protocols described in the HawkWatch International manual (Vekasy, 2002). We used molt pattern to determine age, and wing and tail measurements to determine sex as described in the Identification Guide to North American Birds, Part 1 by Peter Pyle. Each bird was banded using USFWS lock-on bands.

Blood samples were analyzed for Hg at University of Connecticut and isotopes were analyzed at Boston University.

4.5 BAT CAPTURE AND SAMPLE COLLECTION

Single, double, and triple high nets were strung directly in front of ledge outcroppings, between trees along small access roads, or in the middle of river to funnel bats into nets. Using the assumption that bats fly to water for drinking and feeding purposes after leaving daytime roosts, roads were chosen that led towards water.

Nets were set at dusk and monitored until at least 2300 hours; if bats were being captured, nets were left up until 0100 hours. All bats captured were identified to species, checked for reproductive status, sexed, and aged. Small blood samples were collected by puncturing the uropatagial vein (or wing vein) or the femoral vein in the leg with a 27.5 gauge needle. Blood was collected in heparinized capillary tubes. Fur samples were collected with clean stainless steel scissors. All bats were released unharmed at the site.

Texas A&M Trace Element Research Lab (TERL) analyzed mercury in the bat fur and blood samples were archived at BRI.

5.0 RESULTS AND DISCUSSION

5.1 SOIL CALCIUM AND HG

We collected eight soil samples and six litterfall samples from all five sites. At Bog Brook Unique Area, we collected two soil and litterfall layers from the forest. In addition, we collected a soil layer from the wetland area at Bog Brook Unique Area. Soil THg ranged from 0.41 ppm, dry weight (dw) at Bashakill WMA to 0.46 ppm, dw at Neversink-Frost Valley. Soil calcium ranged from 0.76 Cmolc/kg at Bog Brook (forest) to 24.78 Cmolc/kg at also at Bog Brook (wetland). Soil pH ranged from 4.76 at Neversink-Frost Valley to 6.6 at Great Swamp (Figure 2). Litterfall THg ranged from 0.08 ppm,dw at Great Swamp to 0.14 ppm,dw at Devil's Tombstone. Litterfall calcium ranged from 38.8 Cmolc/kg at Bog Brook to 83.8 Cmolc/kg at Great Swamp.

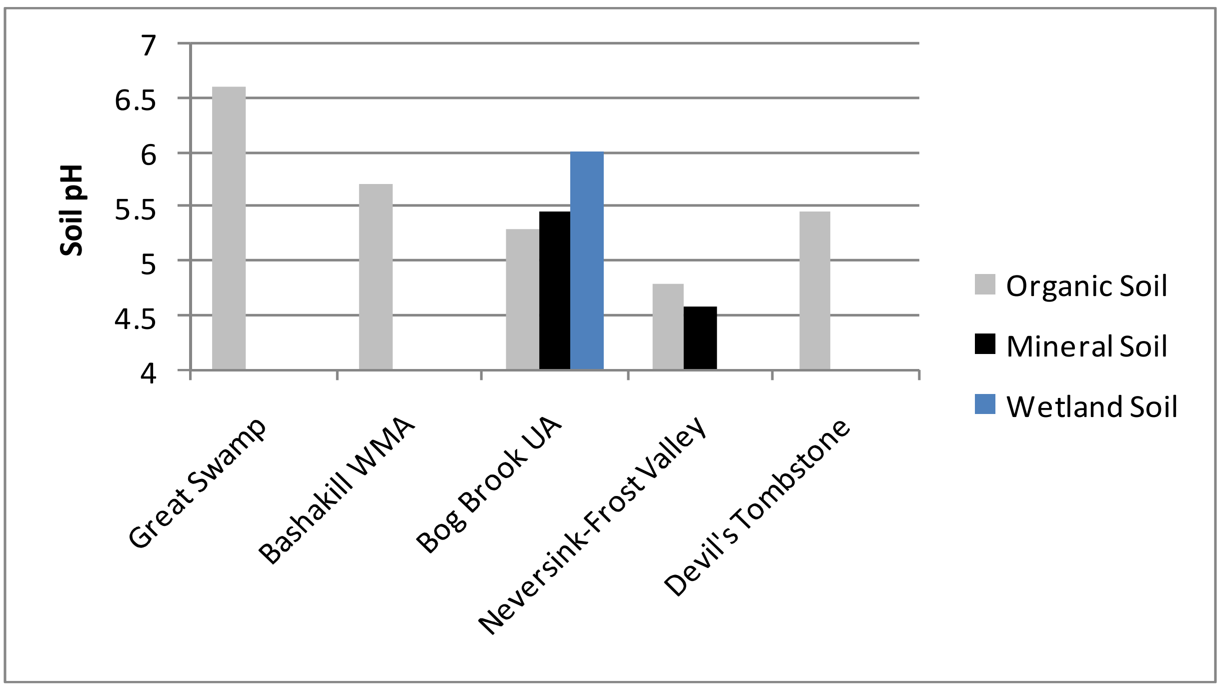

Figure 2. Soil pH for all layers at all sites, 2007.

Of the five sites sampled, Great Swamp and Bashakill have the highest litterfall available calcium and lowest litterfall Hg. Devil's Tombstone and Neversink-Frost Valley have the highest litterfall Hg and the lowest litterfall available calcium (Figure 3 and 4). Neversink-Frost Valley had the highest soil Hg and low available calcium, while Great Swamp had the highest soil available calcium and low soil Hg.

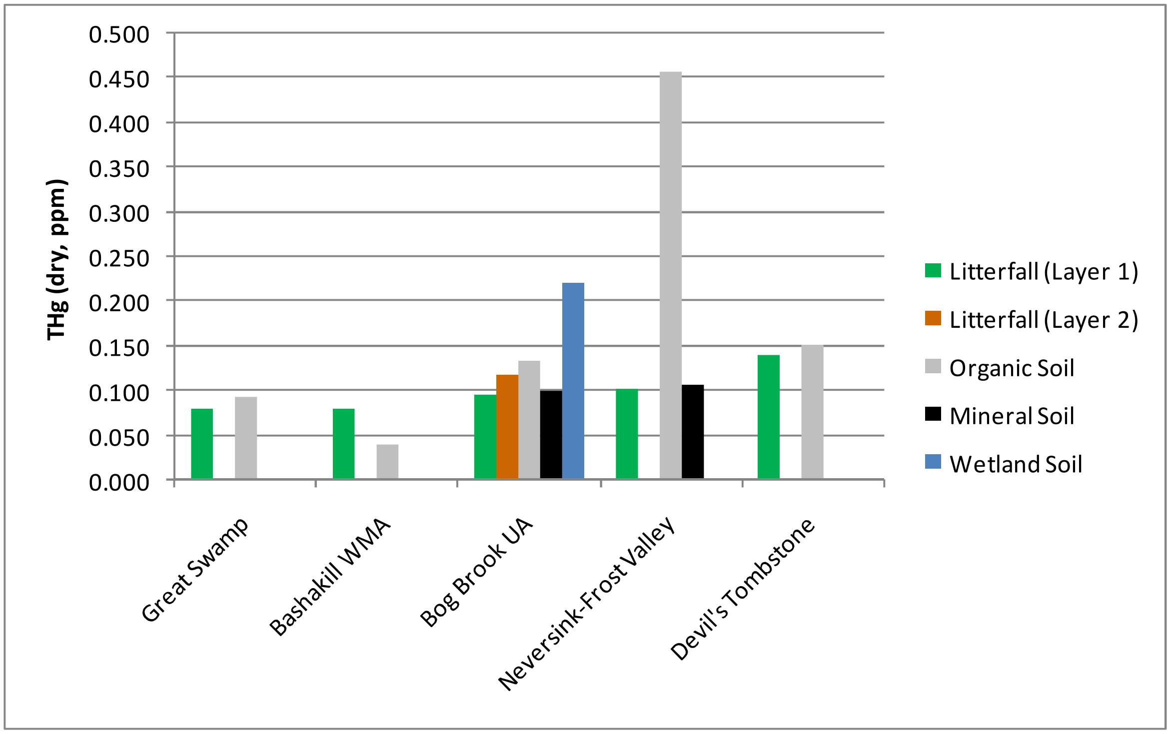

Figure 3. Litterfall and soil Hg for all layers at all sites, 2007.

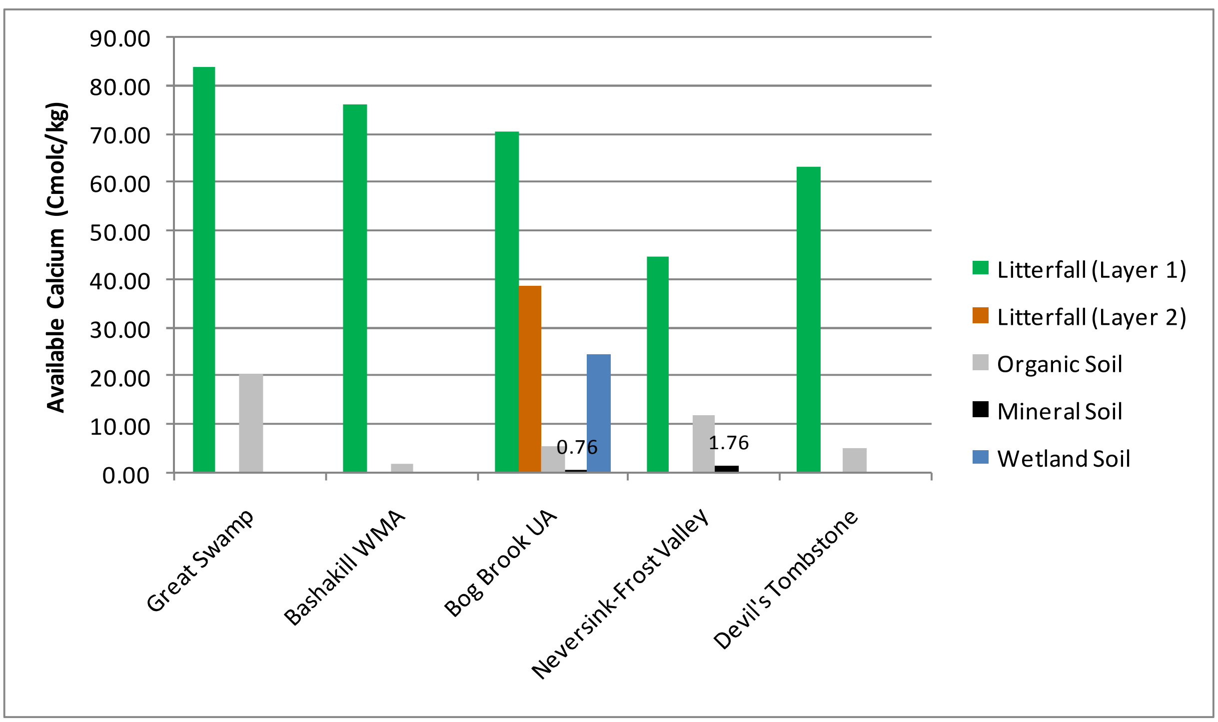

Figure 4. Litterfall and soil available calcium for all layers at all sites, 2007.

5.2 INVERTEBRATES

We sampled 51 invertebrates from all five sites and included data from previously collected data from 2005 and 2006 for data analysis purposes. Percentage of MeHg varied by site and species and ranged

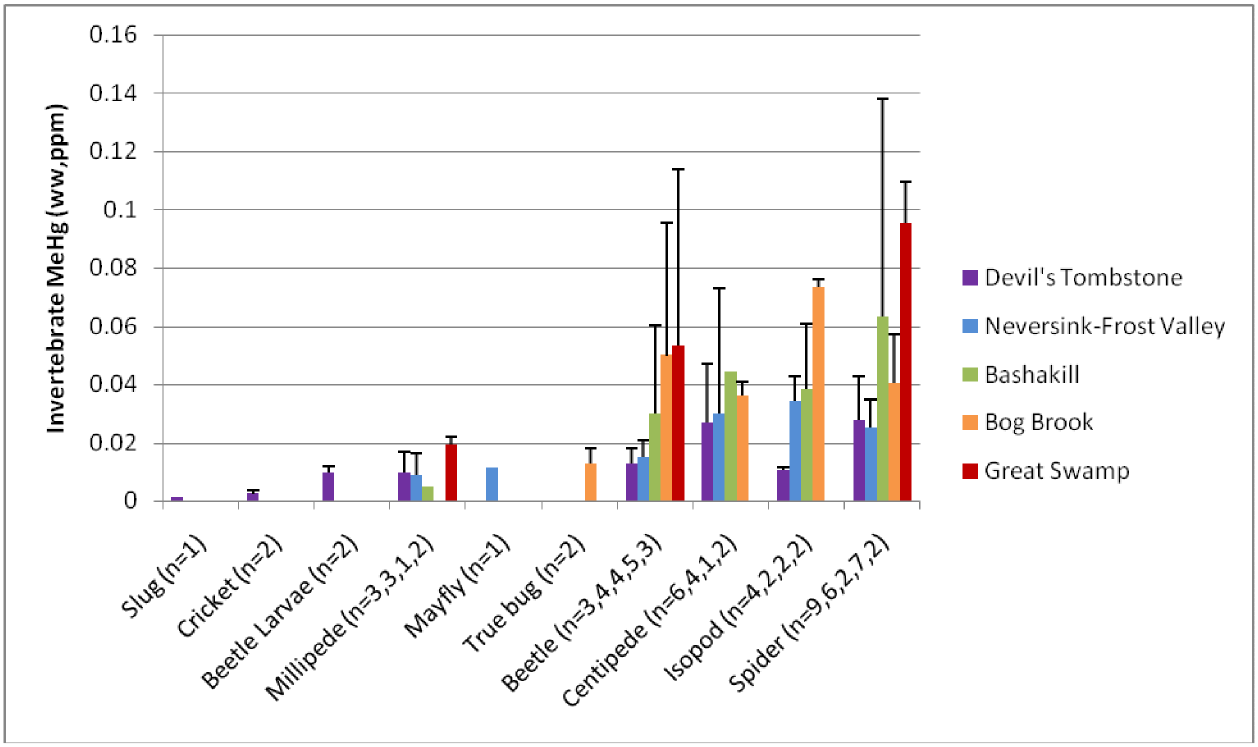

Figure 5. Invertebrate MeHg at all sites, 2005-2007.

from 3 to 87%. Because of this percentage range, we reported MeHg results. There are no studies investigating why MeHg percentages vary, but if rates of methylation vary by habitat, then MeHg could also vary in invertebrates. Invertebrate MeHg ranged from 0.001 ww,ppm in a millipede from Neversink-Frost Valley to 0.121 ww,ppm in a beetle from Great Swamp. Overall, invertebrate MeHg means were highest at Great Swamp, but it is worth mentioning that individuals at Bog Brook were also high (Figure 5). Furthermore, isopods from Bog Brook were higher than spiders sampled at the same site. From a regional perspective, the Lower Hudson River Valley sites had higher invertebrate MeHg means than the Catskill region (Figure 6).

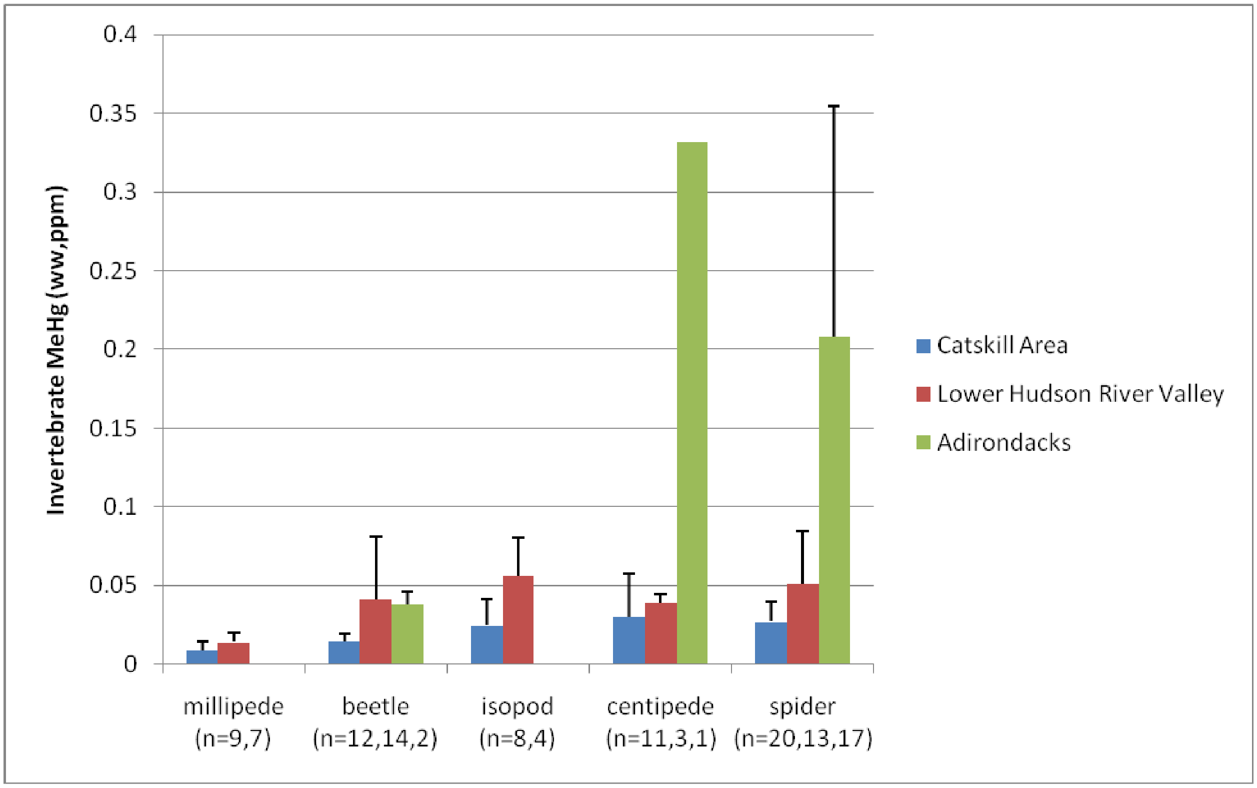

Figure 6. Regional comparison of invertebrate MeHg, 2005-2007.

5.3 SONGBIRDS

Blood Hg measures current Hg levels, while feather Hg measures body burden or Hg over a longer period of time (Evers et. al, 2005). We sampled a total of 68 birds at five sites. Blood Hg levels ranged from 0.02 ppm,wet weight (ww) in a Veery at Great Swamp to 1.17 ppm, ww in an Eastern Wood-Pewee also captured at Great Swamp (Appendix 1). Feather Hg was analyzed for 15 birds and levels ranged from 0.22 ppm in a Red-winged Blackbird from Bashakill to 6.92 ppm in a Hermit Thrush from Neversink-Frost Valley. Blood calcium was tested in 15 birds and 11 birds had levels under 3.0 mEq/L or 60 ppm. Blood Hg levels did not exceed the LOAEL of 1.18 ww,ppm.

Common species caught at all five sites included the Red-eyed Vireo (canopy forager), Veery (ground forager) and Song Sparrow (wetland associated species) (Figure 7). At Bog Brook Unique Area, we caught birds in the forested area and the wetland area. Red-eyed Vireos and Veerys had the highest mean Hg levels at Neversink-Frost Valley. Song Sparrows at Great Swamp had the highest mean Hg levels of the three sites sampled and had levels higher than the ground-foraging Veery and canopy foraging Red-eyed Vireo.

When comparing four common species for the different regions, the Catskill area sites averaged lower than the other regions except for the Ovenbird (Figure 8). The Lower Hudson River Valley region, which included the 2007 study sites, had the highest mean Hg levels for Wood Thrush. Wood thrushes were not sampled in the Adirondacks.

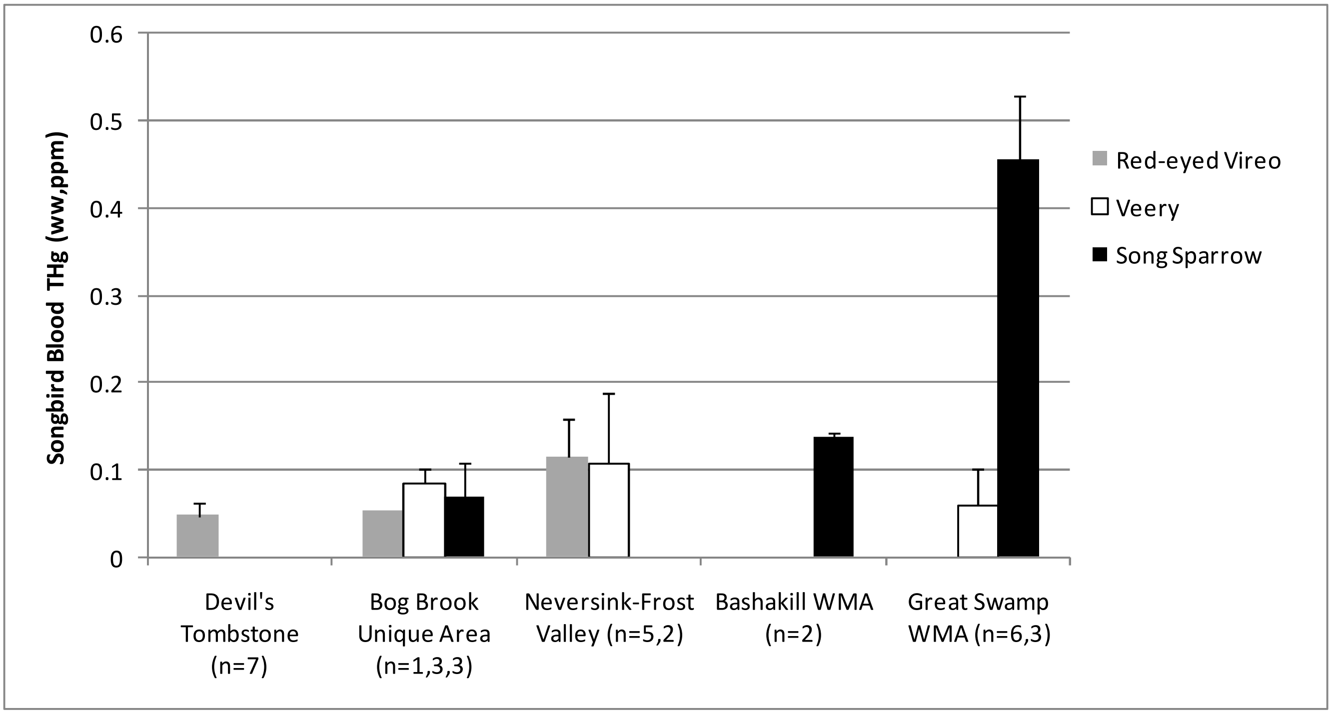

Figure 7. Mean blood Hg in three common species for all sites in 2007.

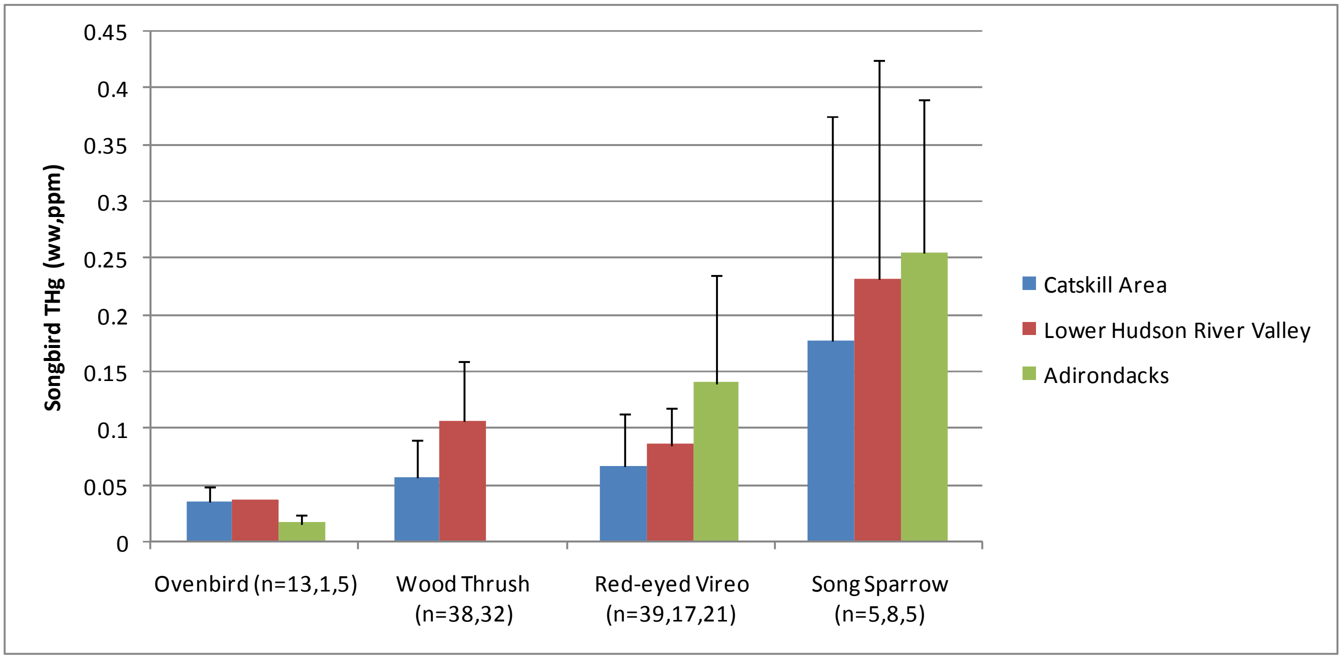

Figure 8. Regional comparison of common species, 2000 and 2004-2007

For Figure 9, we used songbird Hg data from previous years to compare mean Hg levels for species sampled at the NYSDEC sites and to determine whether or not NYSDEC birds were vulnerable to Hg exposure. The 2005-2007 NYSDEC sites (n=122) consisted of all birds (juvenile and adult) sampled in Bashakill WMA, Bog Brook UA, Devil's Tombstone, Great Swamp and Neversink-Frost Valley. The New York 2004-2007 data consisted of all adult, breeding songbird data points sampled within the state of New York (n=274), excluding birds sampled at NYSDEC sites. The National 2001-2007 data (n=290) consisted of all adult, breeding, non-point source songbird data points from Connecticut, Massachusetts, Maine, North Carolina, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, Vermont and West Virginia. Although in some cases sample sizes were small, it could be that Yellow-throated Vireos, Common Yellowthroats, Song Sparrows, Swamp Sparrows and Eastern Phoebes are vulnerable to Hg exposure at NYSDEC sites especially when compared to national and state mean songbird Hg levels. When compared to other New York sites, it is possible that Red-winged Blackbirds and Wood Thrushes are more vulnerable to Hg at NYSDEC sites.

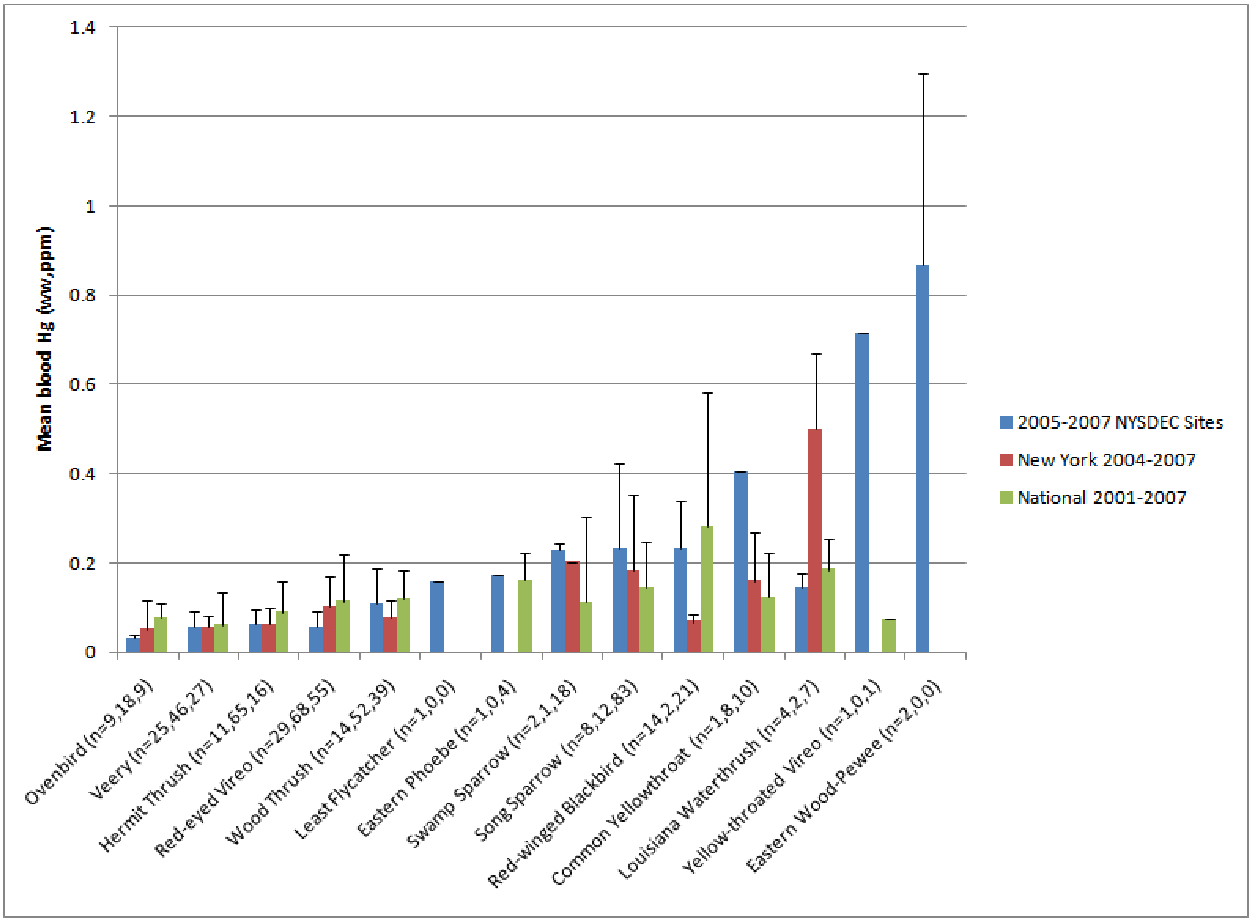

Figure 9. Site, state and national comparison of songbird blood Hg means

5.4 RAPTORS

We sampled three Barred Owls from three sites (Figure 10) in the Lower Hudson River Valley Region (Black Rock Forest was outside the scope of this project, but was included for comparison). Blood Hg levels ranged from 0.16 ppm,ww to 0.33 ppm, ww, with the highest level from Bashakill WMA and the lowest at Black Rock Forest.

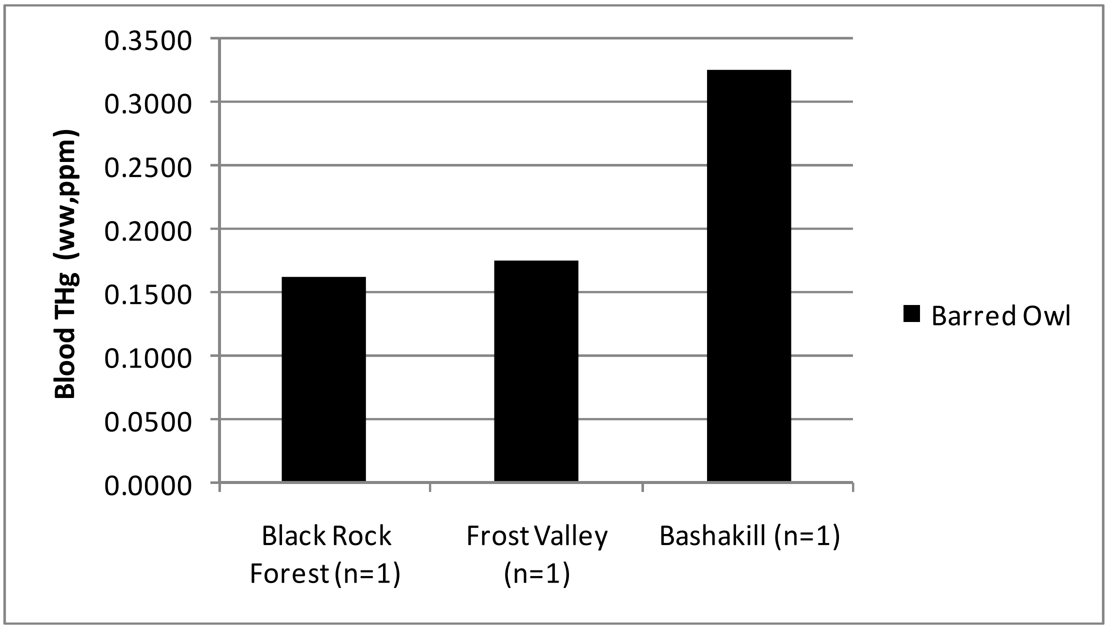

Figure 10. Blood Hg in Barred Owls, 2007.

5.5 BATS

We sampled 16 bats at two sites. Fur Hg levels ranged from 1.29 ppm, fw in a juvenile Northern Long-eared Bat (*Myotis septentrionalis*) from Bashakill WMA to 23.2 ppm, fw in an adult Big Brown Bat (*Eptesicus fuscus*) also from Bashakill WMA. Bat fur Hg levels at both sites did not surpass adverse effects levels set at 30 ppm, fw. Juvenile Big Brown Bat mean fur Hg levels were highest at Great Swamp and overall Big Brown Bats had higher mean fur Hg levels than Northern Long-eared Bats at Bashakill WMA(Figure 11). When comparing the 2007 NYSDEC sites (Lower Hudson River Valley) to sites in the Adirondacks, adult Big Brown Bats in the Lower Hudson River Valley region had higher mean Hg levels than other adult bat species in the Adirondacks (Figure 12).

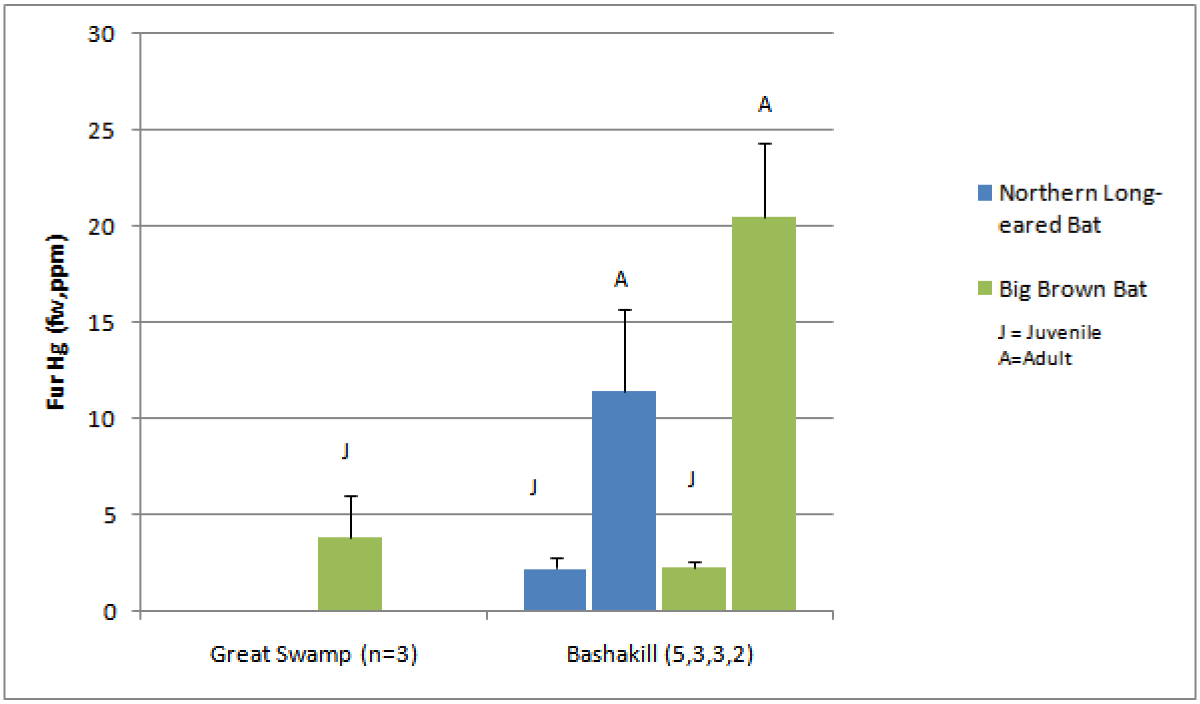

Figure 11. Mean bat fur Hg for two species at Great Swamp and Bashakill, 2007

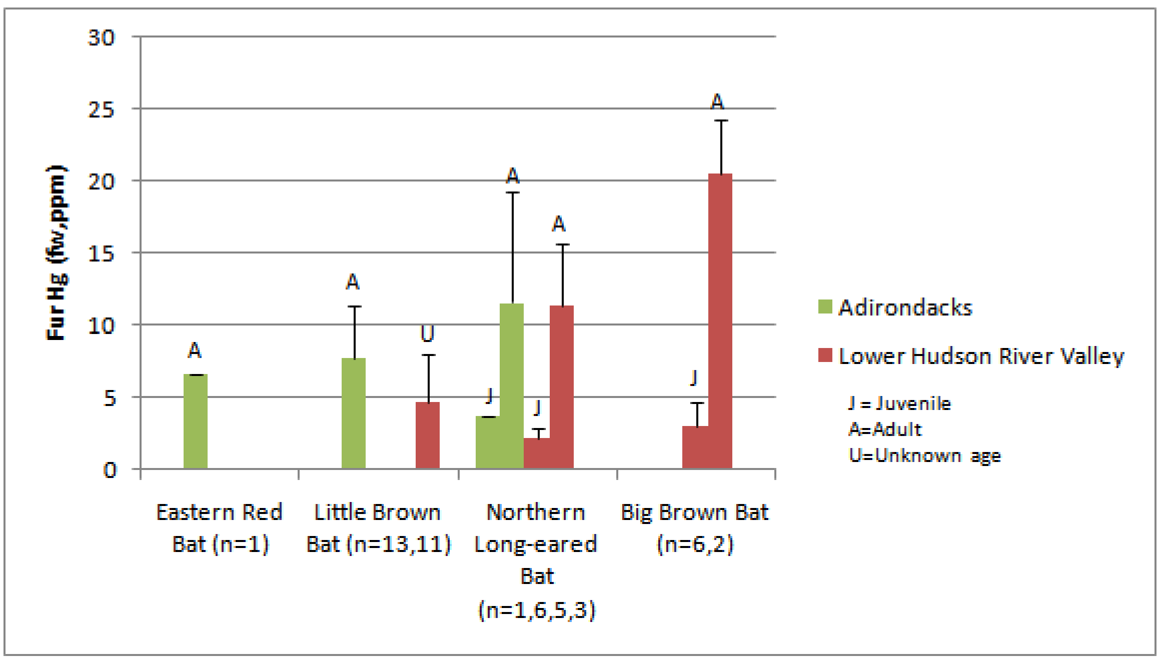

Figure 12. Regional comparison of mean bat fur Hg, 2007.

5.6 RELATIONSHIPS IN HG EXPOSURE

To provide a basic comparison of each site, each sampling category was averaged overall and then ranked 1 to 5 with 1 being the best (least amount of Hg, least acidic and most available calcium) ranking to 5 being the worst (most Hg, most acidic, least available calcium) ranking (Table 2). Although, Neversink-Frost Valley had the highest mean soil Hg, most acidic soil and low to very low available calcium in litterfall and soil, it had one of the lowest mean Hg levels for songbirds and invertebrates. Great Swamp had the highest mean songbird and invertebrate Hg levels, but had one of the lowest soil and litterfall mean Hg levels, the highest available calcium and a pH that was closest to neutral. It seems from this basic comparison that biotic (songbird and invertebrate) mean Hg levels may not be related to abiotic (litterfall and soil) mean Hg levels sampled within the same year. It would be interesting to investigate this further with a larger sample size spread over multiple years at the same sites and at additional sites.

Table 2. Basic site rankings for each sampling category.

	Great Swamp	Bashakill WMA	Devil's Tombstone	Bog Brook Unique Area	Neversink-Frost Valley
Soil Hg	2	1	3	4	5
Soil pH	1	2	4	3	5
Soil Calcium	1	5	4	2	3
Litterfall Hg	1	2	5	3	4
Litterfall Calcium	1	2	4	3	5
Songbird Hg	5	4	1	3	2
Invertebrate MeHg	5	3	1	4	2

Insight into diet and trophic position within a foodweb can be measured by analyzing carbon and nitrogen isotopes (Hobson et al. 2000). As nitrogen moves through the trophic levels, there is an increment of at least +3‰ enrichment factor for $\delta^{15}N$ values (Vander Zanden and Rasmusen, 2001). Carbon isotopes indicated by $\delta^{13}C$, change very little when comparing predator and prey (Oelbermann and Scheu, 2002). In laboratory studies conducted by Oelbermann and Scheu, wolf spiders (*Pardosa lugubris*) were fed different types of diets and subsequent analysis of stable isotopes revealed that the change in $\delta^{13}C$ was generally 1.54‰ or less when moving through trophic levels (2002). To provide a basic comparison of a possible food web structure, similar groups' $\delta^{15}N$ and $\delta^{13}C$ were averaged and graphed (Figure 13). For example, Wood Thrush, Veery and Ovenbird (were grouped together as ground foragers while Red-eyed Vireo, Scarlet Tanager and Yellow-throated Vireo were grouped as canopy foragers. Millipedes had the lowest $\delta^{15}N$ value and are therefore determined to have the lowest trophic position. Due to the similar $\delta^{13}C$ and the >3‰ enrichment factor, it is possible that canopy and ground foragers feed on millipedes or feed on prey with a millipede diet. It is important to note that spiders, beetles and wetland foragers such as Red-winged Blackbird, Swamp Sparrow and Song Sparrow are in a higher trophic position indicated by their higher $\delta^{15}N$ value over millipedes.

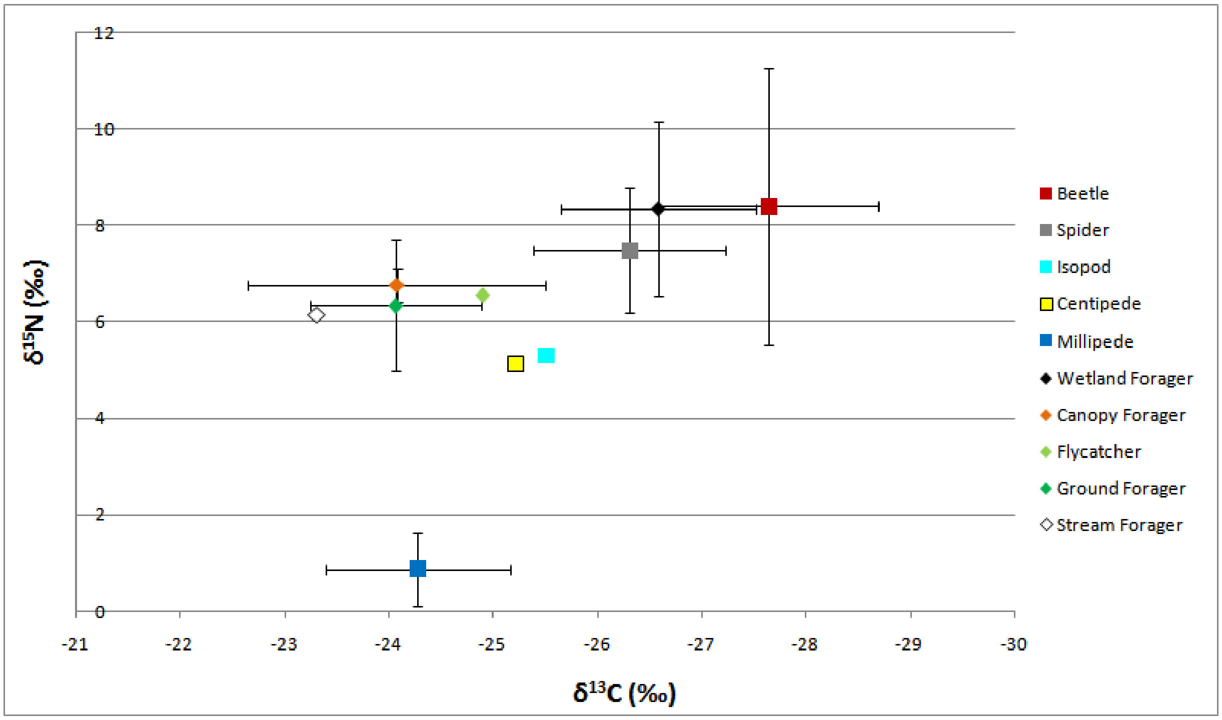

Figure 13. Mean δ15N and δ13C values (‰) for invertebrate and songbird groups.

A predictive model relating measured Hg levels to landscape variables was not developed due to the small number of sites. The model will be developed at a later date using sites sampled in 2008 and will include 2007 study sites from the NYS DEC project. Terrestrial data points from all projects will be pooled for the model in order to determine if there are biological Hg hotspots in the Croton, Delaware and Upper Hudson watersheds and elsewhere in New York.

6.0 CONCLUSIONS

Regionally, bird and invertebrate mean Hg levels were higher at sites in the Lower Hudson River Valley than in the Catskill region. Of the Lower Hudson River Valley sites, Great Swamp and Bashakill stand out as areas that need further investigation. With an Eastern Wood-Pewee (blood Hg = 1.17 ww,ppm) that neared the working LOAEL, Great Swamp also had invertebrates and other songbirds with higher mean Hg levels than their counterparts at other sites. While bat and raptor mean Hg levels did not exceed the LOAEL, Big Brown Bat and Barred Owl mean Hg levels were highest at Bashakill. Therefore, it is possible that certain songbird, raptor and bat species are more vulnerable to Hg exposure at NYSDEC sites. Due to limited data (small sample sizes and few sites), it is not possible to link abiota and biota Hg at this time. It is recommended to continue sampling at Great Swamp and Bashakill as well as including additional sites.

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Appendix 1. Invertebrate results summary table.

Invertebrate_Type	n	MeHg Mean ± SD	Range
Beetle	15	0.04 ± 0.04	0.00 - 0.12
Centipede	3	0.04 ± 0.01	0.03 - 0.04
Isopod	8	0.04 ± 0.03	0.01 - 0.08
Millipede	7	0.01 ± 0.01	0.00 - 0.02
Spider	16	0.05 ± 0.03	0.01 - 0.12
True bug	2	0.01 ± 0.01	0.01 - 0.02

Invertebrate_Type	n	Mean $\delta^{15}N$ ± SD	δ15N Range	Mean $\delta^{13}C$ ± SD	δ13C Range
beetle	2	8.40 ± 2.87	6.37 - 10.43	-27.64 ± 1.05	-28.39 - (-26.90)
centipede	1	5.13		-25.22	
isopod	1	5.31		-25.51	
millipede	3	0.84 ± 0.82	-0.09 - 1.41	-24.28 ± 0.88	-25.26 - (-23.56)
spider	3	7.49 ± 1.29	6.18 - 8.76	-26.31 ± 0.92	-26.91 - (-25.25)

Appendix 2. Songbird results summary table and ancillary data

Common Name	Age	n	Blood Hg Mean ± SD	Range	Family	Species	Forage Guild
Eastern Wood-Pewee	A	2	0.87 ± 0.43	0.57 - 1.17	Tyrannidae	*Contopus virens*	Flycatching
Least Flycatcher	A	1	0.16		Tyrannidae	*Empidonax minimus*	Flycatching
Eastern Phoebe	J	1	0.17		Tyrannidae	*Sayornis phoebe*	Flycatching
Yellow-throated Vireo	A	1	0.72		Vireonidae	*Vireo flavifrons*	Canopy Forager
Red-eyed Vireo	A	13	0.07 ± 0.04	0.03 - 0.18	Vireonidae	*Vireo olivaceus*	Canopy Forager
Veery	A	11	0.08 ± 0.04	0.02 - 0.16	Turdidae	*Catharus fuscescens*	Ground Forager
Hermit Thrush	A	4	0.06 ± 0.04	0.02 - 0.10	Turdidae	*Catharus guttatus*	Ground Forager
Wood Thrush	A	5	0.20 ± 0.04	0.16 - 0.24	Turdidae	*Hylocichla mustelina*	Ground Forager
Ovenbird	A	1	0.03		Parulidae	*Seiurus aurocapilla*	Ground Forager
Louisiana Waterthrush	A	2	0.12 ± 0.02	0.11 - 0.14	Parulidae	*Seiurus motacilla*	Stream Forager
Common Yellowthroat	A	1	0.41		Parulidae	*Geothlypis trichas*	Wetland Forager
Song Sparrow	A	8	0.23 ± 0.19	0.03 - 0.52	Emberizidae	*Melospiza melodia*	Wetland Forager
Swamp Sparrow	A	3	0.19 ± 0.07	0.10 - 0.24	Emberizidae	*Melospiza georgiana*	Wetland Forager
Red-winged Blackbird	A	14	0.23 ± 0.11	0.07 - 0.45	Emberizidae	*Agelaius phoeniceus*	Wetland Forager

Common name	**Age**	**n**	**Mean MeHg Blood ppm**	**Blood MeHg Mean ± SD**	**Mean MeHg%**	**Range**
Eastern Wood-Pewee	Adult	2	0.76	0.76 ± 0.33	87%	0.52 - 0.99
Least Flycatcher	Adult	1	0.14		91%	
Eastern Phoebe	Juve.	1	0.17		96%	
Yellow-throated Vireo	Adult	1	0.76		100%	
Red-eyed Vireo	Adult	13	0.07	0.07 ± 0.04	93%	0.02 - 0.17
Veery	Adult	11	0.07	0.07 ± 0.04	93%	0.02 - 0.15
Hermit Thrush	Adult	4	0.06	0.06 ± 0.03	89%	0.02 - 0.09
Wood Thrush	Adult	5	0.20	0.20 ± 0.04	98%	0.17 - 0.25
Ovenbird	Adult	1	0.03		90%	
Louisiana Waterthrush	Adult	2	0.11	0.11 ± 0.03	93%	0.09 - 0.14
Common Yellowthroat	Adult	1	0.36		90%	
Song Sparrow	Adult	8	0.22	0.22 ± 0.18	94%	0.03 - 0.49
Swamp sparrow	Adult	3	0.18	0.18 ± 0.07	95%	0.10 - 0.22
Red-winged Blackbird	Adult	14	0.22	0.22 ± 0.11	96%	0.07 - 0.43

Appendix 3. Soil and litterfall raw data.

Site	Matrix	Sample Layer	Available Ca, Cmolc/kg	THg, ppm, dw	pH
Bashakill WMA	Litterfall	1	76.42	0.080	
Bog Brook UA	Litterfall	1	70.61	0.096	
Devil's Tombstone	Litterfall	1	63.39	0.141	
Great Swamp	Litterfall	1	83.76	0.079	
Neversink-Frost Valley	Litterfall	1	44.94	0.103	
Bog Brook UA	Litterfall	2	38.77	0.118	
Bashakill WMA	Soil	1	2.08	0.041	5.72
Bog Brook UA	Soil	1	5.45	0.133	5.31
Devil's Tombstone	Soil	1	5.08	0.151	5.46
Great Swamp	Soil	1	20.41	0.094	6.6
Neversink-Frost Valley	Soil	1	12.30	0.458	4.8
Bog Brook UA	Soil	2	0.76	0.100	5.47
Neversink-Frost Valley	Soil	2	1.76	0.107	4.6
Bog Brook UA	Wetland Soil	1	24.78	0.220	6.02

Appendix 4. Invertebrate Hg and MeHg raw data.

Site	Invertebrate Type	THg, ug/g ww	MeHg ug/g ww	MeHg%	Order	Family	*Genus*	*Species*
Bashakill	beetle	0.0083	0.0028	34%	Coleoptera	Cerambycidae	*Odontocera*	
Bashakill	beetle	0.0462	0.0264	57%	Coleoptera	Carabidae	*Pterostichus*	
Bashakill	beetle	0.1141	0.0730	64%	Coleoptera	Carabidae	*Pterostichus*	
Bashakill	beetle	0.0241	0.0176	73%	Coleoptera	Carabidae	*Chlaenius*	
Bashakill	centipede	0.0546	0.0443	81%	Lithobiomorpha			
Bashakill	isopod	0.1076	0.0227	21%	Isopoda	Porcellionidae	*Porcellio*	*Porcellio scaber*
Bashakill	isopod	0.0876	0.0542	62%	Isopoda	Porcellionidae	*Porcellio*	*Porcellio scaber*
Bashakill	millipede	0.0115	0.0048	42%	Polydesmida			
Bashakill	spider	0.0218	0.0107	49%	Araneae	Araneidae	*Gea*	
Bashakill	spider	0.1726	0.1162	67%	Araneae	Tetragnathidae	*Tetragnatha*	
Bog Brook	beetle	0.2624	0.0082	3%	Coleoptera	Scarabaeidae	*Popilla*	*Popilla japonica*
Bog Brook	beetle	0.1818	0.0200	11%	Coleoptera	Scarabaeidae	*Popilla*	*Popilla japonica*
Bog Brook	beetle	0.0455	0.0225	50%	Coleoptera	Carabidae	*Pterostichus*	
Bog Brook	beetle	0.0886	0.0936	100%	Coleoptera	Cantharidae	*Rhagonydrus*	
Bog Brook	beetle	0.0897	0.1053	100%	Coleoptera	Lampyridae		
Bog Brook	centipede	0.0807	0.0328	41%	Lithobiomorpha			
Bog Brook	centipede	0.0606	0.0395	65%	Lithobiomorpha			
Bog Brook	isopod	0.1425	0.0753	53%	Isopoda	Porcellionidae	*Porcellio*	*Porcellio scaber*
Bog Brook	isopod	0.1161	0.0716	62%	Isopoda	Porcellionidae	*Porcellio*	*Porcellio scaber*
Bog Brook	spider	0.0781	0.0282	36%	Araneae	Araneidae	*Araneus*	
Bog Brook	spider	0.1419	0.0675	48%	Araneae	Araneidae	*Zygiella*	
Bog Brook	spider	0.0306	0.0151	49%	Araneae	Agelenidae	*Agelenopsis*	
Bog Brook	spider	0.0666	0.0360	54%	Araneae	Araneidae	*Araneus*	
Bog Brook	spider	0.0763	0.0440	58%	Araneae	Agelenidae	*Agelenopsis*	
Bog Brook	spider	0.0649	0.0377	58%	Araneae	Agelenidae	*Agelenopsis*	
Bog Brook	spider	0.0890	0.0538	60%	Araneae	Agelenidae	*Agelenopsis*	
Bog Brook	true bug	0.0277	0.0092	33%	Hemiptera	Pentatomidae		
Bog Brook	true bug	0.0346	0.0164	47%	Hemiptera	Pentatomidae		
Devil's Tombstone	beetle	0.0289	0.0073	25%	Coleoptera	Carabidae	*Pterostichus*	
Devil's Tombstone	beetle	0.0341	0.0179	53%	Coleoptera	Carabidae	*Pterostichus*	
Devil's Tombstone	isopod	0.0167	0.0089	53%	Isopoda	Porcellionidae	*Porcellio*	*Porcellio scaber*
Devil's Tombstone	isopod	0.0148	0.0104	70%	Isopoda	Oniscidae	*Oniscus*	*Oniscus asellus*
Devil's Tombstone	millipede	0.0071	0.0036	51%	Polydesmida			
Devil's Tombstone	millipede	0.0171	0.0091	53%	Polydesmida			
Devil's Tombstone	spider	0.0363	0.0215	59%	Araneae	Lycosidae	*Schizocosa*	
Devil's Tombstone	spider	0.0404	0.0296	73%	Araneae	Lycosidae	*Schizocosa*	
Great Swamp	beetle	0.0145	0.0049	34%	Coleoptera	Carabidae		
Great Swamp	beetle	0.0516	0.0329	64%	Coleoptera	Carabidae	*Pterostichus*	
Great Swamp	beetle	0.1522	0.1214	80%	Coleoptera	Carabidae	*Pterostichus*	
Great Swamp	millipede	0.0884	0.0212	24%	Polydesmida			
Great Swamp	millipede	0.0611	0.0173	28%	Polydesmida			
Great Swamp	spider	0.1600	0.1055	66%	Araneae	Tetragnathidae	*Leucauge*	
Great Swamp	spider	0.1244	0.0851	68%	Araneae	Tetragnathidae	*Leucauge*	
Neversink-Frost Valley	beetle	0.0218	0.0117	54%	Coleoptera	Carabidae	*Pterostichus*	
Neversink-Frost Valley	isopod	0.0383	0.0283	74%	Isopoda	Porcellionidae	*Porcellio*	*Porcellio scaber*
Neversink-Frost Valley	isopod	0.0273	0.0403	100%	Isopoda	Porcellionidae	*Porcellio*	*Porcellio scaber*
Neversink-Frost Valley	millipede	0.0011	0.0005	45%	Polydesmida			
Neversink-Frost Valley	millipede	0.0204	0.0119	58%	Polydesmida			
Neversink-Frost Valley	spider	0.0251	0.0135	54%	Araneae	Lycosidae	*Pirata*	
Neversink-Frost Valley	spider	0.0436	0.0304	70%	Araneae	Lycosidae	*Schizocosa*	
Neversink-Frost Valley	spider	0.0546	0.0401	73%	Araneae	Lycosidae	*Pirata*	

Appendix 5. Invertebrate isotope raw data.

Site	Invertebrate_Type	Order	Family	Genus	Species	%C	δ13C	% N	δ15N
Neversink-Frost Valley	millipede	Polydesmida				31.03	-25.26	5.77	1.41
Neversink-Frost Valley	spider	Araneae	Lycosidae	*Pirata*		50.15	-25.25	11.24	7.52
Great Swamp	beetle	Coleoptera	Carabidae	*Pterostichus*		51.95	-26.90	10.68	10.43
Devil's Tombstone	isopod	Isopoda	Oniscidae	*Oniscus*	*Oniscus asellus*	32.76	-25.51	6.82	5.31
Devil's Tombstone	millipede	Polydesmida				24.14	-24.01	5.66	-0.09
Bog Brook	centipede	Lithobiomorpha				46.93	-25.22	13.59	5.13
Bog Brook	spider	Araneae	Agelenidae	*Agelenopsis*		52.21	-26.91	10.82	6.18
Bashakill	beetle	Coleoptera	Carabidae	*Chlaenius*		53.79	-28.39	9.91	6.37
Bashakill	millipede	Polydesmida				21.26	-23.56	4.85	1.21
Bashakill	spider	Araneae	Araneidae	*Gea*		48.78	-26.77	12.83	8.76

Appendix 6. Songbird Blood Hg and MeHg Raw Data

band #	Age	OldName	species	sex	BLHg ppm	MeHg Blood ppm	MeHg% Blood
2510-025-15	Juve.	Bashakill WMA	Eastern Phoebe	U	0.17442	0.16708	95.79%
1232-298-05	Adult	Bashakill WMA	Red-winged Blackbird	M	0.08089	0.07421	91.74%
1991-248-23	Adult	Bashakill WMA	Red-winged Blackbird	F	0.16317	0.15442	94.64%
1232-298-43	Adult	Bashakill WMA	Red-winged Blackbird	M	0.16406	0.16047	97.81%
1991-248-22	Adult	Bashakill WMA	Red-winged Blackbird	F	0.18998	0.17432	91.76%
1232-298-44	Adult	Bashakill WMA	Red-winged Blackbird	M	0.2046	0.19019	92.96%
1232-298-42	Adult	Bashakill WMA	Red-winged Blackbird	M	0.20838	0.17089	82.01%
1751-876-27	Adult	Bashakill WMA	Red-winged Blackbird	F	0.225	0.22374	99.44%
1232-298-41	Adult	Bashakill WMA	Red-winged Blackbird	M	0.23729	0.22673	95.55%
1991-248-21	Adult	Bashakill WMA	Red-winged Blackbird	F	0.25589	0.2637	103.05%
1991-248-20	Adult	Bashakill WMA	Red-winged Blackbird	F	0.2854	0.28594	100.19%
1991-248-24	Adult	Bashakill WMA	Red-winged Blackbird	F	0.29547	0.28777	97.39%
1991-248-25	Adult	Bashakill WMA	Red-winged Blackbird	F	0.44513	0.43315	97.31%
2241-23-177	Adult	Bashakill WMA	Song Sparrow	F	0.13303	0.13614	102.34%
2241-23-178	Adult	Bashakill WMA	Song Sparrow	M	0.14136	0.13883	98.21%
1601-371-02	Adult	Bashakill WMA	Yellow-throated Vireo	U	0.71573	0.75759	105.85%
1601-373-07	Adult	Bog Brook Unique Area	Red-eyed Vireo	M	0.0523	0.0564	107.84%
1232-298-04	Adult	Bog Brook Unique Area	Red-winged Blackbird	M	0.07274	0.07694	105.77%
1232-298-03	Adult	Bog Brook Unique Area	Red-winged Blackbird	M	0.42396	0.41134	97.02%
2241-231-62	Adult	Bog Brook Unique Area	Song Sparrow	M	0.02721	0.02696	99.08%
2241-231-66	Adult	Bog Brook Unique Area	Song Sparrow	F	0.08912	0.08456	94.88%
2241-231-67	Adult	Bog Brook Unique Area	Song Sparrow	M	0.09314	0.09075	97.43%
1601-373-08	Adult	Bog Brook Unique Area	Swamp sparrow	F	0.10121	0.09572	94.58%
1601-373-06	Adult	Bog Brook Unique Area	Swamp sparrow	M	0.21912	0.21504	98.14%
1601-373-09	Adult	Bog Brook Unique Area	Swamp sparrow	M	0.23839	0.21953	92.09%
2241-231-64	Adult	Bog Brook Unique Area	Veery	M	0.06397	0.0602	94.11%
2241-231-63	Adult	Bog Brook Unique Area	Veery	F	0.09281	0.09049	97.50%
2241-231-65	Adult	Bog Brook Unique Area	Veery	M	0.09531	0.09071	95.17%
1751-876-24	Adult	Bog Brook Unique Area	Wood Thrush	M	0.16331	0.16589	101.58%
1751-876-22	Adult	Bog Brook Unique Area	Wood Thrush	M	0.23962	0.22774	95.04%
1751-876-23	Adult	Bog Brook Unique Area	Wood Thrush	F	0.24403	0.24545	100.58%

Appendix 6. Songbird Blood Hg and MeHg Raw Data

band #	Age	OldName	species	sex	BLHg ppm	MeHg Blood ppm	MeHg% Blood
2281-678-20	Adult	Devil's Tombstone	Hermit Thrush	M	0.10307	0.0925	89.74%
1601-373-44	Adult	Devil's Tombstone	Louisiana Waterthrush	U	0.10599	0.09118	86.03%
1601-373-51	Adult	Devil's Tombstone	Louisiana Waterthrush	U	0.1386	0.1352	97.55%
1601-373-45	Adult	Devil's Tombstone	Ovenbird	U	0.0346	0.03098	89.54%
1851-995-97	Adult	Devil's Tombstone	Red-eyed Vireo	F	0.02877	0.02441	84.85%
1601-373-50	Adult	Devil's Tombstone	Red-eyed Vireo	U	0.0312	0.02706	86.73%
1601-373-48	Adult	Devil's Tombstone	Red-eyed Vireo	U	0.04386	0.04404	100.41%
1601-373-46	Adult	Devil's Tombstone	Red-eyed Vireo	M	0.04418	0.03599	81.46%
1601-373-49	Adult	Devil's Tombstone	Red-eyed Vireo	U	0.0477	0.04373	91.68%
1601-373-47	Adult	Devil's Tombstone	Red-eyed Vireo	F	0.06155	0.05972	97.03%
1601-373-52	Adult	Devil's Tombstone	Red-eyed Vireo	F	0.07168	0.06733	93.93%
2510-025-14	Adult	Great Swamp WMA	Common Yellowthroat	F	0.40573	0.36392	89.70%
2510-025-12	Adult	Great Swamp WMA	Eastern Wood-Pewee	M	0.56525	0.52422	92.74%
2510-025-13	Adult	Great Swamp WMA	Eastern Wood-Pewee	M	1.17233	0.98639	84.14%
2241-231-75	Adult	Great Swamp WMA	Song Sparrow	M	0.37901	0.33228	87.67%
2241-231-74	Adult	Great Swamp WMA	Song Sparrow	M	0.46706	0.44797	95.91%
2241-231-76	Adult	Great Swamp WMA	Song Sparrow	M	0.52259	0.49226	94.20%
2241-231-72	Adult	Great Swamp WMA	Veery	M	0.01912	0.01779	93.04%
2241-231-69	Adult	Great Swamp WMA	Veery	M	0.03243	0.03248	100.15%
2241-231-71	Adult	Great Swamp WMA	Veery	M	0.04607	0.04461	96.83%
2241-231-68	Adult	Great Swamp WMA	Veery	M	0.05514	0.04673	84.75%
2241-231-70	Adult	Great Swamp WMA	Veery	M	0.06963	0.06669	95.78%
2241-231-73	Adult	Great Swamp WMA	Veery	F	0.1359	0.12764	93.92%
1751-876-25	Adult	Great Swamp WMA	Wood Thrush	F	0.17572	0.17561	99.94%
1751-876-26	Adult	Great Swamp WMA	Wood Thrush	M	0.19369	0.17761	91.70%
2241-231-83	Adult	Neversink-Frost Valley	Hermit Thrush	M	0.02417	0.01938	80.18%
2241-231-84	Adult	Neversink-Frost Valley	Hermit Thrush	M	0.04524	0.04323	95.56%
2241-231-82	Adult	Neversink-Frost Valley	Hermit Thrush	M	0.08214	0.07189	87.52%
2510-025-16	Adult	Neversink-Frost Valley	Least Flycatcher	M	0.15812	0.14438	91.31%
2440-095-56	Adult	Neversink-Frost Valley	Red-eyed Vireo	M	0.07023	0.06299	89.69%
1601-373-10	Adult	Neversink-Frost Valley	Red-eyed Vireo	M	0.09076	0.08562	94.34%
1601-373-13	Adult	Neversink-Frost Valley	Red-eyed Vireo	M	0.09644	0.0887	91.97%
1601-373-11	Adult	Neversink-Frost Valley	Red-eyed Vireo	M	0.13613	0.12011	88.23%
1601-373-12	Adult	Neversink-Frost Valley	Red-eyed Vireo	M	0.18154	0.17011	93.70%
2241-231-80	Adult	Neversink-Frost Valley	Veery	M	0.0518	0.04884	94.29%
2241-231-79	Adult	Neversink-Frost Valley	Veery	M	0.16484	0.14584	88.47%

Appendix 7. Songbird feather Hg, MeHg, blood calcium and blood isotope raw data.

band #	Age	OldName	species	sex	Hg Feather ppm	MeHg Feather ppm	MeHg%Feather	Calcium (ppm)	%C	% N	$\delta^{15}N$	$\delta^{13}C$
2241-231-82	Adult	Neversink-Frost Valley	Hermit Thrush	M	6.92171	6.71025	96.95%	46.75				
2241-231-83	Adult	Neversink-Frost Valley	Hermit Thrush	M	1.50331	1.34917	89.75%	33.78				
2241-231-84	Adult	Neversink-Frost Valley	Hermit Thrush	M					12.22	3.58	5.42	-22.95
1601-373-13	Adult	Neversink-Frost Valley	Red-eyed Vireo	M	1.20042	0.75652	63.02%	58.61				
1601-373-10	Adult	Neversink-Frost Valley	Red-eyed Vireo	M	0.50035	0.33255	66.46%	47.78	15.02	5.37	6.71	-24.01
2241-231-81	Adult	Neversink-Frost Valley	Scarlet Tanager	M	0.34283	0.24711	72.08%	52.56	15.37	4.48	6.31	-22.35
2241-231-80	Adult	Neversink-Frost Valley	Veery	M	0.70733	0.5761	81.45%	52.98				
2241-231-79	Adult	Neversink-Frost Valley	Veery	M	0.58048	0.51093	88.02%	86.3				
2241-231-76	Adult	Great Swamp WMA	Song Sparrow	M	2.04382	1.87497	91.74%	61.94	26.62	8.41	10.50	-27.46
2241-231-68	Adult	Great Swamp WMA	Veery	M	0.92212	0.83639	90.70%	57.38	10.03	2.95	7.24	-25.09
1751-876-25	Adult	Great Swamp WMA	Wood Thrush	F	0.2266	0.2073	91.48%	65.48	9.18	3.71	8.26	-24.62
1601-373-44	Adult	Devil's Tombstone	Louisiana Waterthrush	U	2.27367	1.81001	79.61%	52.6	16.79	6.81	6.15	-23.30
1601-373-45	Adult	Devil's Tombstone	Ovenbird	U	1.75658	0.93447	53.20%	60.45	13.65	5.49	5.83	-23.95
1601-373-52	Adult	Devil's Tombstone	Red-eyed Vireo	F	1.27103	0.428	33.67%	47.99	24.31	9.95	7.14	-24.09
1232-298-03	Adult	Bog Brook Unique Area	Red-winged Blackbird	M					15.98	5.82	7.55	-26.93
1601-373-08	Adult	Bog Brook Unique Area	Swamp sparrow	F					28.51	10.14	9.00	-26.68
1751-876-23	Adult	Bog Brook Unique Area	Wood Thrush	F					10.07	3.08	4.99	-23.74
2510-025-15	Juve.	Bashakill WMA	Eastern Phoebe	U					15.91	4.74	6.55	-24.90
1991-248-25	Adult	Bashakill WMA	Red-winged Blackbird	F	0.22339	0.12961	58.02%	59.47	19.29	5.97	6.34	-25.27
1601-371-02	Adult	Bashakill WMA	Yellow-throated Vireo	U	3.87927	2.71067	69.88%	56.56	23.58	8.60	6.88	-25.85

Appendix 8. Bat fur Hg raw data.

Location	Species	Sex	Age	Fur Hg
Bashakill	Big Brown Bat	M	J	2.07
Bashakill	Big Brown Bat	M	J	2.1
Bashakill	Big Brown Bat	M	J	2.6
Bashakill	Big Brown Bat	F	A	17.8
Bashakill	Big Brown Bat	F	A	23.2
Bashakill	Northern Long-eared Bat	M	J	1.29
Bashakill	Northern Long-eared Bat	F	J	2.09
Bashakill	Northern Long-eared Bat	M	J	2.2
Bashakill	Northern Long-eared Bat	M	J	2.69
Bashakill	Northern Long-eared Bat	F	J	2.84
Bashakill	Northern Long-eared Bat	M	A	8.06
Bashakill	Northern Long-eared Bat	M	A	10
Bashakill	Northern Long-eared Bat	F	A	16.2
Great Swamp	Big Brown Bat	F	J	1.98
Great Swamp	Big Brown Bat	M	J	3.46
Great Swamp	Big Brown Bat	F	J	6.18