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# Mercury Concentrations in Bicknell•s Thrush and Other Insectivorous Passerines in Montane Forests of Northeastern North America

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Abstract. Anthropogenic input of mercury (Hg) into the environment has elevated risk to “sh and wildlife, particularly in northeastern North America. Investigations into the transfer and fate of Hg have focused on inhabitants of freshwater aquatic ecosystems, as these are the habitats at greatest risk for methylmercury (MeHg) biomagni“cation. Deviating from such an approach, we documented MeHg availability in a terrestrial montane ecosystem using a suite of insectivorous passerines. Intensive and extensive sampling of Bicknell•s thrush (Catharus bicknelli) indicated signi“cant heterogeneity in MeHg availability across 21 mountaintops in northeastern North America. Southern parts of the breeding range tended to be at greater risk than northern parts. Mean blood Hea9.9(ing12.Abc9.9a9oo)-8.8e435.5(eu6sC-49sing15om)-or.1(M)nell•sb8a9oob8 0.42 ug/g (ww). Overall concentrations were signi“cantly greater in wintering than in breeding areas. Mercury exposure pro“les for four passerine species on Mt. Mans“eld, Vermont indicated greatest MeHg uptake in Bicknell•s thrush and yellow-rumped warbler (Dendroica coronata), and lowest in blackpoll warbler (Dendroica striata) and white-throated sparrow (Zonotrichia albicollis). The MeHg and total Hg

MeHg is present in forest tree leaves and leaf detritus; saturated soils and other moist microhabitats may also contribute to MeHg availability. Our “nding of a correlation between regional litterfall Hg ”ux patterns and Bicknell•s thrush blood Hg concentrations demonstrates on-site availability of MeHg. Further investigations into MeHg availability in montane environments are recommended to assess risk to insectivorous passerines, particularly the Bicknell•s thrush.

Keywords: Songbirds; Catharus bicknelli; Nearctic-neotropical migratory birds; methylmercury

## Introduction

It is well established that elevated levels of atmospheric mercury (Hg) deposition and methylmercury (MeHg) bioavailability in the northeastern United States in”uence wildlife populations. Investigations have focused on multiple trophic levels of freshwater aquatic ecosystems (Evers et al., 2004; Bank et al., 2005; Chen et al., 2005; Kamman et al., 2005; Pennuto et al., 2005), where converted MeHg biomagni“es through the aquatic foodweb, from phytoplankton and zooplankton to invertebrates, amphibians, “sh, and piscivorous vertebrates. Particular emphasis has been on higher trophic piscivorous wildlife, which are most at risk from mercury•s ability to bioaccumulate and biomagnify (Thompson, 1996; USEPA, 1997; Evers et al., 2005).

restricted to coniferous forest typically above 900 m (Ouellet, 1993; Atwood et al., 1996; Rimmer et al., 2001). It winters in the Greater Antilles from sea level to >2000 m, chie”y in mesic and wet broadleaf forest (Rimmer et al., 2001). Due to its small global population, estimated at <50,000 individuals

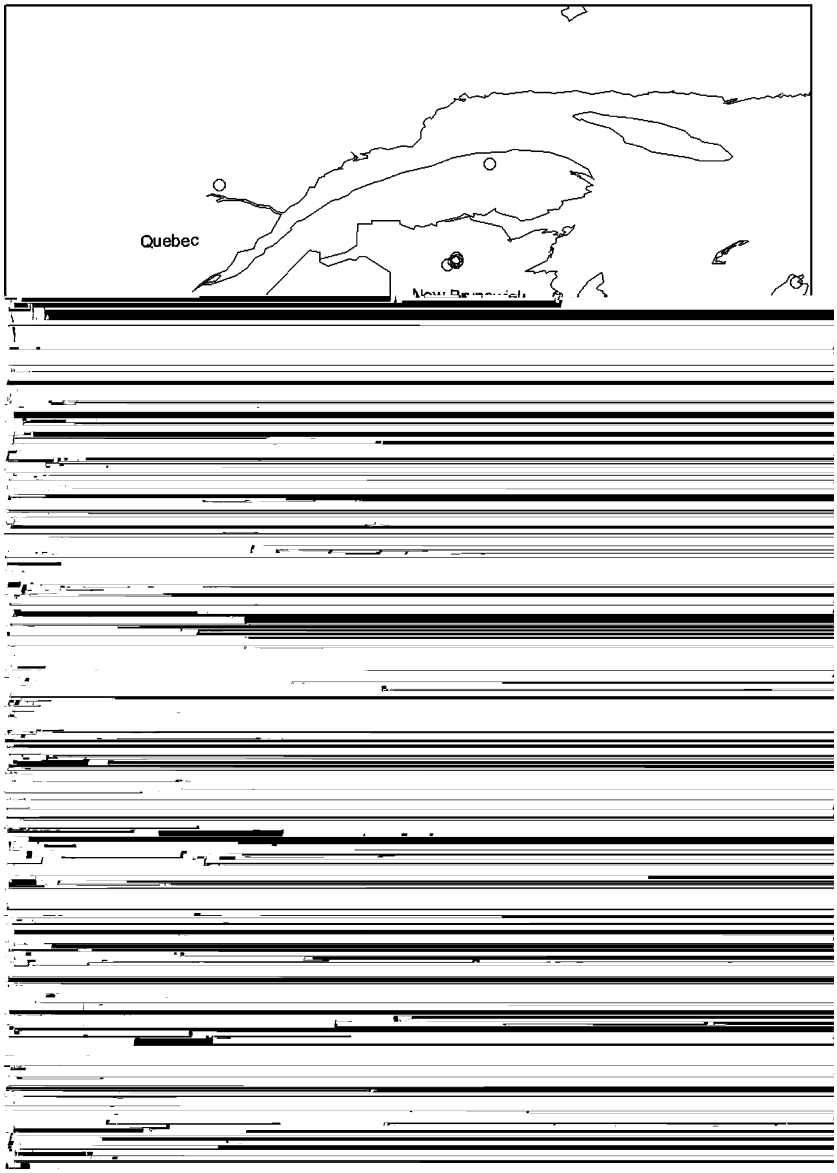


Figure 1 Distribution of sampling locations for the Bicknell•s thrush.

northern tip of Cape Breton Island, covering an extensive plateau that projects into the Cabot Strait. The dense habitat at this site consists primarily of balsam “r, paper birch and mountain ash, ranging from 2 to 5 m in height. The forests at Gaspéand Cape North contain many dead standing trees and are stunted due to heavy winter snow cover, ice loading, and chronically harsh winds.

Our extensive sampling included only Bicknell•s thrush and was conducted during 2000…2004 at 10 additional peaks in the northeastern US, six additional sites in eastern Canada, and seven sites on the species• Greater Antillean wintering range (Table 1). Preferred winter habitats of this species are mesic to wet broadleaf forests with a dense understory, mainly at high elevations (Rimmer et al., 2001). At all sampling sites in North America and the Caribbean, birds were captured in nylon mist nets (12· 2.6 m, 36-mm mesh), either passively or using vocal playbacks as lures. Each

Table 1 Montane forest sites sampled for Bicknell•s thrush blood and feather Hg levels, 2000…2004

| Site name | State/ Province | Geographic cluster[a] | Lat-long | Elevation (s) Sampled (m) | Feather Hg (ug/g, fw) Mean ± SD ( n)[b] | Blood Hg (ug/g, ww) Mean ± SD ( n) |
|---|---|---|---|---|---|---|
| Canada | | | | | | |
| Cape North (Cape Breton Island) | NS | 8 | 46 53¢N, 60 31¢W | 344…426 | | 0.13 ± 0.03 (12) |
| Mt. DesBarres | NB | 5 | 47 19¢N, 66 35¢W | 668…683 | | 0.13 ± 0.05 (2) |
| Fisher Ridge | NB | 5 | 47 15¢N, 66 38¢W | 654 | | 0.08 (1) |
| Gaspé Peninsula | PQ | 2 | 49 00¢N, 66 00¢W | 1040 | 0.37 ± 0.2 (18) | 0.09 ± 0.02 (21) |
| Mt. Gosford | PQ | 9 | 45 18¢N, 70 52¢W | 1192 | 0.64 ± 0.23 (24) | 0.11 ± 0.04 (26) |
| Mt. Mitchell | NB | 5 | 47 16¢N, 66 34¢W | 688 | | 0.15 (1) |
| Mt. Nalaisk | NB | 5 | 47 12¢N, 66 45¢W | 621 | | 0.12 ± 0.04 (2) |
| Mt. Valin | PQ | 7 | 48 37¢N, 70 50¢W | 860 | 0.46 ± 0.18 (6) | 0.08 ± 0.14 (5) |
| Unnamed Mtn. near Mt. Mitchell | NB | 5 | 47 14¢N, 66 35¢W | 645…664 | | 0.11 ± 0.01 (3) |
| United States | | | | | | |
| Avery Peak | ME | 9 | 45 09¢N, 70 16¢W | 900…990 | 0.29 ± 0.09 (4) | 0.27 ± 0.28 (6) |
| Burke Mtn. | VT | 6 | 44 34¢N, 71 54¢W | 930 | | 0.18 ± 0.05 (4) |
| Carter Notch | NH | | 44 16¢N, 71 12¢W | 1025 | 0.48 (1) | |
| East Mtn. | VT | 6 | 44 40¢N, 71 46¢W | 1010…1030 | | 0.15 ± 0.08 (5) |
| Equinox Mtn. | VT | 3 | 43 10¢N, 73 06¢W | 1122 | | 0.09 (1) |
| Mt. Mans“eld | VT | 4 | 44 32¢N, 72 49¢W | 990…1175 | 0.70 ± 0.23 (34) | 0.10 ± 0.04 (56) |
| Mt. Snow | VT | 3 | 42 57¢N, 72 55¢W | 1025 | | 0.141 (1) |
| Spruce Peak | VT | 4 | 44 33¢N, 72 47¢W | 1000 | 0.75 ± 0.45 (2) | 0.06 ± 0.01 (3) |
| Stratton Mtn. | VT | 3 | 43 05¢N, 72 55¢W | 1065…1200 | 0.81 ± 0.36 (12) | 0.12 ± 0.04 (45) |
| Mt. Washington | NH | 1 | 44 15¢N, 71 17¢W | 1350 | 0.91 (1) | 0.09 (1) |
| W. Kennebago Mtn. | ME | 9 | 45 07¢N, 70 48¢W | 1060 | | 0.38 (1) |
| Whiteface Mtn. | NY | 4 | 44 22¢N, 73 54¢W | 1275…1330 | 1.21 ± 0.39 (5) | 0.08 ± 0.004 (5) |
| Hispaniola | | | | | | |
| Pueblo Viejo | DR | n/a | 18 12¢ | | | |

individual was banded, aged, sexed, measured, and weighed. A 30…50l blood sample from the subcutaneous ulnar (brachial) vein was collected in a heparinized capillary tube, refrigerated in a vaccutainer in the “eld, and frozen within 12…48 h. Samples were frozen until contamination analyses were conducted. We collected both “fth secondary wing feathers from most birds by clipping the calamus close to its insertion point; these were stored in glassine envelopes prior to Hg analyses.

## Laboratory analyses

Analysis of tissue samples from 2000 was conducted at the Environmental Chemistry Laboratory of the Sawyer Research Center, Orono, Maine, while all 2001…2003 samples from the US, Dominican Republic, and Haiti were analyzed at Texas A & M Trace Element Research Laboratory (TERL), College Station, Texas. Analysis of Canadian and Cuban samples was performed at

the National Wildlife Research Centre of Environment Canada, Ottawa, Ontario.

Blood samples were expressed from sealed capillary tubes and diluted with 2 ml of double deionized water, then homogenized and aliquoted into total Hg and MeHg fractions. Samples were prepared for total Hg according to TERL SOP-ST16, with volumes reduced to accommodate the small volumes available. This method incorporated digestion with nitric acid, sulfuric acid, potassium permanganate, and potassium persulfate. Digest solutions were reduced with hydroxylamine hydrochloride to eliminate excess $MnO_2$. Samples were prepared for MeHg analysis according to TERL SOP-9712, again with volumes reduced to accommodate sample size limitations. In this method, MeHg was extracted from an acid bromide sample into an organic solvent and prepared for analysis by a permanganate digestion. Feathers were analyzed only for total Hg; using the same digestion process and reagents as were used for blood samples.

Prior to 2003, total Hg and MeHg were both analyzed by element-speci“c cold vapor atomic absorption using an LDC Mercury Monitor equipped with a 30 cm path cell (SOP-9024). Samples were quanti“ed based on peak height compared with external calibration standards. Quality assurance samples accompanying sample batches included method blanks, laboratory control samples (LCS), certi“ed reference materials (NRCC DOLT-2), matrix spike samples, and duplicate samples. All analytes are reported in units of parts per million (ppm or ug/g), on a wet weight (ww) basis for blood and a fresh weight (fw) basis for feathers. Detection limits were dependent upon sample weights and dilution factors but averaged approximately 0.009 ug/g for both total Hg and MeHg and 0.04 ug/g for total Hg in feathers.

In 2003 and 2004, blood and feather samples were analyzed for total Hg according to TERL SOP-0301. This method utilized a Milestone DMA 80 to combust blood and feather samples in nickel boats in an oxygen-rich atmosphere. Combustion products were passed through a heated catalyst to complete oxidation and then through a gold column which trapped Hg. Upon completion of combustion, the gold trap was heated and the Hg released for analysis by atomic absorption. SuTnforSO549.isc0

Further, because individuals sampled in both June and July within a single year invariably showed signi“cantly higher blood Hg concentrations in June (see below), we excluded all July samples in our population-level analyses. For feather Hg analyses from individuals that provided samples in multiple years, we used only those samples obtained in the “rst year. Feathers re”ect chronic Hg body burdens (Burger, 1993), such that between-year samples can not be treated independently. We examined di erences in blood and feather Hg samples from the “ve intensive breeding sites using ANOVA with sex, age, sample site, and their interactions as independent variables.

To correlate Bicknell•s thrush Hg levels at Mans“eld and Stratton with those of regional atmospherically-deposited Hg, we calculated average values for the aggregate presumed breeding home ranges of sampled birds from modeled data (Miller et al., 2005). We selected deposition data for two of eight available habitat classes within this sampling area on each mountain, balsam “r-red spruce-white birch and balsam “r-red spruce, as Bicknell•s thrush is most closely associated with these two montane forest types (Rimmer et al., 2001). We considered total deposition rates as well as three di erent Hg deposition modes (wet, reactive gaseous, and litterfall) that might re”ect di erent degrees of bioavailability of atmospherically-borne Hg to Bicknell•s thrush (Miller et al., 2005). Mercury deposited with litterfall is thought to represent primarily elemental mercury vapor that has been assimilated by leaves. Reactive gaseous mercury is $HgCl_2$ that deposits to the surface of leaves.

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blood, however, feather Hg data from all sampling sites increased along an East…West gradient, with levels highest in New York and lowest in Maine and Canada (Table 1).

Blood Hg concentrations of Bicknell•s Thrush from breeding areas in North America (Cape North, Gaspé, Gosford, Mans“eld, and Stratton) and wintering areas in the Greater Antilles (Dominican Republic and Haiti) were compared using an ANOVA with sample site nested within season. Signi“cant e ects were found between season ($F_{1,182} = 149.55$, $p < 0.00001$) and site(season) ($F_{5,182} = 4.96$, $p = 0.00028$). Blood Hg concentrations in wintering birds were generally 2…3 times higher than in birds sampled on their breeding sites. Although small sample sizes limit statistical comparisons among wintering sites, birds from more western locations (Cuba, Haiti, and western Sierra de Bahoruco [Pueblo Viejo]) tended to have higher blood Hg concentrations than birds further east in the Dominican Republic (eastern Sierra de Bahoruco [El Cachote] and Cordillera Central [Valle Nuevo and Cienaga de Manabao]; Table 1).

## Bicknell•s thrush Hg levels and regional deposition patterns

The signi“cantly higher Hg blood concentrations of thrushes on Stratton versus Mans“eld paralleled modeled deposition patterns at the two sites. In the two forest types used by Bicknell•s thrush at each site, deposition was consistently higher at Stratton for the three deposition modes we examined (Table 3). Both absolute and relative di erences were higher for total Hg deposition than for the other three Hg deposition modes.

## Bicknell•s thrush demographic Hg pro“le

Among the “ve intensively-sampled North American sites, male Bicknell•s thrushes had a signi“cantly higher mean blood Hg concentration (0.11 ug/g ± 0.05; SD range 0.04…0.29) than females (0.09 ug/g ± 0.04; SD range 0.02…0.23) (ANOVA: $F_{1,92} = 4.9$, $p = 0.04$). Mean feather Hg concentrations did not di er signi“cantly between males and females (ANOVA: $F_{1,84} = 0$, $p = 0.96$). The relationship between blood and feather Hg concentrations for Bicknell•s thrushes from which we obtained both samples in a given year was only weakly positive and not signi“cant (Fig. 2).

Mean feather Hg concentrations of, 2-year old (after second-year [ASY]) Bicknell•s thrushes were signi“cantly higher overall than those of yearling (second-year [SY]) birds (ANOVA: $F_{1,84} = 16.63$, $p < 0.0001$), although this was not the case at Gaspé (Table 4). However, among ASY individuals of precisely known age at Mans“eld and Stratton, based on multi-year banding histories, no relationship existed between feather Hg concentrations and age. Similarly, no consistent trend was evident among the 20 individuals from which we obtained feathers in multiple years (Fig. 3). Of these birds, from which we obtained samples 1…3 years apart, nine had increased feather Hg concentrations between “rst and last captures, while the concentrations of 11 individuals decreased. The overall population mean rate of Hg accumulation was ) 0.01 ug/g ± 0.51 SD (range ) 0.81 to 1.55). Males ($n = 13$) accumulated feather Hg at an overall mean rate of ) 0.13 ug/g ± 0.37 (range ) 0.81 to 0.44), while the mean overall accumulation rate of females ($n = 7$)

Table 3. Modeled atmospheric Hg deposition for Stratton and Mans“eld. Data presented as ng/m$^2$/yr (extracted from maps described in Miller et al., 2005)

| Deposition mode | Fir-spruce-birch zone | | Fir-spruce zone | |
|---|---|---|---|---|
| | Mans“eld | Stratton | Mans“eld | Stratton |
| Reactive gaseous Hg | 10.8 | 12.9 | 10.8 | 12.6 |
| Litterfall Hg | 13.8 | 13.9 | 15.4 | 15.6 |
| Wet (rain + cloud) | 9.3 | 12.9 | 13.5 | 20.7 |
| Total Hg[a] | 35.2 | 42.4 | 41.2 | 51.5 |

[a]Includes dry particulate deposition.

was 0.22 ug/g ± 0.68 SD (range) 0.56 to 1.55). Of thrushes examined in consecutive years, representing 26 accumulation-years, the mean annual accumulation rate was ) 0.03 ug/g ± 0.48 SD (range = ) 0.94 to 0.87). Of 13 males representing 23 accumulation-years, 12 of those years showed an increase, and the mean annual accumulation rate in males was) 0.04 ug/g ± 0.51 SD. Of “ve recaptured fema=

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examined to date are associated with aquatic-based systems and are at the top of piscivorous or aquatic insectivorous trophic webs (Thompson, 1996; Evers et al., 2005). Bicknell•s thrushes inhabit conifer-dominated forests and are not closely tied to aquatic habitats at any phase of their annual cycle. Methylation dynamics and MeHg availability in terrestrial systems are not well understood, but our results indicate that a mechanism for biotic

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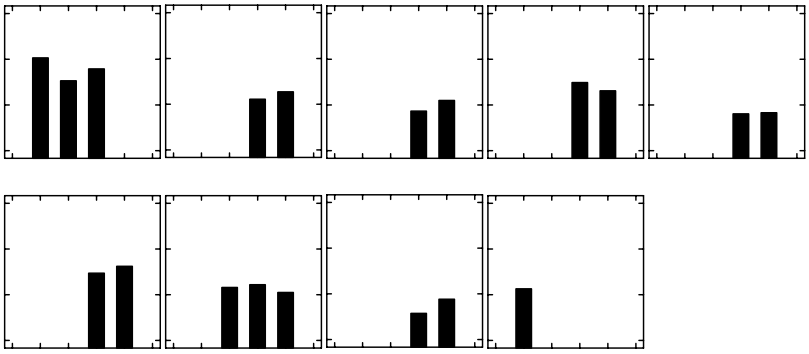

was expected, even though there are species-speci“c di erences in how MeHg is absorbed into the blood (Monteiro and Furness, 2001). Unlike “sh, which form the dietary basis for piscivorous birds and generally have whole body content >85% MeHg (Wiener and Spry, 1996), insects generally have far less MeHg content (average 65%; Pennuto et al., 2005), but exhibit a broad range with lowest levels in detritivores (20…25%) and highest levels in predatory insects like dragon”ies (95%) (Tremblay et al., 1996; Tremblay and Lucotte, 1997). However, the transfer of more limited MeHg concentrations in insect prey to insectivorous birds does not appear to be signi“cantly di erent than in piscivorous birds. Both Gerrard and St. Louis (2001) and Wolfe and Norman (1998) found high MeHg:Hg ratios in the tissues of various insectivorous passerines. Our analysis indicates that even insectivorous birds dependent on terrestrial food-webs are susceptible to MeHg availability and bioaccumulation.

Comparisons of Hg exposure during the breeding season

Blood Hg concentrations of four montane breeding birds at Mans“eld fell into two general groups: higher exposure (pooled mean, 0.09 ug/g) in Bicknell•s thrush and yellow-rumped warbler and lower exposure in blackpoll warbler and white-throated sparrow (pooled mean, 0.06 ug/g). Compared to other sampling sites in northeastern North America, Bicknell•s thrush blood Hg concentrations were 34% lower at Mans“eld than elsewhere (unweighted, arithmetic mean = 0.14 ± 0.08 SD, n = 18 sampling locations). Because there are few studies documenting insectivorous passerine Hg exposure (Bishop et al., 1995; Wolfe and Norman, 1998; Gerrard and St. Louis, 2001; Reynolds et al., 2001; Adair et al., 2003) and because none of the existing studies sampled blood for Hg analysis, few comparisons are available. Two exceptions are from northeastern North America. Shriver et al. (2002) sampled and

analyzed the blood Hg concentrations of saltmarsh and Nelson•s sharp-tailed sparrows (Ammodramus caudacutus and A. nelsoni, respectively) at “ve Maine estuaries and found relatively high Hg levels. Mean concentrations for the saltmarsh sharp-tailed sparrow (0.69 ug/g) were signi“cantly higher than for the closely related Nelson•s sharp-tailed sparrow (0.41 ug/g), and both were higher than the mean concentrations found in Bicknell•s thrush from 21 distinct breeding sites (Table 1). Blood Hg concentrations in 10 insectivorous passerines associated with riverine habitats on the Sudbury River, Massachusetts varied from 0.04 ug/g in the yellow warbler (Dendroica petechia) to 0.92 ug/g in the northern waterthrush (Seiurus noveboracensis) (Evers et al., 2005). In that study, adult mean Hg blood concentrations were lower than those of Bicknell•s thrush for three of the 10 species (barn swallow [Hirundo rustica], gray catbird [Dumetella carolinensis], and yellow warbler).

The causes of intra-site di erences in the blood Hg concentrations of insectivorous passerines likely parallel patterns found in piscivorous birds. Evers et al. (2005) identi“ed di erences among species within the same habitat as primarily related to trophic level. Biomagni“cation of MeHg in aquatic systems is largely dictated by the diversity and density of the planktivorous community (Chen et al., 2005). An analogous community of terrestrially-based microorganisms is likely present in montane habitats, as passerine blood Hg concentrations average only one order of magnitude less than concentrations in small piscivores such as the belted king“sher (Ceryle alycon) (Evers et al., 2005). The trophic level of MeHg in the diet of a Bicknell•s thrush is likely higher than in a blackpoll warbler because thrushes are larger-bodied and feed on larger arthropods (Hunt and Eliason, 1999; Rimmer et al., 2001) that tend to be more predaceous and have higher levels of MeHg than smaller arthropods (Tremblay and Lucotte, 1997). While Bicknell•s thrush and blackpoll warbler follow the regression model by Evers et al. (2005) that predicts >10 4 2.96 3

lower blood and feather Hg concentrations than those in thrushes and even smaller species such as warblers. The relatively high and variable mean Hg concentrations in yellow-rumped warbler blood may be an artifact of small sample size, a more varied diet, and preference toward black ”ies (Simulus spp.), which have an aquatic larval phase that is likely more exposed to MeHg availability than terrestrial insects.

Geographic patterns in Bicknell•s thrush

The lack of a clear geographic pattern in Hg levels of Bicknell•s thrush by individual mountain is not surprising, given the heterogeneity of Hg deposition across northeastern North America (Miller et al., 2005; VanArsdale et al., 2005). However, the overall trend of higher Hg blood and feather concentrations in thrushes in the southern part of the species• breeding range and lower concentrations in northern areas implies a linkage between atmospherically-deposited Hg and MeHg availability. This is reinforced by the strong correlation of deposition and thrush blood data on Stratton and Mans“eld. Higher modeled deposition data from Stratton re”ect a plume of atmospheric-borne Hg from the southwestern part of the study area (Miller et al., 2005), which decreases northward and eastward. The signi“cantly higher blood and feather Hg concentrations of Bicknell•s thrushes on Stratton versus Mans“eld further suggest linkages with regional MeHg availability.

The markedly higher mean blood Hg concentrations of thrushes in the Greater Antilles versus the northeastern North America sampling sites is counter to expected lower levels. Sampling of birds in marine (Burger and Gochfeld, 1991) and estuarine (Burger et al., 1992) environments in Puerto Rico in the late 1980s found relatively low body burdens of Hg. Signi“cant local or regional industrial sources of Hg are unknown for the Greater Antilles. Because the global pool of Hg is increasing (UNEP, 2003), isolated islands and other areas disconnected from local and regional

uptake of MeHg and blood MeHg is typical (Kambamandi-Dimou et al., 1991) and because egg MeHg primarily re”ects blood MeHg levels (Evers et al., 2003), the in”uence of egg MeHg depuration on blood-feather decoupling of Hg levels is likely not a driving factor. However, loss of Hg through eggs may at least partly contribute to gender di erences in Hg levels of Bicknell•s Thrush, particularly because the species exhibits no signi“cant sexual dimorphism in body mass or bill size (important metrics for dimorphism) (Rimmer et al., 2001) that might account for niche partitioning of prey.

Age responses to MeHg availability are well quanti“ed with this study. One-year-old (SY) thrushes had signi“cantly lower feather Hg concentrations than adults (ASY) at both intensively sampled Vermont sites and one of two Quebec sites (Table 1). Other studies have documented similarly signi“cant di erences in Hg body burdens between un”edged young and adult birds (Thompson, 1996), including passerines (Evers et al., 2005). However, di erences in Hg levels among age classes of adult passerines have not previously been described. In our study, some known-age adult thrushes exhibited a signi“cant increase in feather Hg concentrations with increasing age, while other individuals did not. Feather Hg concentrations were highly variable among individual birds examined in multiple years, likely re”ecting the variable dynamics of MeHg availability in wintering and breeding areas. Because feathers provide one of the most e ective pathways of MeHg depuration (70…93

thrush (see Table 1 for how sampling sites were grouped) demonstrated a signi“cant correlation with litterfall Hg deposition ( $r^2 = 0.49$, $p < 0.05$) (Fig. 6).

Conservation of Bicknell•s thrush and the montane bird community

Biogeochemical factors that dictate MeHg availability in terrestrial montane habitats of northeastern North American and in the Greater Antilles are poorly known and warrant further investigation. The issue is of particular concern because the Bicknell•s thrush is the most highly ranked Nearce

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