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MERCURY IN THE INVERTIVORE FOOD WEB OF ONONDAGA LAKE



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Biodiversity Research Institute (BRI) is a 501(c)3 nonprofit organization located in Gorham, Maine. Founded in 1998, BRI is dedicated toward supporting global health through collaborative ecological research, assessment of ecosystem health, improving environmental awareness, and informing science based decision making.

*Hg in Invertivore Food Web of*

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**FRONT PHOTO CAPTION:** *Left: Male red-winged blackbird captured on Onondaga Lake.  
Right: An array of emergence traps set up in the southwest corner of Onondaga.*

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## Table of Contents

1. LIST OF FIGURES .....	5
2. LIST OF TABLES .....	6
3. SPECIES CODES .....	7
4. 1.0 INTRODUCTION .....	8
5. 2.0 STUDY AREA .....	9
6. 3.0 METHODS .....	10
3.1 INVERTEBRATE COLLECTION AND TAXONOMY .....	10
3.2 COLLECTION AND ANALYSIS OF BAT FECES .....	11
3.3 MERCURY AND METHYLMERCURY ANALYSIS OF INVERTEBRATE PREY .....	11
3.5 STABLE ISOTOPE ANALYSIS OF INVERTEBRATE PREY .....	12
7. 4.0 RESULTS AND DISCUSSION .....	13
4.1 AVIAN FOOD WEB .....	15
4.2 BAT FOOD WEB .....	18
4.2a <i>Myotis lucifugus</i> – little brown myotis .....	19
4.2b <i>Eptesicus fuscus</i> – big brown bat .....	20
4.2c Other Species of Interest .....	24
4.3 COMPARISON OF INVERTEBRATE Hg CONCENTRATIONS BETWEEN SITES .....	24
4.4 COMPARISON OF SPIDER Hg CONCENTRATIONS AT ONONDAGA LAKE WITH OTHER STUDIES .....	25
8. 5.0 SUMMARY .....	25
APPENDIX 1 .....	31
APPENDIX 2: TOTAL Hg, MeHg, AND STABLE ISOTOPE CONCENTRATIONS FOR INVERTEBRATE PREY ITEMS SAMPLED FROM ONONDAGA LAKE. ....	34

**List of Figures**

Figure 1. % occurrence and % volume of invertebrate prey in fecal pellets of MYLU. .... 22

Figure 2. % occurrence and % volume of invertebrate prey in fecal pellets of EPFU. .... 23

## **List of Tables**

Table 1. Invertebrate prey selected for total-Hg, methyl-Hg, and stable isotopes.....	14
Table 2. THg, MeHg and stable isotope concentrations of different trophic levels within the avian invertivore food web of Onondaga Lake.....	17
Table 3. Number of bat fecal samples distributed by site and species. ....	19
Table 4. THg, MeHg and stable isotope concentrations of different trophic levels within the bat food web of Onondaga Lake .....	21

## Species Codes

4-letter code	Latin name	Common name
<b>Birds</b>		
SPSA	<i>Actitis macularia</i>	Spotted sandpiper
TRES	<i>Tachycineta bicolor</i>	Tree swallow
RWBL	<i>Agelaius phoeniceus</i>	Red-winged blackbird
<b>Bats</b>		
EPFU	<i>Eptesicus fuscus</i>	Big-brown bat
LABO	<i>Lasiurus borealis</i>	Eastern red bat
MYLU	<i>Myotis lucifugus</i>	Little brown myotis
MYSE	<i>Myotis septentrionalis</i>	Northern long-eared myotis
MYSO	<i>Myotis sodalis</i>	Indiana myotis
MYSU	<i>Perimyotis subflavus</i>	Tri-colored bat*

\*MYSU was initially considered part of the genus *Pipistrellus* (common name Eastern pipistrelle). Recent taxonomic revisions of have placed it in its own genus, *Perimyotis*. We used the traditional abbreviation (MYSU) for this species to avoid confusion with earlier studies.

## **1.0 INTRODUCTION**

Research on food web dynamics within contaminated ecosystems suggests that biological transport represents a significant mechanism for the transfer of contaminants from aquatic into adjacent terrestrial ecosystems. One of the primary biological pathways for contaminant exposure in these ecosystems is emergent aquatic insects that 'export' contaminants during emergence (Tremblay et al. 1998; Walters et al. 2008). These emergent aquatic insects are then consumed by terrestrial invertivores such as birds (Maul et al. 2006) and bats (Wada et al. 2010). Recent work has also highlighted the role that spiders can play as a source of Hg to the food web (Cristol et al. 2008; Walters et al. 2010, Northam et al. 2011). Spiders, which also consume aquatic and terrestrial insects, can account for a significant component of the diet in songbirds (20 - 30%, Cristol et al. 2008) and have also been documented in bat diets (Brack and Whitaker 2001).

Biodiversity Research Institute (BRI), under the direction of the Natural Resource Trustees for the Onondaga Lake Natural Resource Damage Assessment, conducted research on mercury (Hg) exposure in invertivores adjacent to Onondaga Lake during 2008 and 2009. Results from these initial screenings of songbirds (Lane et al. 2011) and bats (Divoll et al. 2009) suggest that invertivores adjacent to Onondaga Lake are exposed to Hg. More than 30% of the songbirds sampled during 2008 and 2009 had blood Hg concentrations at or above recently proposed reproductive effect threshold concentrations for the tree swallow : 0.63 µg/g Hg in blood (Lane et al. 2011) and Carolina wren: 0.70 µg/g Hg in blood ( Jackson et al. 2011). Based on Hg egg injection work conducted by Heinz et al. (2009) on 26 bird species, the tree swallow was found to be moderately sensitive to Hg, more sensitive than species such as the mallard and hooded merganser, but less sensitive than species such as the American kestrel and osprey. Heinz et al. (2009) did not evaluate the sensitivity of the Carolina wren or other wren species to injected Hg.

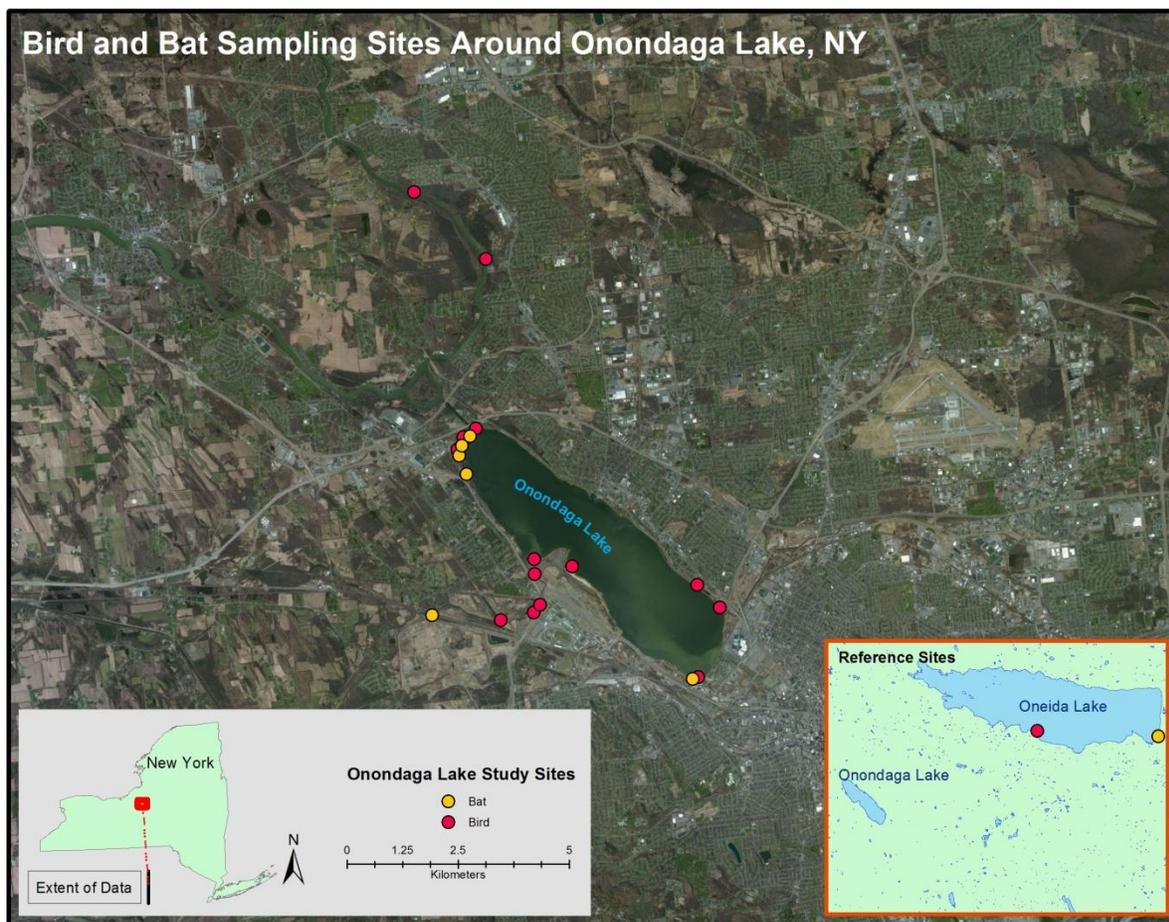
There are no effects thresholds for Hg in bats; however some bats sampled at Onondaga Lake and the Oneida Lake reference area had concentrations of Hg in fur that have

been associated with adverse effects in species such as mink and deer mice. Approximately 53% of the adult bats captured at Onondaga Lake in 2009 had fur Hg concentrations (range = 1.43 - 60.78  $\mu\text{g/g}$ ) that exceeded a deer mouse fur lowest observable adverse effects level (LOAEL) of 10.8  $\mu\text{g/g}$  (fw) (Burton et al. 1977). Approximately 28% of adult bats (17 % of juvenile and adult bats) captured at the reference site had fur Hg concentrations in excess of a deer mouse fur LOAEL of 10.8  $\mu\text{g/g}$ . A small number of bats (< 5%) from Onondaga Lake (no bats from reference area) also had fur Hg concentrations that exceeded an adverse effects threshold for mink (40 – 50  $\mu\text{g/g}$ ), as described in Basu et al. (2007).

In an effort to better understand the mechanisms for the bioaccumulation of Hg in songbirds and bats, we collected potential prey items from multiple sites on Onondaga Lake and the Oneida Lake reference area. In addition, fecal pellets from bats were collected from 129 individuals from Onondaga and Oneida Lakes and analyzed to determine the food habits of bats foraging adjacent to the lake. This report summarizes these results and identifies potential pathways for Hg bioaccumulation on Onondaga Lake.

## **2.0 STUDY AREA**

Invertebrate sampling was conducted at sites where bird and bat sampling was also conducted including: the Beach site on Onondaga Lake; 9 Mile Creek; the Southwest Corner of Onondaga Lake, Maple Bay (also referred to as 'Outlet' in Divoll et al. 2009), Wetzel Road along the Oswego River, and a reference site on Oneida Lake. In addition, samples were collected from the shoreline area immediately to the north of the 9 Mile Creek mouth (here referred to as 9 Mile Beach). Detailed descriptions of these sites are provided in Lane et al. 2011.



### **3.0 METHODS**

#### **3.1 Invertebrate Collection and Taxonomy**

Invertebrate collection followed protocols outlined in Buck et al. (2009) and included sweep netting, opportunistic capture with aspirators, emergence traps, and the use of back lights and a white sheet for night-time insect capture. Individual invertebrate samples were stored in snap-cap centrifuge vials (1.5mL), given a unique sample ID, and stored on ice while in the field. Upon returning from the field, sample fresh weights ( $\pm 0.0001$  g) were determined using an analytical balance and then all samples were stored frozen prior to being transported to BRI's Wildlife Mercury Lab for taxonomic identification. All individuals were identified to Family level. Samples were then freeze-dried and re-weighed to obtain a dry weight. Dry

weight measurements were calculated for each individual. For individuals with a dry weight < 0.02 g, composite samples were made using individuals of the same taxonomic family, collected from the same sample location, and with a similar dry weight. Compositing samples were homogenized using acid-rinsed stainless steel spatulas and prepared for analysis.

### **3.2 Collection and Analysis of Bat Feces**

A description of the bat capture techniques are provided in Divoll et al. (2009). Bats were held in disposable paper bags for approximately 30 minutes and fecal samples were collected from the bag and stored in snap-cap centrifuge vials. Fecal samples were dried and prey remains were separated for taxonomic identification using methods from Kunz and Whitaker (1983) and Whitaker et al. (2011). Prey remains were identified to lowest taxonomic level possible (order in most cases). A dissecting microscope and comparative reference collections were used. The percent occurrence for each taxon in the feces of individual bats was determined and a visual estimate of the percent volume of each prey taxa was made. Percent occurrence and mean percent volume were then summarized for each bat species at each site. Percent occurrence for a species was calculated as the number of bats of a particular species feeding on a prey taxa divided by the total number of individual bats for a particular species. The mean percent volume was calculated by summing the volume of a prey taxa fed on by a particular bat species divided by the total number of bat species.

### **3.3 Mercury and Methylmercury Analysis of Invertebrate Prey**

Invertebrate prey items were analyzed for total mercury (THg) at 2 separate labs. BRI's Wildlife Mercury Research Laboratory analyzed samples following EPA method 7473 by gold-amalgamation atomic absorption spectroscopy following thermal desorption of the sample using a Milestone DMA-80. Additional invertebrate samples were analyzed for both THg and methylmercury (MeHg) at the Wright State University. The concentration of MeHg can vary substantially in invertebrates (Cristol et al. 2008) and knowledge of the percent MeHg in particular prey items can help identify primary pathways for MeHg bioaccumulation within food webs. Dried samples were weighed (+/- 0.00001 g) and placed into 15-mL vessels and then

digested with 1.75 mL of 4.57 M nitric acid for 12 h in a 60° C water bath (Hammerschmidt and Fitzgerald 2006). Digestates were analyzed for monomethylmercury (MMHg=MeHg) by derivatization with sodium tetraethylborate and detection with flow-injection gas chromatographic atomic fluorescence spectrometry. Analyses were calibrated with MeHg standards taken through the acid digestion procedure. All analyses of two standard reference materials from the National Research Council of Canada (TORT-2 and DORM-3) were within the certified range, indicating little or no bias. The method detection limit for MeHg was about 0.3 ng/g for a 10-mg sample. Digestates used for MeHg analysis were oxidized with BrCl and analyzed for total Hg. The method is detailed and validated in Hammerschmidt and Fitzgerald (2006). Total Hg was determined after reduction with stannous chloride by dual-Au amalgamation cold-vapor atomic fluorescence spectrometry (Bloom and Fitzgerald 1988). Analyses were calibrated versus aqueous Hg(II) solutions traceable to the U.S. NIST. Method detection limit for total Hg was about 20 ng/g for a 10-mg sample.

### **3.5 Stable Isotope Analysis of Invertebrate Prey**

Stable isotopes measured in producers and consumers can provide an integrated assessment of trophic interactions and help describe food web pathways leading from the base of the food web up to top level consumers (Peterson and Fry 1987). The ratio of stable carbon (e.g.,  $^{13}\text{C}$  and  $^{12}\text{C}$ ) and nitrogen (e.g.,  $^{15}\text{N}$  and  $^{14}\text{N}$ ) isotopes as measured in tissue samples are reported using the delta notation ( $\delta$ ) and reflect the per mill (‰) difference between the sample and a known reference (Michener and Lajtha 2007). Stable nitrogen isotopic concentrations ( $\delta^{15}\text{N}$ ) values help confirm the trophic position of organisms within a food web while stable carbon isotopic concentrations ( $\delta^{13}\text{C}$ ) help determine the origin of basal resources within particular food webs (Peterson and Fry 1987; Knoff et al. 2001). When used in conjunction with contaminant analysis, it is possible to examine the bioaccumulation and biomagnification of contaminants within a food web. Contaminants that enter food webs are accumulated by organisms at lower trophic levels and then can be magnified by consumers at higher levels in the food web (Rasmussen and Vander Zanden 2004).

The same subset of samples analyzed for THg and MeHg were split and analyzed for stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotopic concentrations at Boston University, Boston Massachusetts, using automated continuous-flow isotope ratio mass spectrometry (Michener and Lajtha 2007). Dried invertebrate samples (approximately 400 micrograms) were transferred to tin capsules and combusted in a EuroVector Euro EA elemental analyzer. The combustion gases ( $\text{N}_2$  and  $\text{CO}_2$ ) were separated on a GC column, passed through a reference gas box and introduced into the GV Instruments IsoPrime isotope ratio mass spectrometer; water was removed using a magnesium perchlorate water trap. Ratios of  $^{13}\text{C}/^{12}\text{C}$  and  $^{15}\text{N}/^{14}\text{N}$  are reported as standard delta ( $\delta$ ) notation and are expressed as the relative permil (‰) difference between the samples and international standards (Vienna Pee Dee Belemnite (V-PDB) carbonate and  $\text{N}_2$  in air) where:

$$\delta X = (R_{\text{sample}} / R_{\text{standard}} - 1) \times 1000 \text{ (‰)}$$

$$\text{Where } X = ^{13}\text{C} \text{ or } ^{15}\text{N} \text{ and } R = ^{13}\text{C}/^{12}\text{C} \text{ or } ^{15}\text{N}/^{14}\text{N}$$

The sample isotope ratio is compared to a secondary gas standard, the isotope ratio of which was calibrated to international standards. For  $^{13}\text{C}$ -VPDB, the gas was calibrated against NBS 20 (Solenhofen Limestone). The  $^{15}\text{N}_{\text{air}}$  gas was calibrated against atmospheric  $\text{N}_2$  and International Atomic Energy Agency (IAEA) standards N-1, N-2, and N-3 (all are ammonium sulfate standards).

## **4.0 Results and Discussion**

During 2009, BRI collected a total of 776 individual invertebrates. After compositing samples to have adequate mass for analyses, we selected 81 samples as part of this preliminary assessment of Hg within the invertivore food webs of Onondaga. Samples were selected that (1) had sufficient sample mass for both mercury and stable isotope analysis and (2) were captured in the same sampling site as the target invertivores (see section 4.1 and section 4.2). This included 56 samples for THg and an additional 25 samples for THg/MeHg analysis and stable isotope analysis. Samples were distributed across 3 orders and 19 families and were

separated into avian versus bat food webs based on the timing (day vs. night) and location of sampling (Table 1). Small sample sizes prevent any robust statistical tests for differences within the data and the discussion of prey mercury instead focuses on trends within and across sampling sites.

**Table 1. Invertebrate prey items selected for total-Hg, methyl-Hg, and stable isotope analysis**

TAXA	AVIAN FOOD WEB		BAT FOOD WEB	
	THg	MeHg & isotopes	THg	MeHg & isotopes
<b>Aranaea</b>				
Lycosidae	7	3		
Tetragnathidae	4	3		
<b>Diptera</b>				
Culicidae			1	
Dolichopodidae			6	2
Sciomyzidae				2
Muscidae		1	4	2
Syrphidae		1		
Chironomidae				1
Sarcophagidae	1			
Scathophagidae	4	1	1	
Sepsidae	4			
Sphaeroceridae	4	1		
Therevidae			1	1
Tipulidae			1	1
<b>Coleoptera</b>				
Carabeidae				1
Chrysomelidae			4	1
Curculionidae			7	2
Elatridae			2	
Scarabeidae			5	2
<b>subtotal</b>	24	10	32	15

## **4.1 Avian Food Web**

The Spotted Sandpiper (SPSA) was the primary avian invertivore target for the preliminary assessment of Hg bioaccumulation. Spotted Sandpipers sampled during the 2008 and 2009 field seasons had the highest blood Hg concentration of any bird sampled during those years (Lane et al. 2011). On Onondaga Lake, SPSA have been observed in the highest densities along the southwestern shore of the lake, between the Beach and the 9-Mile Creek mouth (Lane et al. 2011). SPSA are primarily ground foraging birds that utilize shorelines and aquatic vegetation washed up on shores to forage for adult and larval invertebrates including flies (Diptera), crickets (Orthoptera), spiders (Aranea), as well as worms, mollusks, crustaceans and occasional carrion washed up on shore (Rubbelke 1976; Oring et al. 1997).

The invertebrate prey items collected from the Beach and 9-Mile Creek Beach sites included 2 families of spiders (Table 2). Lycosid (wolf) and Tetragnathid (long-jawed) spiders are predatory spiders commonly found within littoral and riparian zone habitats. Both families have been the focus of other contaminant studies linking spiders as a source of Hg to birds and other vertebrates (Cristol et al. 2008; Walters et al. 2010; Northam et al. 2011; Buck et al. 2011). Tetragnathid spiders collected from Lake George, NY, a lake in the Adirondacks region, were previously reported as having a mean THg of 0.31 ppm (dw) (Buck et al. 2011). Lycosid spiders within the riparian zone of the South River (Virginia), a site impacted by a point source of mercuric sulfate, had a mean THg concentration of 1.24 ppm (dw) (Cristol et al. 2008). Mean THg concentrations in Lycosid spiders from the Onondaga Lake beach sites are higher than either of these studies [Table 2; mean THg of 1.34 ppm (dw)]. Both Lycosid and Tetragnathid spiders from Onondaga Lake have relatively high  $\delta^{15}\text{N}$  isotopic concentrations (mean of  $12.3 \pm 0.2$  ‰ and  $11.7 \pm 0.2$  ‰, respectively). Based on these  $\delta^{15}\text{N}$  values, spiders at the two beach sites occupy a similar or slightly higher trophic level as SPSA (Table 2).

In addition to spiders, day-time capture of invertebrates at the Beach and 9-Mile Creek Beach sites included several families of sapro- and coprophagous flies (Table 2). Sphaerocerid flies are often referred to as dung flies or corpse flies and play an important role in the

decomposition of organic matter (Roháček 2001). Both Sepsid and Scathophagid flies have similar life histories and feeding strategies as Sphaerocerids, with larval and adult stages consuming decaying plant and animal matter (McAlpine 1987). Sarcophagid flies (commonly referred to as flesh flies) lay eggs within decaying plant and animal matter (McAlpine 1987). At both the 9-Mile Beach and Beach sites, these above-mentioned families of flies were abundant along the littoral zone of the lake, particularly in areas where aquatic vegetation, algal mats and fish carcasses had washed ashore. The other two families of flies analyzed as part of this study include Syrphid and Muscid flies. Syrphid flies are often referred to as flower flies and can have a wide range of feeding habits but are primarily considered nectar feeders (McAlpine 1987). Muscid flies include the common house fly.

The fly samples analyzed here represent adult Dipterans. We note that larval dipterans may accumulate greater or lesser amounts of Hg than adults (Sarica et al. 2009; Wurtsbaugh et al. 2011; Rossaro et al. 1986).

Mitchell et al. (1996) report stable isotopic concentrations for food web components of nearby Oneida Lake. Lower trophic levels within Oneida Lake such as sediments and seston have  $\delta^{15}\text{N}$  values ranging from 6.0 ‰ to 7.5 ‰ while upper trophic level fish such as yellow perch and walleye have  $\delta^{15}\text{N}$  values of 12.5 ‰ and 15.7 ‰, respectively (Mitchell et al. 1996). Walleye collected in Onondaga Lake as part of Honeywell's baseline monitoring program had  $\delta^{15}\text{N}$  values of 18 – 19 ‰ (Parsons et al. 2012), possibly reflecting greater organic inputs to Onondaga Lake than Oneida Lake.

**Table 2. Mercury, methylmercury (MeHg) and stable isotope concentrations (mean ± 1 standard deviation) of different trophic levels within the avian invertivore food web of Onondaga Lake collected during the 2009 field season (sample sizes are shown in parentheses).**

	THg (ppm, ww)	THg (ppm, dw)	MeHg (ppm, dw)	% MeHg	δ <sup>13</sup> C (‰ vs. VPDB)	δ <sup>15</sup> N (‰ vs. AIR)
<b>Invertivores *</b>						
<b>Spotted Sandpiper</b>	1.91 +/- 0.47 (9)	2.54 +/- 0.63 ^		> 90 ‡	-24.8 +/- 0.2 (9)	11.4 +/- 0.7 (9)
<b>Tree Swallow</b>	0.39 +/- 0.04 (18)	0.52 +/- .05 ^		> 90 ‡	-28.1 +/- 0.2 (18)	10.9 +/- 0.2 (18)
<b>Red-winged Blackbird</b>	0.77 +/- 0.21 (28)	1.03 +/- 0.28 ^		> 90 ‡	-21.4 +/- 0.5 (28)	9.1 +/- 0.4 (28)
<b>Aranaea</b>						
<b>Lycosidae</b>		1.34 +/- 0.36 (10)	0.84 +/- 0.21 (3)	84.1	-25.9 +/- 0.2 (3)	12.3 +/- 0.2 (3)
<b>Tetragnathidae</b>		0.54 +/- 0.16 (7)	0.40 +/- 0.17 (3)	78.4	-27.9 +/- 0.7 (3)	11.7 +/- 0.2 (3)
<b>Diptera</b>						
<b>Sphaeroceridae</b>		0.37 +/- 0.15 (5)	0.31 (1)	93.9	-25.3 (1)	14.7 (1)
<b>Sepsidae</b>		0.28 +/- 0.12 (4)	-----	-----	-----	-----
<b>Scathophagidae</b>		0.18 +/- 0.11 (5)	0.051 (1)	87.9	-26.3 (1)	12.9 (1)
<b>Sarcophagidae</b>		0.12 (1)	-----	-----	-----	-----
<b>Muscidae</b>		0.055 (1)	0.04 (1)	72.7	-26.5 (1)	5.9 (1)
<b>Syrphidae</b>		0.03 (1)	0.009 (1)	29	-28.2 (1)	6.7 (1)

\* Mercury and stable isotope concentrations in bird blood Lane et al. (2011; Appendix D); data only from Onondaga Lake

^ Wet weight to dry weight conversion done assuming 75% moisture loss (Rimmer et al. 2005).

‡ Bird blood contains greater than 90% MeHg (Rimmer et al. 2005).

## **4.2 Bat Food Web**

A total of 151 bats from 5 different species were captured during the 2009 assessment of Hg exposure in bats on Onondaga Lake and nearby Oneida Lake (Yates et al. 2012). Mean bat fur Hg for all species collected from Onondaga Lake was two times higher in adult bats and almost 4 times higher in juvenile bats than the reference site of Oneida Lake. In an effort to understand potential food web pathways for Hg accumulation within bats on Onondaga Lake, BRI collected fecal samples from captured bats and evaluated the prey remains.

Bat fecal analysis provides valuable information on the feeding habits of bats without sacrificing animals. The disadvantages of fecal analysis have been noted in the literature, including a bias towards hard-bodied insects (Rabinowitz and Tuttle 1982) and the challenge of identifying beyond order for certain taxa such as moths without culled insect parts collected from a roosting site (Whitaker et al. 2011). These limitations to bat fecal analysis can be minimized by pooling samples for individual species to obtain a more accurate assessment of preferred prey items of insectivorous bats (Kunz and Whitaker 1983).

Fecal samples were collected from a total of 129 individual bats from 5 different sites, including 3 sites at Onondaga Lake, 1 site along the Oswego River, and 1 site on Oneida Lake (Table 4; see figure 1 in Divoll et al. 2009 for locations). In this section of the report, we discuss the feeding habits and their relation to the observed THg concentrations in the two most commonly captured bats on Onondaga Lake, *Myotis lucifugus* (Little brown myotis) and *Eptesicus fuscus* (Big brown bat). The full data set of prey remains is presented in Appendix 1.

**Table 3. Number of bat fecal samples distributed by site and species.**

<b>Bat Species</b>	<b>Southwest Corner</b>	<b>9-Mile Creek</b>	<b>Maple Bay</b>	<b>Oswego River</b>	<b>Oneida (reference)</b>
MYLU	13	25	10	6	16
EPFU	13	--	--	10	14
MYSE	--	--	8	3	--
MYSO	--	--	9	--	--
MYSU	--	1	--	--	--
LABO	1	--	--	--	--

#### **4.2a *Myotis lucifugus* – little brown myotis**

The little brown myotis (*Myotis lucifugus*, MYLU) was the most commonly caught bat at Onondaga Lake during the 2009 field season (Yates et al. 2012). Previous studies on the diet of MYLU have suggested that it is an opportunistic feeder foraging on a broad prey base including Coleoptera, Hemiptera, Lepidoptera, Diptera, and Trichoptera (Whitaker and Hamilton 1998). Results from our bat fecal analysis are consistent with these results (Figures 1a and 1b; Appendix 1). MYLU on Onondaga Lake forage on a broad prey base that includes Coleoptera, Lepidoptera, and Diptera and to a lesser degree, Trichoptera and Hymenoptera (Figure 1a). Lepidopterans dominate the diet, with a percent volume consistently near 60% (Figure 1b). The exception to this is MYLU captured adjacent to the Oswego River whose diet had a lower percent volume of Lepidopterans (15.4%) and a higher percent volume of Dipterans relative to the MYLU from the other sites (Figure 1b; Appendix 1).

Mean THg in fur from adult MYLU on Onondaga Lake ranged from 8.88 µg/g (fw) at Maple Bay (near the outlet of the lake), to 15.77 µg/g (fw) at 9-Mile Creek, and up to 22.23 µg/g (fw) in the Southwest corner of the lake. Mean THg in MYLU fur from the Oswego River was 7.18 µg/g (fw) and mean THg in the fur of Oneida Lake bats was 3.83 µg/g (fw) (Yates et al. 2012; table 6). No Diptera were collected from the Maple Bay site but THg concentrations in Diptera were higher in the Southwest corner of Onondaga Lake than at 9-Mile Creek (Table 5).

Although Lepidopterans represented a significant component of the MYLU diet, no Lepidoptera were collected during field sampling. Along the South River, VA, Cristol et al. (2008) reported an average THg in Lepidopterans of  $0.38 \pm 2.08 \mu\text{g/g dw}$  and a percent MeHg of  $24 \pm 20 \%$ . The large standard deviation in the data from the South River suggests significant variability in Lepidoptera Hg accumulation. While no data exist on Lepidopterans from Onondaga Lake, these above-mentioned South River data suggest that Lepidopterans could potentially represent a significant pathway of THg within the bat food web, particularly given their prominence within the bat diet at Onondaga Lake.

#### **4.2b *Eptesicus fuscus* – big brown bat**

Big brown bats (EPFU) were caught at three sites during the 2009 field season, including the southwest corner of Onondaga Lake, the Oswego River, and Oneida Lake (Table 4). Big brown bats are considered beetle (Order Coleoptera) specialists (Black 1974; Carter et al. 2003). Beetle remains were recorded in every EPFU fecal sample at consistently high percent volumes (Figure 2a and 2b). On Oneida Lake and along the Oswego River, EPFU consumed a higher volume of Elaterid beetles than EPFU from the southwest corner of Onondaga Lake (52.8% (Oneida) and 39.7% (Oswego) versus 11.7% (SW corner @ Onondaga). EPFU captured in the SW corner consumed a larger volume of Scarabeid beetles relative to the other sites {30.2% (SW corner) versus 14.7% (Oswego) and 11.1% (Oneida)} (Appendix 1). In addition to beetles, Lepidopterans occurred in over 80% of the EPFU fecal remains from the SW corner while occurring in only 20% or less of the EPFU fecal samples from Oneida Lake and the Oswego River (Figure 2a and 2b).

These within species dietary differences in prey selection across sites may explain the differences observed in the THg concentrations of EPFU across these sites as well. EPFU captured along the Oswego River had the highest mean THg of any species at any site (mean THg =  $29.08 \mu\text{g/g, fw}$ ) (Yates et al. 2012). These bats consumed more Chrysomelid, Elaterid and Carabid beetles than other EPFU while also consuming less Lepidoptera than EPFU

captured at the SW corner. Carabid beetles are carnivorous and Elaterid beetles feed on carrion as larvae, potentially exposing them to high concentrations of Hg.

**Table4. Mercury, methylmercury and stable isotope concentrations (mean ± 1 standard deviation) of different trophic levels within the bat food web of Onondaga Lake (sample sizes are shown in parenthesis)**

	<b>THg (ppm, dw)</b>	<b>MeHg (ppm, dw)</b>	<b>% MeHg</b>	<b>δ<sup>13</sup>C<sup>1</sup> (‰ vs. VPDB)</b>	<b>δ<sup>15</sup>N<sup>1</sup> (‰ vs. AIR)</b>
<b>9 Mile Creek</b>					
<b>Coleoptera</b>	0.05 +/- 0.05 (2)	--	--	--	--
<b>Diptera</b>	0.13 +/- 0.04 (5)	0.18 +/- 0.03 (2)	82	-24.9 +/- 0.9 (2)	15.1 +/- 1.7 (2)
<b>Maple Bay</b>					
<b>Coleoptera</b>	0.09 +/- 0.12 (13)	0.02 +/- 0.03 (4)	10.9	-29.1 +/- 1.8 (4)	2.5 +/- 1.5 (4)
<b>SW corner</b>					
<b>Diptera</b>	0.53 +/- 0.18 (5)	0.40 +/- 0.53 (2)	51.9	-26.1 +/- 0.5 (2)	9.4 +/- 3.5 (2)
<b>Oswego</b>					
<b>Coleoptera</b>	0.03 +/- 0.04 (3)	0.053 (1)	70.6	-25.5 (1)	7.9 (1)
<b>Diptera</b>	0.23 +/- 0.18 (6)	0.13 +/- 0.15 (3)	79.8	-25.6 +/- 0.8 (3)	8.9 +/- 2.8 (3)
<b>Oneida (reference)</b>					
<b>Coleoptera</b>	0.05 +/- 0.03 (6)	0.01 (1)	22.9	-27.3 (1)	4.5 (1)
<b>Diptera</b>	0.08 +/- 0.03 (7)	0.07 +/- 0.01 (2)	89.4	-26.4 +/- 0.3 (2)	8.3 +/- 0.4 (2)

<sup>1</sup> Samples for stable isotopes in bats were not collected during the 2009 field season. Stable isotope data on invertebrates are reported here for future reference.

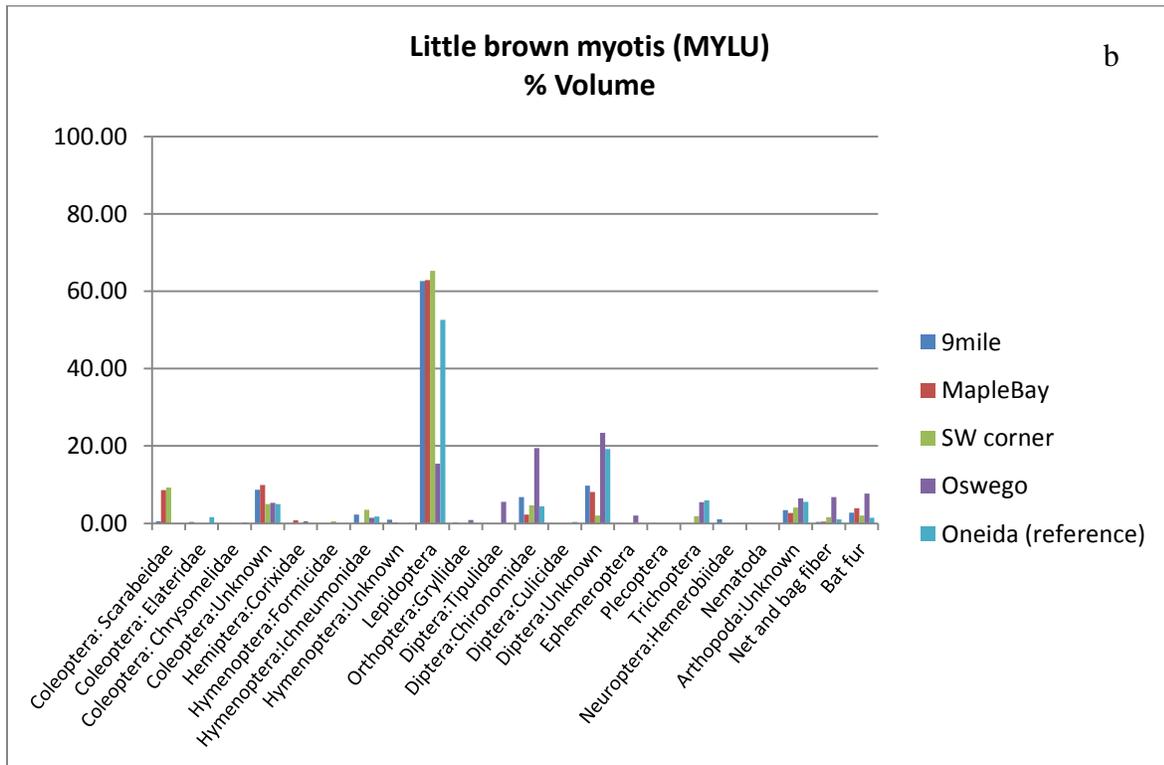
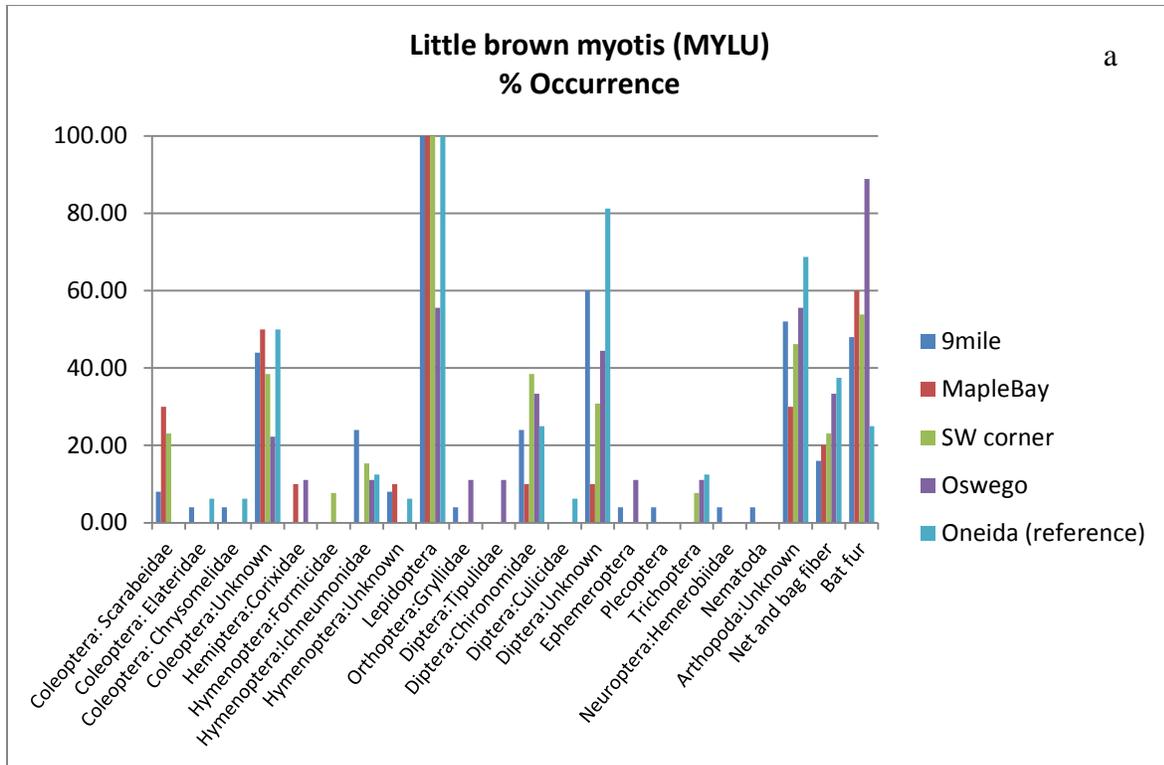


Figure 1. Percent occurrence and percent volume of invertebrate prey in fecal pellets of MYLU.

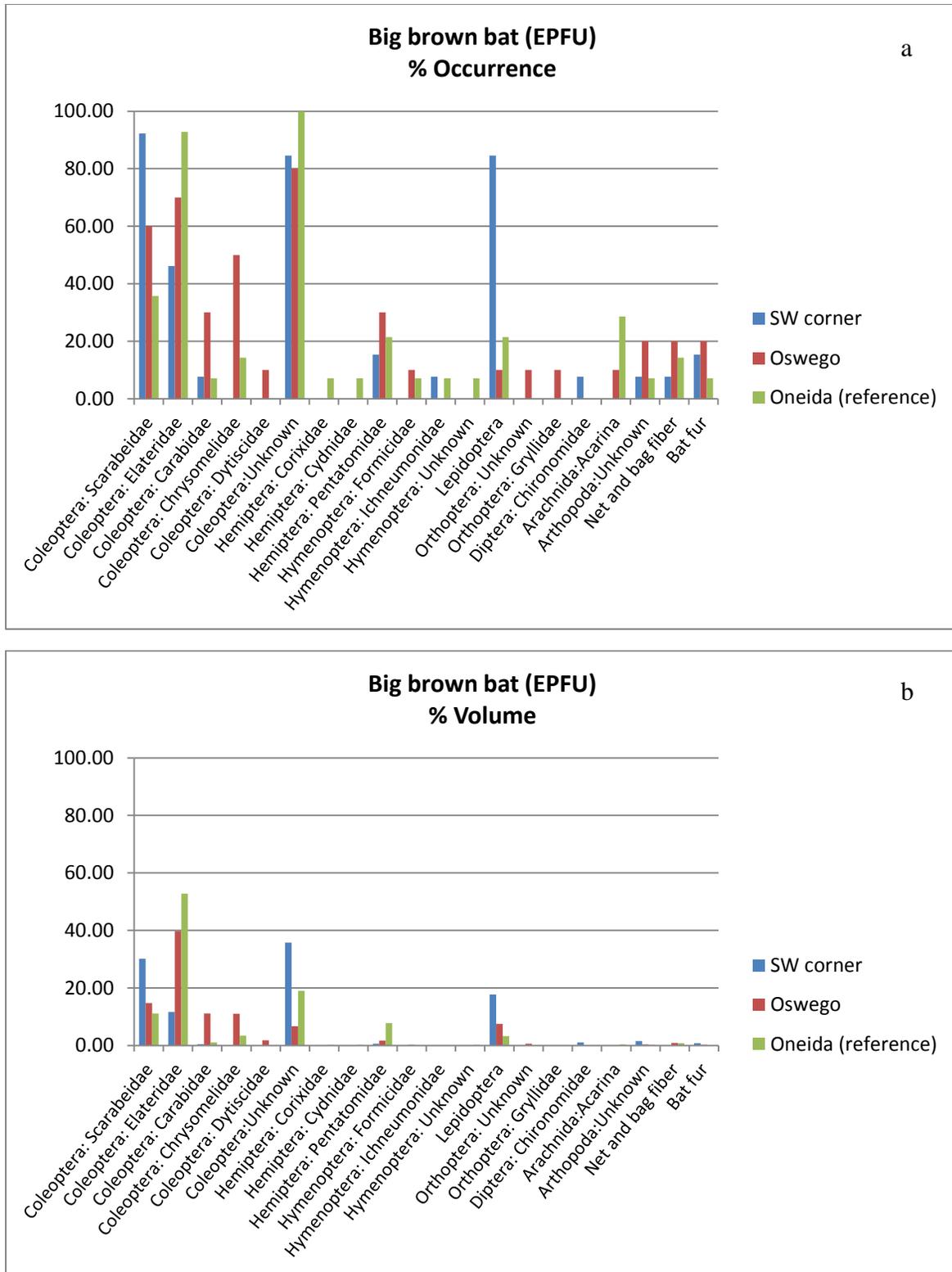


Figure 2. Percent occurrence and percent volume of invertebrate prey in fecal pellets of EPFU.

#### **4.2c Other Species of Interest**

Other bat species captured on Onondaga Lake for fecal analysis included MYSE, LABO, MYSO, and MYSU (Table 4). Sample sizes were low for these species (Table 4) but Lepidopteran prey represented large components of the diet for all of these bat species captured on Onondaga Lake. The percent volume of Lepidopteran remains in fecal pellets ranged from 38.7% of the volume in fecal remains of the Northern long-eared myotis (*Myotis septentrionalis*, MYSE) to 97% in the feces of the single juvenile *Lausurus borealis* (Eastern red bat, LABO) captured in the Southwest corner (Appendix 1). Lepidopterans occurred in 100% of the fecal remains of the Indiana bat (*Myotis sodalis*, MYSO) with an estimated volume of 56.8% (Appendix 1). MYSO also consumed a high concentration of beetles (Appendix 1).

#### **4.3 Comparison of Invertebrate Hg Concentrations Between Sites**

Invertebrates collected for Hg analysis at the Onondaga Lake sites (Beach, 9-Mile Creek Beach, SW Corner, Maple Bay) included individuals of the orders Aranaea (spiders), Diptera (flies), and Coleoptera (butterflies and moths). At the Oneida Lake reference site, only limited numbers of Dipterans and Coleopterans were collected. Dipterans from Oneida Lake were dominated by individuals from the family Muscidae (only 1 non-Muscidae sample), whereas Onondaga Lake samples included samples from eleven Dipteran families, with only one Muscidae sample. The only Coleopterans in common between the Onondaga and Oneida Sites were samples from the families Chrysomelidae and Curculionidae. Sample sizes are considered too limited for comparative purposes.

#### **4.4 Comparison of Spider Hg concentrations at Onondaga Lake with other studies**

Both Lycosid and Tetragnathid spiders have been the focus of recent contaminant studies linking spiders as a source of Hg to birds and other vertebrates (Cristol et al. 2008; Walters et al. 2010; Northam et al. 2011; Buck et al). Tetragnathid spiders collected from Lake George, NY, a lake in the Adirondacks region, were previously reported as having mean THg of 0.31 ppm (dw) (Buck et al. 2011). Tetragnathid spiders from Onondaga Lake have a mean THg concentration of  $0.54 \pm 0.16$  ppm (dw). Sample size differences and non-normal distributions between the two sites prohibit the use of parametric statistics to compare the two sites. However, when compared using the non-parametric Mann-Whitney U-statistic, mean THg in Tetragnathids is higher at Onondaga Lake than at Lake George ( $U = 22$ ;  $p = 0.002$ ). Lycosid spiders from the previously mentioned study at Lake George have a mean THg concentration of 0.462 ppm (dw) (Buck et al. 2011). Total Hg concentrations in Lycosids from Onondaga Lake (mean THg =  $1.34 \pm 0.36$  ppm (dw)) are significantly higher than at Lake George ( $U = 7$ ;  $p=0.015$ ). The THg concentrations in Lycosid spiders at Onondaga Lake are more comparable to those measured on Lycosids within the riparian zone of the South River (Virginia), a site impacted by a point source of mercuric sulfate. Lycosids at the South River had a mean THg concentration of 1.24 ppm (dw) (Cristol et al. 2008).

#### **5.0 Summary**

Spotted sandpipers on Onondaga Lake have high THg body burdens. Results from this food web study suggest that some invertebrates, including spiders, also contain high THg and MeHg concentrations and may represent a pathway for the bioaccumulation of Hg within the

sandpiper food web. The  $\delta^{15}\text{N}$  values for spiders from this study are similar to or greater than the  $\delta^{15}\text{N}$  values for SPSA, suggesting that spiders may not constitute a significant portion of the SPSA diet. A more intensive dietary study would be needed to clarify the relationship between SPSA blood Hg and Hg concentrations in their diet.

The diet of bats on Onondaga Lake is dominated by beetles (Coleoptera), moths (Lepidoptera), and flies (Diptera). During 2009, the little brown bat (*Myotis lucifugus*) was the most commonly caught bat on Onondaga Lake and its diet was dominated by moths, and to a lesser degree flies. Big brown bats (*Eptesicus fuscus*) on Onondaga Lake primarily consumed beetles. Of the invertebrate prey items sampled during this study, Dipterans were consistently higher in THg and MeHg than other insect orders. Although Lepidopterans were consistently present in the diet of bats on Onondaga, no site-specific data are currently available on mercury concentrations in these prey items.

Data were insufficient to compare Hg concentrations in invertebrates from Onondaga Lake and Oneida Lake. However, a comparison of Hg concentrations in spiders from Onondaga Lake with other studies indicates that Hg concentrations in these spiders are elevated above Hg concentrations in spiders from Lake George, New York and the South River, VA.

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**Appendix 1.** Percent occurrence and percent volume of prey items for each bat species from each site captured during the 2009 field season.

	9 Mile Creek				Maple Bay						
	MYLU		MYSU		MYLU		MYSE		MYSO		
	%Occ	%Vol	%Occ	%Vol	%Occ	%Vol	%Occ	%Vol	%Occ	%Vol	
<i>Arthropoda</i>											
<i>Arachnida: Acarina</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Insecta</i>											
<i>Coleoptera</i>											
<i>Adenophaga: Carabidae</i>	0	0	100	3	0	0	0	0	0	0	0
<i>Polyphaga</i>											
<i>Chrysomelidae</i>	4	0.0	0	0	0	0	0	0	0	0	0
<i>Curculionidae</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Elateridae</i>	4	0.36	0	0	0	0	62.5	16.1	11.1	1.1	
<i>Scarabeidae</i>	8	0.56	0	0	30	8.6	25	5.1	22.2	9.2	
Unknown	44	8.68	0	0	50	9.9	75	12.1	66.7	24.2	
<i>Diptera</i>											
<i>Chironomidae</i>	24	6.8	0	0	10	2.3	0	0	0	0	
Unknown	60	9.76	0	0	10	8.1	12.5	0.5	0	0	
<i>Hemiptera: Heteroptera:</i>											
<i>Pentatomidae</i>	0	0	0	0	0	0	0	0	0	0	
<i>Hymenoptera: Ichneumonidae</i>	24	2.28	100	8	0	0	12.5	2.5	0	0	
<i>Lepidoptera: Unknown</i>	100	62.6	100	72	100	62.9	100	55.9	100	56.8	
Unknown	52	3.4	100	12	30	2.7	37.5	3.1	22.2	6	
Bat Fur	48	2.76	100	1	60	3.9	25	3.3	11.1	0.1	
Net and Bag Fiber	16	0.4	100	4	20	0.5	0	0	11.1	0.3	
Other	1.8	0.1	0	0	1.3	0.1	0.8	0	0.7	0	

*Hg in Invertivore Food Web of*

Appendix 1, cont.

	SouthWest Corner						Oswego River					
	MYLU		EPFU		LABO		MYLU		MYSE		EPFU	
	%Occ	%Vol	%Occ	%Vol	%Occ	%Vol	%Occ	%Vol	%Occ	%Vol	%Occ	%Vol
<i>Arthropoda</i>												
<i>Arachnida: Acarina</i>	0	0	0	0	0	0	0	0	33.3	0.3	10	0.1
<i>Insecta</i>												
<i>Coleoptera</i>												
<i>Adenophaga: Carabidae</i>	0	0	7.7	0.4	0	0	0	0	0	0	30	11.1
<i>Polyphaga</i>												
<i>Chrysomelidae</i>	0	0	0	0	0	0	0	0	0	0	50	11
<i>Curculionidae</i>	0	0	0	0	0	0	0	0	33.3	26.7	0	0
<i>Elateridae</i>	0	0	46.2	11.7	0	0	0	0	0	0	70	39.7
<i>Scarabeidae</i>	23.1	9.2	92.3	30.2	100	1	0	0	33.3	15.3	60	14.7
Unknown	38.5	5	84.6	35.8	0	0	22.2	5.3	100	8.7	80	6.7
<i>Diptera</i>												
<i>Chironomidae</i>	38.5	4.7	7.7	1.1	0	0	33.3	19.4	0	0	0	0
Unknown	30.8	2	0	0	0	0	44.4	23.4	0	0	0	0
<i>Hemiptera: Heteroptera:</i>												
<i>Pentatomidae</i>	0	0	15	1	0	0	0	0	0	0	30	1.7
<i>Hymenoptera:</i>												
<i>Ichneumonidae</i>	15.4	3.5	8	0	0	0	11.1	1.4	0	0	0	0
<i>Lepidoptera: Unknown</i>	100	65.2	85	18	100	97	55.6	15.4	66.7	38.7	10	7.5
Unknown	46.2	4.1	7.7	1.5	0	0	55.6	6.4	66.7	5.3	20	0.3
Bat Fur	53.8	2	15.4	0.8	100	2	88.9	7.7	33.3	0.7	20	0.2
Net and Bag Fiber	23.1	1.6	7.7	0.2	0	0	33.3	6.8	66.7	4.3	20	0.9
Other	1	0.1	0	0	0	0	3.5	0.9	0	0	2.5	0.2

Appendix 1, cont.

	Oneida Lake – Reference Site			
	MYLU		EPFU	
	%Occ	%Vol	%Occ	%Vol
<i>Arthropoda</i>				
<i>Arachnida: Acarina</i>	0	0	28.6	0.4
<i>Insecta</i>				
<i>Coleoptera</i>				
<i>Adenophaga: Carabidae</i>	0	0	7.1	1.1
<i>Polyphaga</i>				
<i>Chrysomelidae</i>	6.3	0.2	14.3	3.4
<i>Curculionidae</i>	0	0	0	0
<i>Elateridae</i>	6.3	1.6	92.9	52.8
<i>Scarabeidae</i>	0	0	35.7	11.1
Unknown	50	5	100	19
<i>Diptera</i>				
<i>Chironomidae</i>	25	4.4	0	0
Unknown	81.3	19.3	0	0
<i>Hemiptera: Heteroptera:</i>				
<i>Pentatomidae</i>	0	0	21.4	7.8
<i>Hymenoptera: Ichneumonidae</i>	12.5	1.8	7.1	0.1
<i>Lepidoptera: Unknown</i>	100	52.6	21.4	3.2
Unknown	68.8	5.6	7.1	0.2
Bat Fur	25.0	1.4	7.1	0.1
Net and Bag Fiber	37.5	1.1	14.3	0.8
Other	1.6	0.4	1.8	0.1

**APPENDIX 2:** Total Hg, MeHg, and stable isotope concentrations for invertebrate prey items sampled from Onondaga Lake.

Lab ID	Territory	Order	Family	Notes	THg (mg/kg, dw)	MeHg (mg/kg, dw)	%MeHg	d13C, permil	d15N, permil	composited samples
<b>BIRD PREY ITEMS</b>										
ONON-SP1	beach	Aranaea	Lycosidae		1.709					# 343, 351, 349, 341, 346
ONON-SP2	beach	Aranaea	Lycosidae		1.403					# 347, 352, 350, 348, 342
ONON-SP3	beach	Aranaea	Lycosidae		1.735					# 338, 335, 336
ONON-SP4	beach	Aranaea	Lycosidae		1.1	1.08	98.2	-26.07	12.33	# 333, 334, 339
ONON-SP5	beach	Aranaea	Lycosidae		1.385					# 327, 332
ONON-SP6	beach	Aranaea	Lycosidae		0.756	0.674	89.2	-25.67	12.18	# 330, 344
ONON-SP7	beach	Aranaea	Lycosidae		1.901					# 337, 340
ONON-SP8	beach	Aranaea	Lycosidae		1.233					# 331
ONON-SP9	beach	Aranaea	Lycosidae		1.004					# 328
ONON-SP10	beach	Aranaea	Lycosidae		1.18	0.766	64.9	-25.85	12.54	# 329
ONON-SP11	beach	Aranaea	Tetragnathidae		0.385	0.281	73.0	-27.53	11.80	# 95, 93, 82, 94, 67, 100
ONON-SP12	beach	Aranaea	Tetragnathidae		0.402					# 96, 63, 77
ONON-SP13	beach	Aranaea	Tetragnathidae		0.519					# 65, 92
ONON-SP14	beach	Aranaea	Tetragnathidae	Male	0.436	0.322	73.9	-27.51	11.49	# 91, 64
ONON-SP15	beach	Aranaea	Tetragnathidae	Male	0.679	0.6	88.4	-28.78	11.80	# 61
ONON-SP16	beach	Aranaea	Tetragnathidae	Male	0.840					# 66
ONON-SP17	beach	Aranaea	Tetragnathidae	Male	0.546					# 76
ONON-IN1	9 mile beach	Diptera	Sepsidae		0.345					# 274A, 275A, 278A

*Hg in Invertivore Food Web of*

ONON-IN2	9 mile beach	Diptera	Sepsidae		0.169					# 279A, 280A
ONON-IN3	9 mile beach	Diptera	Sepsidae		0.190					# 281A, 282A
ONON-IN4	9 mile beach	Diptera	Sphaeroceridae	30 ind	0.262					# 274, 275, 276
ONON-IN5	9 mile beach	Diptera	Sphaeroceridae	30ind	0.332	0.312	94.0	-25.32	14.66	#277, 278, 279
ONON-IN6	9 mile beach	Diptera	Sphaeroceridae	30ind	0.284					# 280, 281, 282
ONON-IN7	beach	Diptera	Muscidae		0.055	0.04	72.7	-26.56	5.89	# 68, 101
ONON-IN8	beach	Diptera	Sarcophagidae		0.117					# 84
ONON-IN9	beach	Diptera	Scathophagidae		0.265					# 83
ONON-IN10	beach	Diptera	Scathophagidae		0.153					# 289, 291
ONON-IN11	beach	Diptera	Scathophagidae		0.098					# 309
ONON-IN12	beach	Diptera	Scathophagidae		0.058	0.051	87.9	-26.27	12.93	# 307, 308, 304
ONON-IN13	beach	Diptera	Scathophagidae		0.308					# 305, 306, 310, 311
ONON-IN14	beach	Diptera	Sepsidae		0.410					# 439A, 440A
ONON-IN15	beach	Diptera	Sphaeroceridae	15 ind	0.633					# 439, 468
ONON-IN16	beach	Diptera	Sphaeroceridae	40 ind	0.317					# 440, 469, 470, 471
ONON-IN17	beach	Diptera	Syrphidae		0.031	0.009	29.0	-28.16	6.74	# 85, 88
<b>BAT PREY ITEMS</b>										
ONON-IN18	9 mile creek	Diptera	Dolichopodidae		0.079					# 219
ONON-IN19	9 mile creek	Diptera	Dolichopodidae		0.183					# 220, 221
ONON-IN20	9 mile creek	Diptera	Dolichopodidae		0.143	0.16	89.4	-24.33	13.89	# 225, 228

*Hg in Invertivore Food Web of*

ONON-IN21	9 mile creek	Diptera	Sciomyzidae	0.153	0.205	74.6	-25.62	16.22	# 218
ONON-IN22	9 mile creek	Diptera	Tipulidae	0.104					# 223
ONON-IN23	oneida	Diptera	Dolichopodidae	0.092					# 408
ONON-IN24	oneida	Diptera	Muscidae	0.063	0.068	92.6	-26.62	8.61	# 401
ONON-IN25	oneida	Diptera	Muscidae	0.068					#402
ONON-IN26	oneida	Diptera	Muscidae	0.093					#403, 404
ONON-IN27	oneida	Diptera	Muscidae	0.094	0.081	86.2	-26.22	8.02	#405
ONON-IN28	oneida	Diptera	Muscidae	0.126					#407
ONON-IN29	oneida	Diptera	Muscidae	0.033					#406, 409
ONON-IN30	sw corner	Diptera	Chironomidae	0.783	0.78	99.6	-26.41	11.91	#461, 467
ONON-IN31	sw corner	Diptera	Culicidae	0.331					# 127, 128, 130, 131, 133
ONON-IN32	sw corner	Diptera	Dolichopodidae	0.500					# 125, 126
ONON-IN33	sw corner	Diptera	Scathophagidae	0.437					#465, 466
ONON-IN34	sw corner	Diptera	Tipulidae	0.611	0.026	4.3	-25.73	6.93	#129
ONON-IN35	wetzel road	Diptera	Dolichopodidae	0.295					#166
ONON-IN36	wetzel road	Diptera	Dolichopodidae	0.407	0.31	76.2	-24.73	11.04	# 169, 175
ONON-IN37	wetzel road	Diptera	Dolichopodidae	0.453					#177, 179
ONON-IN38	wetzel road	Diptera	Sciomyzidae	0.06	0.056	93.3	-26.28	5.88	# 168, 178
ONON-IN39	wetzel road	Diptera	Therevidae	0.05	0.035	70.0	-25.72	10.02	#170
ONON-IN40	wetzel road	Diptera	Therevidae	0.105					# 176
ONON-IN41	maple bay	Coleoptera	Curculionidae	0.003					# 18

*Hg in Invertivore Food Web of*

ONON-IN42	maple bay	Coleoptera	Curculionidae	0.0048	0.0002	4.2	-30.65	1.27	#19
ONON-IN43	maple bay	Coleoptera	Curculionidae	0.014					#20
ONON-IN44	maple bay	Coleoptera	Curculionidae	0.005					#21
ONON-IN45	maple bay	Coleoptera	Curculionidae	0.006					#22
ONON-IN46	maple bay	Coleoptera	Curculionidae	0.0043	0.0003	7.0	-30.51	2.68	#23
ONON-IN47	maple bay	Coleoptera	Elatridae	0.014					# 27
ONON-IN48	maple bay	Coleoptera	Scarabeidae	0.060					#58
ONON-IN49	maple bay	Coleoptera	Scaraberidae	0.288	0.062	21.5	-27.10	4.53	#59
ONON-IN50	wetzel road	Coleoptera	Curculionidae	0.007					#199
ONON-IN51	wetzel road	Coleoptera	Carabidae	0.075	0.053	70.7	-25.51	7.86	#201
ONON-IN52	wetzel road	Coleoptera	Curculionidae	0.016					#205
ONON-IN53	9 mile creek	Coleoptera	Chrysomelidae	0.050					# 253
ONON-IN54	9 mile creek	Coleoptera	Scarabeidae	0.046					#254
ONON-IN55	maple bay	Coleoptera	Scarabeidae	0.346					#256
ONON-IN56	maple bay	Coleoptera	Scarabeidae	0.144					#257
ONON-IN57	maple bay	Coleoptera	Scarabeidae	0.025	0.0027	10.8	-27.96	1.58	#258
ONON-IN58	maple bay	Coleoptera	Scarabeidae	0.220					#259
ONON-IN59	oneida	coleoptera	Elatridae	0.071					#420
ONON-IN60	oneida	coleoptera	Curculionidae	0.005					#421
ONON-IN61	oneida	coleoptera	Chrysomelidae	0.042					#422
ONON-IN62	oneida	coleoptera	Chrysomelidae	0.033					#424
ONON-IN63	oneida	coleoptera	Chrysomelidae	0.077					#425
ONON-IN64	oneida	coleoptera	Chrysomelidae	0.048	0.0111	22.9	-27.27	4.47	#428

