PILOT ASSESSMENT OF MERCURY AND PCB EXPOSURE IN BIRDS AT ONONDAGA LAKE:

2008 BREEDING SEASON FINAL REPORT

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PILOT ASSESSMENT OF MERCURY AND PCB EXPOSURE IN BIRDS AT ONONDAGA LAKE:

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(BRI 2010-12)

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1.0 EXECUTIVE SUMMARY

In 2008, BioDiversity Research Institute (BRI) conducted a pilot study on Onondaga Lake in Syracuse, New York, to assess the exposure of insectivorous songbirds and shorebirds to mercury (Hg) and polychlorinated biphenyls (PCBs) at six sampling locations. We also collected samples at a reference site on Oneida Lake to estimate a baseline for contaminants in songbirds for the region. Findings from the pilot study indicate that a number of insectivorous songbirds and shorebirds had blood mercury concentrations that exceed a calculated lowest observed adverse effects level (LOAEL) of 0.63 µg/g (ww) for tree swallows (see Appendix III). Five of six sites on Onondaga Lake had birds with blood mercury concentrations that exceeded this level of concern. Birds sampled from the Canal site had mercury blood burdens below 0.63 µg/g (wet weight) as did birds from the reference site on Oneida Lake. All shorebirds sampled (five species total) exceeded the level of concern, with spotted sandpipers having the highest blood mercury concentrations of any bird sampled (range = 1.56-6.42 µg/g (ww); n=3). Across the sites, birds for which blood mercury concentrations were evaluated came from different foraging guilds, with the following species collected: tree swallow, song sparrow, red-winged blackbird, belted kingfisher, northern rough-winged swallow, yellow warbler, killdeer, spotted sandpiper, gray catbird, Baltimore oriole, and American redstart. Three composites of mallard eggs were collected and their mercury concentrations were below established effect levels.

A total of 13 composite egg samples (eight red-winged blackbird eggs and five tree swallow eggs) were collected from sites on Onondaga Lake and analyzed for total PCBs, total DDT, and total chlordane. No eggs were collected from the reference site on Oneida Lake. Of the 13 eggs sampled, tree swallow eggs had higher concentrations of PCBs than red-winged blackbird eggs. Tree swallows collected at the Ley Creek site had the highest concentration of PCBs, with one sample measuring 1.7 ug/g (ww). Eggs collected downstream of Onondaga Lake at the Canal site had the lowest concentration of PCBs.

2.0 INTRODUCTION

Onondaga Lake (Fig. 1) has been heavily impacted by industrial and municipal wastes for over 100 years and is considered to be highly contaminated with mercury and other compounds related to the release of industrial waste (U.S. Fish and Wildlife Service [USFWS] 2005; TAMS and YEC 2002). In 1994, Onondaga Lake and upland areas of the Lake that have released or continue to release hazardous substances were added to the U.S. Environmental Protection Agency's (USEPA) National Priorities List (NPL), thereby designating the Lake as a Superfund site. In 1998 Onondaga Lake was added to the New York State Department of Environmental Conservation (NYSDEC) Registry of Inactive Hazardous Waste Disposal Sites. The Lake has since been the focus of a remedial investigation by the USEPA and NYSDEC.

The Natural Resource Trustees for Onondaga Lake include the U.S. Department of the Interior, NYSDEC, and the Onondaga Nation. The Trustees are participating in a Natural Resource Damage Assessment (NRDA) for the Lake, a process that is specifically designed to address natural resource injuries related to exposure to hazardous substances and to identify and evaluate alternatives for restoration of those resources.

A Baseline Ecological Risk Assessment (BERA) for Onondaga Lake related to the release of hazardous substances, particularly mercury, suggested that the contamination of Onondaga Lake has "either impacted or potentially impacted every trophic level…" in the Lake (TAMS and YEC 2002). Numerous studies at Onondaga Lake, summarized in USFWS (2005), identified impacts potentially resulting from mercury contamination, including impaired water quality and reduced species richness of zooplankton, benthic macroinvertebrates, resident and migratory fish species, and amphibians and reptiles (NYSDEC 1987; Auer et al. 1996; Tango and Ringler 1996; Ducey et al. 1998).

Although previously undocumented, it is hypothesized that birds at Onondaga Lake may be exposed to concentrations of mercury and other contaminants that may adversely impact them. Onondaga Lake is located between two primary corridors of the Atlantic Flyway for migratory birds, and provides habitat for approximately 112 species of birds during the breeding season, 70 over-wintering species, 19 waterfowl, and six waterbird species (TAMS and YEC 2002; USFWS 2005). To date, however, no data are available on contaminant exposures in avian species foraging in and around Onondaga Lake.

This pilot study is designed to identify potential exposure of indicator and migratory birds that nest and forage within the littoral zone and abundant wetland areas adjacent to Onondaga Lake. The primary contaminants of interest include mercury and total PCBs. Three insectivorous songbirds that forage within the Onondaga Lake floodplain were selected as primary target indicators of mercury and PCB contamination. Other contaminants were not investigated in this pilot study due to limited funding. The target species were selected based on their foraging preferences:

- *Red-winged blackbird*. This species arrives in late February-April and begins nesting in May. Its diet consists mainly of animal matter. In nonagricultural habitats, approximately 84% of male stomach contents may consist of insects, and the female diet may be comprised of 79% insects (McNicol et al. 1982). In the marshes of Manitoba 100% of diet was determined to be animal matter (Bird and Smith 1964).

- *Tree swallow*. This species arrives in April and begins nesting in early-mid May. Since tree swallows readily occupy artificial nest boxes (Robertson et al. 1992), they are a commonly-used species for contaminant exposure studies (Secord et al. 1999; Custer et al. 2001; Gerrard and St. Louis 2001). Tree swallow foraging territory is generally within approximately 400 m from their nest box (Quinney and Ankney 1985). The tree swallow is considered an aerial insectivore, feeding predominantly on flying insects. Food items may include Dipterans (flies), Hemipterans (leaf-hoppers, etc.), and Odonates (dragonflies and damselflies) (McCarty and Winkler 1999). Diptera comprised approximately 70% of adult tree swallows' diet; egg-laying females also consumed mayflies (15%). Females during the nestling stage preyed on Odonata (10%) and a variety of small terrestrial prey (<1 cm) consisting of mostly adult flies and small leafhoppers (Quinney and Ankney 1985). Food of aquatic origin constituted 65% of the nestling diet by mass in Ontario (Blancher and McNicol 1991) and 47% in North Dakota (Custer et al. 2008).

- *Song sparrow*. This songbird returns to its breeding area in New York in March-April and breeds in a wide range of forest, shrub, and riparian habitats (Arcese et al. 2002). During the breeding season, the song sparrow feeds primarily on insects and other invertebrates and some seeds and fruit (Aldrich 1984). In the Northeast, its diet consists mostly of plant material in the winter (86%), but is generally >50% animal food in the summer. The song sparrow is a generalist and feeds on a wide variety of insects, including those from the orders Coleoptera, Hemiptera, Lepidoptera, Diptera, Odonata, and Ephemeroptera (Judd 1901).

All bird species captured were sampled regardless of whether they were targeted.

2.1 Objectives

To determine the mercury body burdens in songbirds from Onondaga Lake, we collected whole blood and feather tissues using non-lethal capture techniques. Blood mercury levels in birds represent recent dietary uptake (Evers et al. 2005, Hobson and Clark 1993, 1994, Bearhop et al. 2000), so blood mercury levels measured in this study reflect mercury accumulated by birds feeding on Onondaga Lake and adjacent wetlands or in reference areas. Feathers are indicators of a bird's body burden of mercury, reflecting both recent dietary uptake and body accumulation of mercury over time (Burger 1993, Evers et al. 2005). Eggs are used to assess contaminant burdens in the embryo.

To evaluate avian exposure to mercury we identified the following objectives:

1. Determine mercury concentrations in bird blood and eggs to identify:
    a. Mercury exposure in target species,
    b. Geographical extent of mercury contamination in target species, and
    c. Blood-egg mercury relationship in tree swallows to compare with existing predictive model.

2. Collect and archive feather samples for future mercury analysis to determine body burden.

3. Determine PCB, DDT, and chlordane concentrations in eggs of red-winged blackbirds and tree swallows.

4. Determine carbon and nitrogen stable isotope concentrations in bird blood to better understand the origin (terrestrial vs. aquatic) and complexity (food chain length) of avian food webs.

5. Opportunistically collect mallard eggs to assess mercury body burdens in waterfowl.

3.0 STUDY AREA

Onondaga Lake is a shallow, hypereutrophic lake (Becker and Bigham 1995). The assessment area (where hazardous substances released from the Superfund site are located) includes, but is not limited to, the entire lake, including all pelagic, littoral, and upland areas, tributary rivers, and creeks. For this study, seven site locations were selected with the intention of measuring a range in breeding bird mercury exposures (Fig. 1). The sites included Maple Bay, White Cliffs (Ninemile Creek), Beach, Harbor Brook, Ley Creek, Long Branch Road, and Canal (aka Grenadier, a site downstream from Onondaga Lake along the Oswego River). A detailed description of these sampling sites is below. In addition, a reference site on Oneida Lake, located at the Cornell Field Station on Shackleton Point, was used to estimate a baseline for contamination. We used swallows nesting in the nest boxes previously installed by Cornell University. Oneida Lake is a large lake with relatively undeveloped shoreline and has no known historic point-sources of mercury or other industrial pollution. Similar bird species are found breeding on Oneida Lake as Onondaga Lake.

3.1 Maple Bay

The Maple Bay site is located at the north end of Onondaga Lake, near the outlet canal, and adjacent to a Liverpool community park and foot trail. The lake bottom is sandy, with the shoreline covered by a narrow area of unmaintained grasses and mature hardwoods. Small patches of reeds (*Phragmites australis*) were present. Nine nest boxes were erected in shallow water (< 1.0 m deep) along the shoreline.

3.2 White Cliffs (Ninemile Creek)

The White Cliffs site is located near the mouth of Ninemile Creek and is surrounded by approximately two acres of wetland dominated by *Typha* sp. and *P. australis*. The site is at the base of an approximately 6.0 m high plateau consisting of predominantly Solvay waste[1]. Nest boxes were erected in shallow water (< 0.3 m).

3.3 Beach

The Beach site is bounded by Ninemile Creek to the north and Tributary 5A to the south. It includes two stretches of mixed sandy beaches separated by a small (<1.0 ha) stand of *Typha* sp. The beach slopes upward through a scrub/shrub and mudflat area and is bounded by mixed

---

[1] The Solvay Process is used in the production of soda ash (sodium bicarbonate; Na_2CO_3). The overall reaction is:

$$CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$$

A Solvay plant operated near Onondaga Lake from the 1880s to early 1986 and used Onondaga Lake waters as a coolant for the reaction. In addition, waste products, including waste slurry containing $CaCl_2$ and unreacted $CaCO_3$ and NaCl, were pumped into waste beds on the SW shore of the lake. These waste beds and associated waste bed overflows have contributed to the high ion concentrations documented in the lake (Wang and Driscoll 1995; Effler et al. 1996).

hardwoods. The littoral zone of the beach includes a high density of uprooted and washed up macrophytes mixed with zebra mussel (*Dreissena polymorpha*) shells. Submerged macrophytes occur in high density within 50 m of the shoreline.

3.4 Harbor Brook

The Harbor Brook site encompasses a large (approximately 2 ha) stand of *P. australis*-dominated wetlands near the southwest corner of the Lake. Upslope from the wetland area is a large stand of mixed hardwoods. Lake substrate at this site is a mixture of soft mud and hardpan, likely a product of calcium and chloride deposition in the Lake. Patches of submerged macrophytes occur within 25 m of the shore. Nest boxes were erected in shallow water (<0.3 m) along the shoreline.

3.5 Ley Creek

The Ley Creek site is located on the northeast bank of the Lake, near the mouth of Ley Creek. The site is bounded by Interstate 690 and includes a small patch (<0.25 ha) of *Typha*-dominated wetland with mixed hardwoods, open grass area, gravel bed with railroad tracks, and a narrow fringing littoral forest. Nest boxes were erected in shallow water (<1.0 m deep) along the shoreline.

3.6 Canal

The Canal site is located at the outlet of Onondaga Lake, in a wetland adjacent to and downstream on the Oswego River. It is relatively large (~3 ha) and is at the confluence with an unnamed non-navigable stream. The wetland includes small patches of *Typh*a and water depth is shallow (<0.5 m). Nest boxes were erected along the edges of the wetland.

3.7 Long Branch Road

This site is a large wetland dominated by cattails (*Typha* spp.) and located slightly off Onondaga Lake along Long Branch Road. Only red-winged blackbirds and mallards (no tree swallows) were monitored at this site.

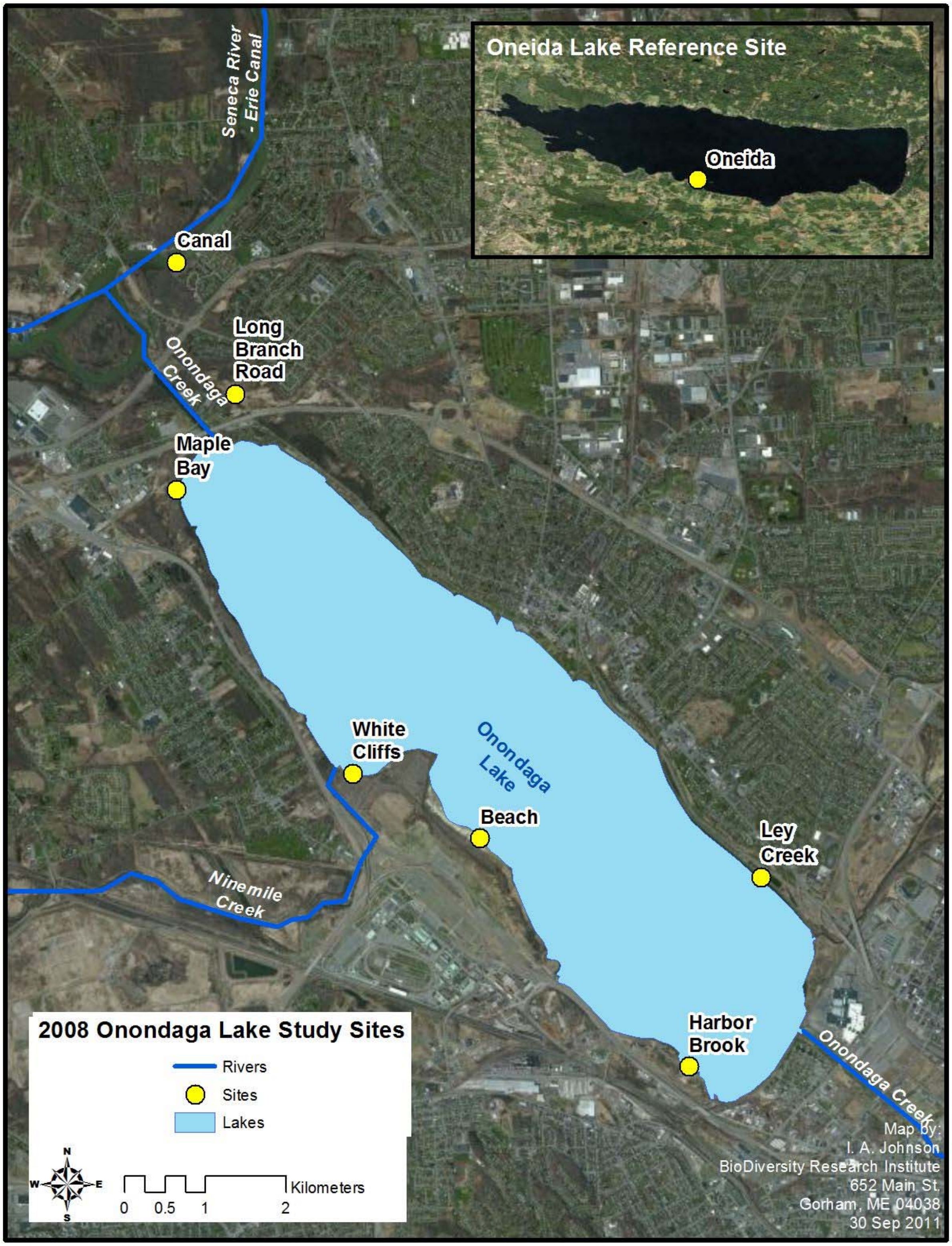

Figure 1. Bird sampling locations along Onondaga and Oneida (reference) Lakes in 2008.

4.0 METHODS

4.1 Capture and Sample Collection

4.1.1 Tree swallows and red-winged blackbirds

Nine boxes were placed at each of six study sites (the Long Branch Road site was excluded) for a total of 54 nest boxes in April 2008 to attract breeding tree swallows (Fig. 1). Boxes were attached to 3.0 m pipes that were sunk into the Lake sediment. The boxes were placed within the littoral zone of the Lake, 15-25 m apart and facing the water. Nesting activity was checked one to two times per week beginning May 9 through June 25, 2008. The boxes in the reference location were already in place and attached to the trees along the shore of Oneida Lake.

Egg clutches were collected for PCB and mercury analysis and blood samples were collected from nesting tree swallow females for mercury analysis once the clutch was completed (Appendix IV- BRI Protocols). Adult tree swallows were captured in the box for blood and feather collection. Non-lethal capture methods were used for sampling of all birds. Sampled females were banded with a unique aluminum USGS band, their sex confirmed through plumage, and presence of a brood patch, and the birds aged by plumage. Basic morphometric measurements were collected as required by the Bird Banding Lab, including wing chord, tail length, weight, and bill dimensions. These data are solely for the Federal banding permit and are not summarized in this report.

One full clutch of tree swallow eggs was collected from each of the six sites for PCB analysis. One additional egg was collected for mercury analysis from the remaining nests. All eggs were collected from abandoned/unviable nests for archiving or analysis. We determined that a nest/egg was abandoned/unviable if at least one of the following conditions was met: 1) A previously banded female was observed/captured at a new nesting box (assuming her first clutch in the original box failed); 2) Eggs were cold and no activity was observed at the nest for ≥10 days from last egg laid; 3) Eggs remained for ≥5 days from last egg hatching; or 4) Female was dead on nest. Eggs were placed on ice in the field and refrigerated within eight hours.

Red-winged blackbird nests at each of the six sites were located after observing a female flush from the wetland vegetation and then were marked with flagging tape to relocate during subsequent visits to the site. An additional site off Long Branch Road was added for the collection of red-winged blackbird and mallard eggs because it was an extensive wetland adjacent to Onondaga Lake and a potential sediment depositional area. One to three eggs from three blackbird nests were collected for mercury and PCB analyses.

4.1.2 Mallard eggs

Seventeen mallard eggs were collected opportunistically from three sites and three nests. The entire clutch was collected for mercury analysis.

4.1.3 Songbirds and Shorebirds

Available species of breeding songbirds and shorebirds were captured with mist netting at each of the six sites (same as tree swallow sites) from the end of May through June 2008. Six to ten 12-meter-long mist-nets (36 mm mesh size) were used at each site. Some nets were set next to playback recordings to target certain species (e.g., song sparrow). Mist-nets were distributed more or less uniformly but opportunistically within target habitat. The nets were checked every 20-40 minutes, captured birds removed, and placed in cotton holding bags until processing. Bird identification and banding techniques followed Pyle (1997). All birds were released unharmed approximately 15-40 minutes after capture. Measurements recorded for reporting to the Bird Banding Lab were age, sex, weight, wing chord, bill morphometrics, molt pattern, and body condition (as indicated by the thickness of the fat layer). Any external physical abnormalities were also noted. All birds were banded with a USGS aluminum band. This work was conducted under appropriate state and Federal scientific collection/banding permits.

4.2 Blood and feather collection

Blood and feather samples were collected from each bird. For blood samples, a 26-27 gauge needle was used to puncture the cutaneous ulnar vein. No more than 1% of the bird's body weight in blood was collected in heparinized capillary tubes. The tubes were sealed on both ends with Critocaps® and placed in a clean, labeled 10 cc plastic vacutainer. Blood samples were stored on ice in a cooler; samples were frozen within six hours of collection. In addition to the blood samples, two outer tail feathers were pulled from most species, when feasible. Collected feathers were placed in a clean, labeled, plastic bag and stored in a refrigerator. All samples were labeled with the date of collection, age, and sex of the bird, USGS band number, and capture location. All samples were shipped by overnight delivery to the analytical labs in the fall of 2008.

4.3 Egg collection and processing

All eggs were weighed and measured and placed in a zip-lock bag where they were labeled with collection date, box/nest #, species, and site. Eggs were stored in the plastic bags in the refrigerator for one to four days in an air-tight container. As soon as was practical (end of the collection week) eggs were transferred to the lab at Syracuse University and processed.

In the laboratory at Syracuse University, each egg was weighed to 0.001 g, measured (length and width, mm) with digital calipers, and opened with a clean blade to determine developmental stage of the embryo. We transferred the egg contents into a tared 20 ml chemically pre-cleaned I-CHEM jar (series 200), and recorded the weight. The jar was labeled with collection date, species, site, analysis (mercury or PCBs), and sample identification number. Occasionally eggs from the same nest or site had to be composited for the PCB analysis, which required more mass than the mercury test. All processed eggs (egg contents) were placed in a secure freezer and kept at approximately -10°C until being shipped to the Texas A&M Trace Element Research Lab or B&B Labs of TDI-Brooks International, Inc. in College Station, Texas, for mercury and PCB analysis, respectively. Mallard egg contents and songbird feathers were shipped to the Center for

Environmental Sciences and Engineering at the University of Connecticut in Storrs for mercury analysis.

4.4 Lab sample analysis

4.4.1 Mercury

Mercury analysis of bird blood and eggs focused on total mercury instead of methylmercury concentrations. Total mercury analysis is less costly than methylmercury analysis and a high percentage (90-95%) of the total mercury in songbird blood and feathers is in the methylmercury form (Rimmer et al. 2005; Gerrard and St. Louis 2001).

Mercury analysis of blood and songbird eggs was conducted by Texas A&M Trace Element Research Lab (TERL), College Station, Texas. Blood samples were analyzed wet. The entire blood sample was expressed from the capillary tube and used in the analysis. All egg samples were freeze-dried prior to analysis using a Labconco freeze dryer, and homogenized using a Retsch ZM200 ultracentrifugal mill. A representative aliquot of the dried egg material was taken for analysis. Sample homogeneity was critical since sample analysis was limited to ~0.01-0.02 g of dried material. All samples were analyzed using a direct combustion/trapping atomic absorption (AA) method using a Milestone DMA 80. This approach has been incorporated by EPA in EPA SW-846 Method 7473. Calibration curve was used in each of the two detector cells. Instrument response was evaluated immediately following calibration and thereafter following every 20 samples and at the end of each analytical run by running check standards and a check blank. Analysis included measurement of an instrument blank, two certified reference materials (Dorm 2 and Dolt 3), duplicate samples, and spiked samples for every 20 samples analyzed. Method blanks were used to determine that sample preparation and analyses were free of contaminants. Duplicate samples were used to determine precision. Spiked samples were used to determine the accuracy and precision of sample preparation and analyses. Matrix spikes were samples fortified with known amounts of target analytes. All blank, duplicate, spiked samples, and reference materials were subject to the identical preparation and analysis steps as field samples.

Mallard eggs and songbird feathers were also analyzed for total mercury instead of methylmercury at the Center for Environmental Sciences and Engineering, University of Connecticut, Storrs, Connecticut, using a Milestone DMA 80. Mercury concentrations are presented on a wet weight (ww) basis in eggs and blood and fresh weight (fw) basis in feathers.

4.4.2 Organochlorines including PCBs

Eggs were analyzed at B&B Labs of TDI-Brooks International, Inc. in College Station, Texas. All residual aliquots of freeze-dried eggs were hand delivered from TERL to the B&B lab. The PCB residues are reported as the total PCB present based on quantification of the following congeners: 8/5, 18, 28, 29, 31, 44, 45, 49, 52, 56/60, 66, 70, 74/61, 87/115, 95, 99, 101/90, 105, 110/77, 118, 128, 138/160, 146, 149/123, 151, 153/132, 156/171/202, 158, 170/190, 174, 180, 183, 187, 194, 195/208, 199, 201/157/173, 206, 209. In addition to total PCBs the lab provided data on total DDT and total chlordane. Method B&B 1012 was used for organochlorine matrix preparation, method B&B 1010 was used for organochlorine extraction, and method 1007A for pesticide and PCB analysis.

The analyses of a method blank, duplicate, matrix spike/matrix spike duplicate, and standard reference material (SRM) CARP-1 per analytical batch of no more than 20 samples assured quality control. Quality Assurance (QA) criteria were met. The QA criteria for blanks specified that no more than two target analytes exceed three times the method detection limits. The QA criteria for spiked samples specified recoveries between 40-120% for individual target analytes of valid spikes with an average recovery of 80-120% for all valid spike recoveries. The QA criterion for valid duplicates and spiked duplicates was ±35% for individual analytes. The SRM QA criterion for organochlorines was ±30% the certified mean value. Surrogate solutions equivalent to 5-10 times the MDL were prepared for various hydrocarbon analyses. The appropriate surrogate solution was added to every sample including quality control samples. All data were corrected based on surrogate recovery.

4.4.3 Stable isotopes

Blood samples were shipped to the Boston University Stable Isotope Laboratory for analysis. Samples were analyzed using automated continuous-flow isotope ratio mass spectrometry (Michener and Lajtha 2007). Using hematocrit tubes, blood was transferred into pre-weighed tin capsules. Assuming a content of 70% water, approximately 1.3 mg of blood (1.3 ml) was added to the capsules. All capsules were oven dried at 60˚C for 24 hours and then reweighed to get the dry mass. The capsules were then folded and compressed prior to analysis. The samples were combusted in a EuroVector Euro EA elemental analyzer. The combustion gases (N_2 and 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 $^{13}C/^{12}C$ and $^{15}N/^{14}N$ are reported as standard delta (δ) notation and are expressed as the relative permil (‰) difference between the samples and international standards (Vienna Pee Dee Belemnite (V-PDB) carbonate and N_2 in air) where:

$$X = (R_{sample}/R_{standard} - 1) \times 1000\ (‰)$$
Where $X = {}^{13}C$ or ^{15}N and $R = {}^{13}C/^{12}C$ or $^{15}N/^{14}N$

The sample isotope ratio is compared to a secondary gas standard, the isotope ratio of which was calibrated to international standards. For $^{13}C_{V\text{-}PDB}$ the gas was calibrated against NBS 20 (Solenhofen Limestone). The $^{15}N_{air}$ gas was calibrated against atmospheric N_2 and International Atomic Energy Agency (IAEA) standards N-1, N-2, and N-3 (all are ammonium sulfate standards). All international standards were obtained from the National Bureau of Standards in Gaithersburg, Maryland.

4.5 Statistical Analysis

Only adult (after hatch year) bird blood mercury results were used in statistical analyses. Because of small sample sizes and non-normally distributed data with unequal variances, we used nonparametric Kruskal-Wallis tests with Chi Square (χ^2) Approximation Analysis for statistical analyses. For all data analyses and summary statistics, we used a JMP 5.0 statistical program along with Microsoft Excel. Factors were considered significant at a probability level of less than 0.05. Data were aggregated by site. The Canal site was treated separately for statistical tests. Dunnett's Test was used to compare contaminated sites with the reference site. If sample sizes were too small for statistical analysis, we summarized the data and presented it graphically. All mercury results reflect total mercury concentrations in whole blood, eggs, and feathers.

4.6 Lowest Observed Adverse Effect Levels

Our calculated lowest observed adverse effect level (LOAEL) for blood is 0.63 µg/g (ww) for tree swallows (see Appendix III for a description of this LOAEL). Although some species-specific LOAELs have been developed (such as that for the common loon, *Gavia immer*; Evers et al. 2008, Burgess and Meyer 2008), there is not yet a LOAEL for any of the songbird or shorebird species that were sampled in this study. Therefore, we use a LOAEL value of 0.63 µg/g to indicate the potential for adverse effects. Additional information may result in an alternate LOAEL value.

5.0 RESULTS

5.1 Sampling effort

5.1.1 Blood

In 2008, a total of 162 adult birds were captured, including 12 recaptured individuals, representing 26 species at six sites along Onondaga Lake and one site on Oneida Lake (Appendix I). From these birds, we collected 137 blood samples from Onondaga Lake and 25 samples from Oneida Lake. Eighty-three bird blood samples were analyzed for stable isotopes (SI) $\delta^{13}C$ and $\delta^{15}N$ (Appendix II).

5.1.2 Eggs

Sixty-three individual eggs from 11 tree swallow nests and 12 red-winged blackbird nests were analyzed for mercury and 13 egg composites, representing 63 eggs from five tree swallow nests and 13 red-winged blackbird nests, were analyzed for PCB congeners and other organochlorines (OCs). Seventeen eggs from three mallard nests were opportunistically collected and also analyzed for mercury.

5.1.3 Feathers

Nineteen feathers from three species, belted kingfisher (1), common grackle (4), and red-winged blackbirds (14), captured at two sites on Onondaga Lake were analyzed for mercury. Feathers collected from the remaining birds were archived.

5.2 Contaminant exposure in bird species

5.2.1 Blood mercury

We found mercury concentrations varied by species and site (Fig. 2; Appendix I). All target species from Onondaga Lake had significantly higher blood mercury concentrations than birds from Oneida Lake (red-winged blackbird: χ^2=7.4, p<0.03; song sparrow: χ^2=9.5, p<0.009; tree swallow: χ^2=20.7; p<0.0001, Table 1). Of the three target species sampled, song sparrows and red-winged blackbirds tended to have higher blood mercury levels than tree swallows. Of all sites sampled on Onondaga Lake, it appears that Ley Creek, Harbor Brook, and White Cliffs Creek had higher mercury levels in bird blood than the remaining sites (Fig. 2). The Canal site had the lowest mean blood mercury concentration of all sites sampled on Onondaga Lake (Fig. 2), and the Canal site is excluded from statistical analyses comparing Onondaga versus Oneida blood mercury samples. We found that mercury concentrations in each of the three target species tested were significantly higher in birds sampled on Onondaga Lake than on Oneida, the reference site (Fig. 3).

Table 1. Mean mercury concentrations in blood (µg/g ww). Summary statistics for three target species sampled on Onondaga (without the Canal site) and Oneida Lakes, 2008 (stdev=standard deviation, n=# of adult birds sampled).

Species	Mean +/ SD (n) Onondaga	Mean +/ SD (n) Onondaga-Canal	Mean +/ SD (n) Oneida
Red-winged blackbird	0.74 +/-0.80 (27)	0.23 +/-0.07 (2)	0.11 +/-0.03 (13)
Song sparrow	1.35 +/-0.88 (19)	0.06 (1)	0.06 +/-0.01 (3)
Tree swallow	0.62 +/-0.44 (15)	0.18 +/-0.03 (6)	0.08 +/-0.03 (6)

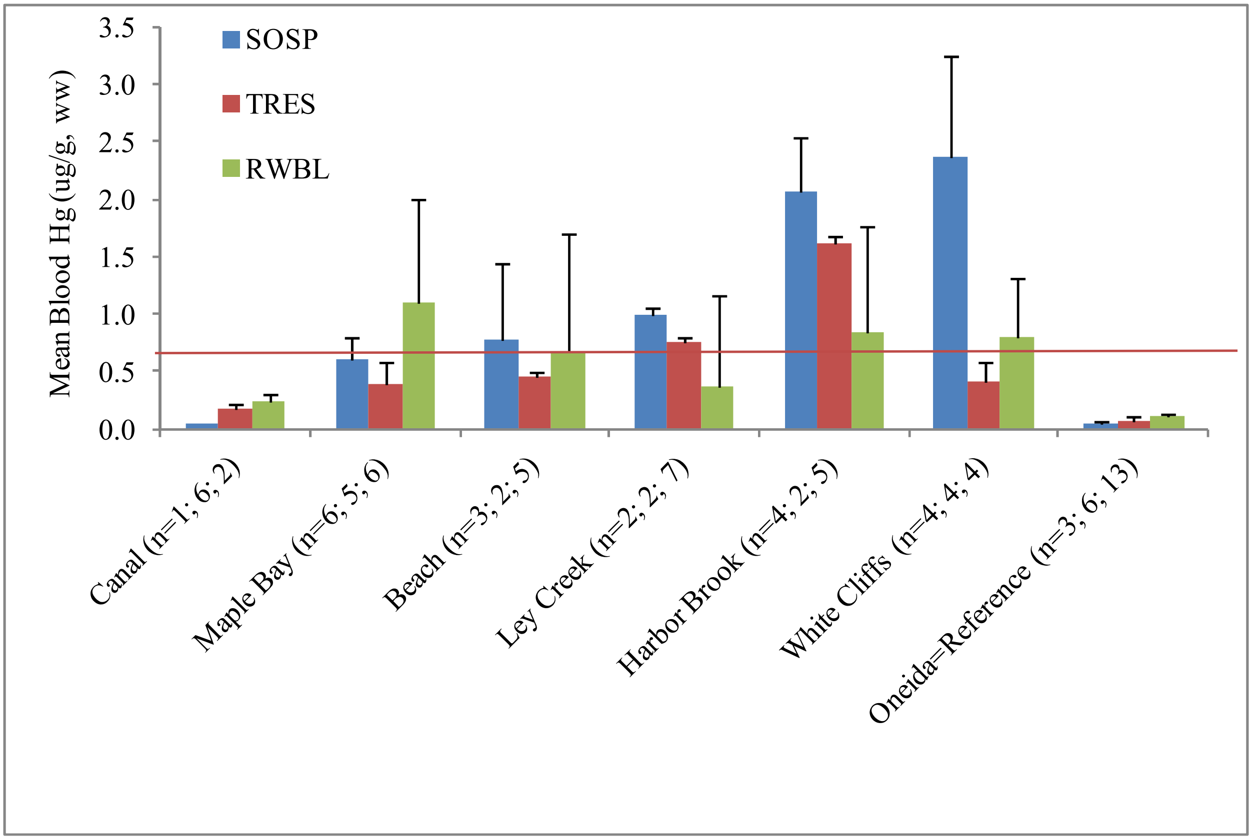

Figure 2. Mean mercury concentrations in the blood of three target species (SOSP=song sparrow, TRES=tree swallow, RWBL=red-winged blackbirds) sampled on Onondaga Lake in 2008 (n= # of adults sampled, red line indicates 0.63 µg/g (ww) LOAEL for tree swallows) (see Appendix III).

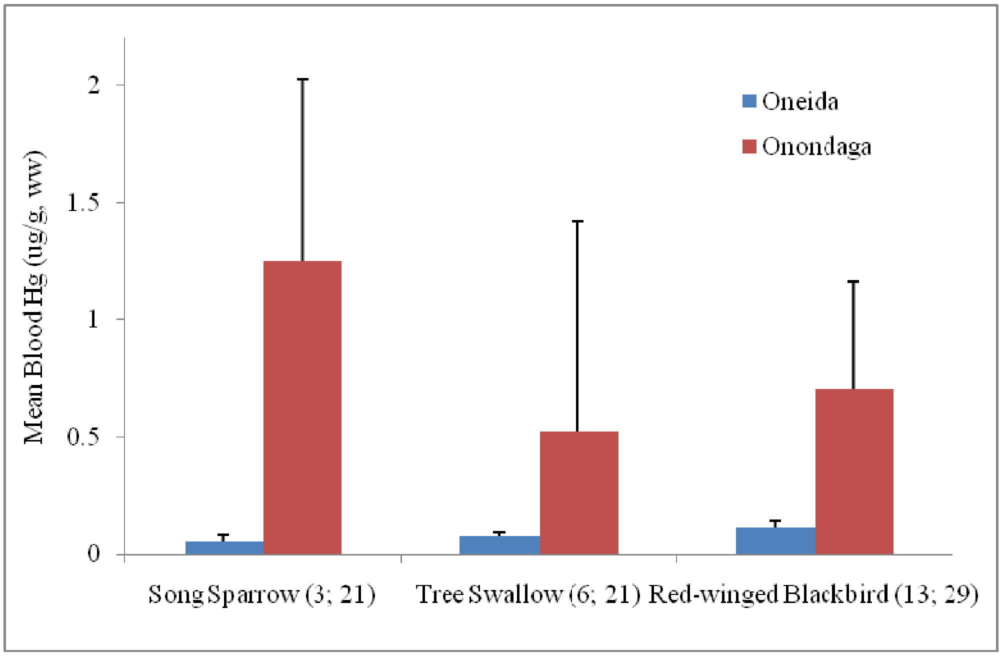

Figure 3. Mean mercury concentrations in blood of adult tree swallows, song sparrows, and red-winged blackbirds sampled on Onondaga and Oneida Lakes, 2008.

Blood mercury concentrations in female red-winged blackbirds (mean=1.3 +/-0.87 µg/g, ww, n=8) were significantly higher than in males (mean=0.48 +/-0.63 µg/g, ww, n=21) from Onondaga Lake (t-test: t=2.8; df=27; p<0.009) and significantly higher than males (mean=0.11 +/-0.02 µg/g, ww, n=9) and females (mean=0.12 +/-0.04 µg/g, ww, n=4) (χ^2: χ^2=7.4; p<0.007) from Oneida Lake (Fig. 4). Blood mercury levels in red-winged blackbird males were higher at Onondaga Lake than Oneida Lake, but there was not a statistically significant difference between males from the two lakes (χ^2: χ^2=2.4; p=0.12).

All shorebird blood mercury concentrations sampled during the 2008 pilot season were above the 0.63 µg/g (ww) level of concern. The mean blood mercury concentration for killdeer was 1.25 +/-0.01 µg/g (ww), while spotted sandpipers had blood mercury concentrations ranging from 1.56-6.42 µg/g (ww), with a mean of 3.86 µg/g (ww).

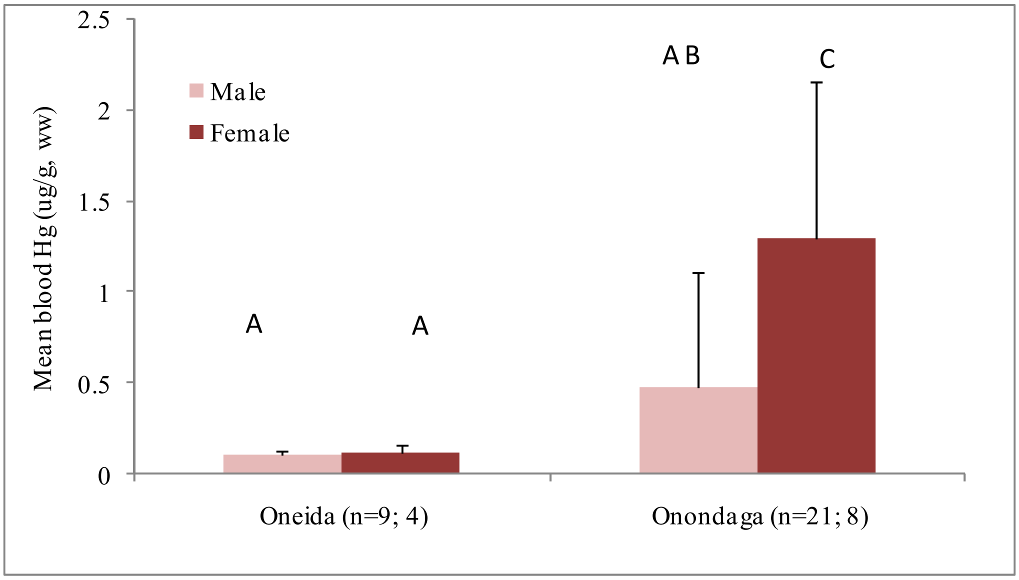

Figure 4. Mean blood mercury concentrations in red-winged blackbirds sampled on Onondaga and Oneida Lakes in 2008 (n= # of adults sampled). Means not showing a common letter are significantly different.

Blood from six nesting female tree swallows were sampled in May and then again in June to determine if mercury exposure changed as the summer progressed. We did not observe a pattern; in half of the birds the blood mercury levels declined and in the rest, blood mercury levels increased (Fig. 5). Swallows from Ley Creek and Harbor Brook had a greater change in blood mercury concentrations than birds from other sites sampled (Fig. 5).

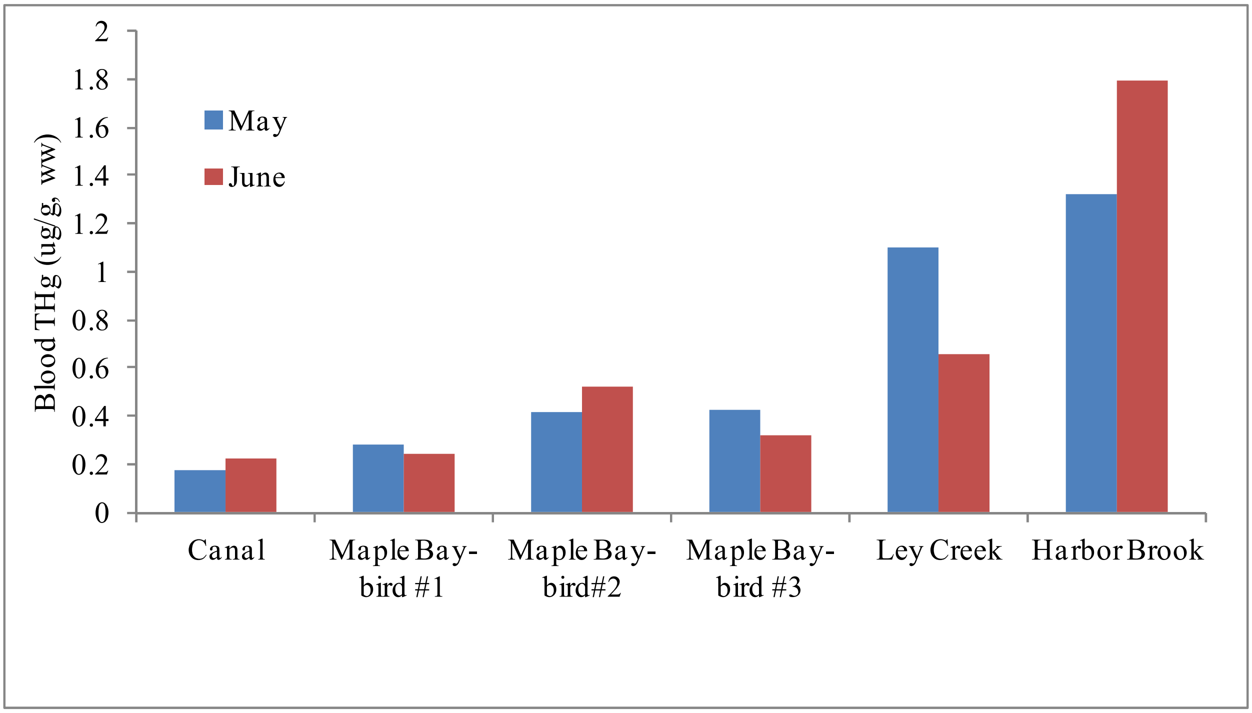

Figure 5. Mercury concentrations (µg/g, ww) in the blood of nesting female tree swallows sampled in May and recaptured in June of the same breeding season at the same site.

5.2.2 Egg mercury

In general, egg mercury concentrations in most sampled songbird species were below 0.2 µg/g (ww), the level of concern, but individual samples did exceed the 0.2 µg/g LOAEL (Table 2). Mercury concentrations ranged from the lowest value of 0.006 µg/g from the Canal site to the highest value of 0.378 µg/g from White Cliffs site in red-winged blackbird eggs (Table 2).

Table 2. Egg mercury (Hg) results, May-June 2008, on Onondaga Lake, New York, sites are arranged in increasing RWBL Hg concentration, Hg values are expressed in µg/g, ww, (RWBL=red-winged blackbird, TRES=tree swallow, n=number of nests). Mallard egg Hg concentrations were averaged within a nest, one clutch was collected from 3 sites.

Site	RWBL Mean Hg +/- std (n)	RWBL Range	TRES Mean Hg +/- std (n)	TRES Range	Mallard Mean Hg
Ley Creek	0.012 +/-0.01 (3)	0.007-0.016	0.097 (1)	0.097	0.19 (1)
Canal	0.015 +/-0.01 (2)	0.006-0.023	0.060+/-0.02 (4)	0.046-0.08	
Long Branch Rd	0.023 +/- 0.004 (4)	0.019-0.028			0.353 (1)
Maple Bay			0.102 +/-0.03 (3)	0.080-0.133	
Harbor Brook			0.201 +/-0.04 (2)	0.170-0.232	
Beach	0.169 +/-0.03 (2)	0.149-0.188	0.178 (1)	0.178	0.305 (1)
White Cliffs	0.253 +/-0.18 (2)	0.129-0.378			

There was a significant positive relationship between female tree swallow blood and egg mercury concentrations (r^2=0.83, $p<0.05$) (Fig. 6).

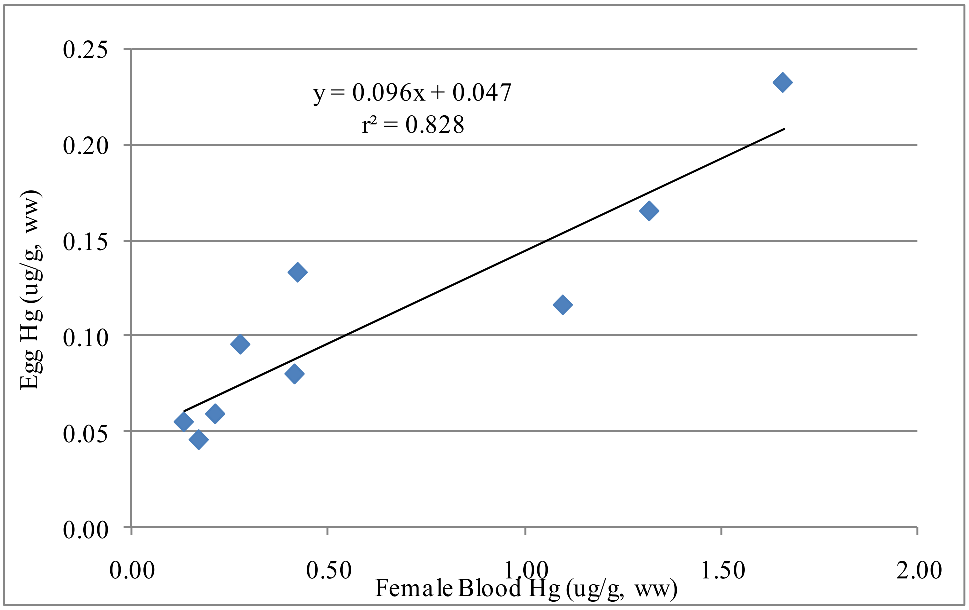

Figure 6. Relationship between mercury concentrations in nesting female tree swallow blood and their eggs, Onondaga Lake, New York, 2008.

5.2.3 Organochlorines in eggs

Organochlorine (OC) data are summarized in Table 3. In general, PCB, DDT, and chlordane concentrations tended to be higher in tree swallow than in red-winged blackbird eggs (Table 3, Fig. 7). Total PCB concentrations ranged from 0.827 µg/g (dw) in red-winged blackbird eggs from Long Branch Road Marsh to 8.38 µg/g (dw) in tree swallow eggs from the Ley Creek site (Table 3). Total DDT and chlordane concentrations were low across all species and sites tested (Table 3). On average the percent moisture in the analyzed eggs was 80%, to convert dry weight concentrations into wet weight we can use the formula dw x (100-%moisture)/100.

Table 3. Selected organochlorine contaminants in songbird eggs (µg/kg, dw) collected on Onondaga Lake, 2008 (total DDT includes all metabolites).

	Red-winged blackbird			Tree swallow		
Site	**Total PCBs**	**Total DDT**	**Total Chlordane**	**Total PCBs**	**Total DDT**	**Total Chlordane**
Onondaga Lake						
Long Branch	827	519	34.4			
Ley Creek	869	177	37.1	8376	802	230
Canal	883	1324	34.2	2770	1259	99.5
White Cliffs	1638	211	33.4			
Ley Creek	2049	208	38.5			
Beach	5613	715	99.2	5152	699	195
Beach	5848	589	127			
White Cliffs	8366	353	89.6			
Harbor Brook				4114	542	145
Maple Bay				6165	764	84

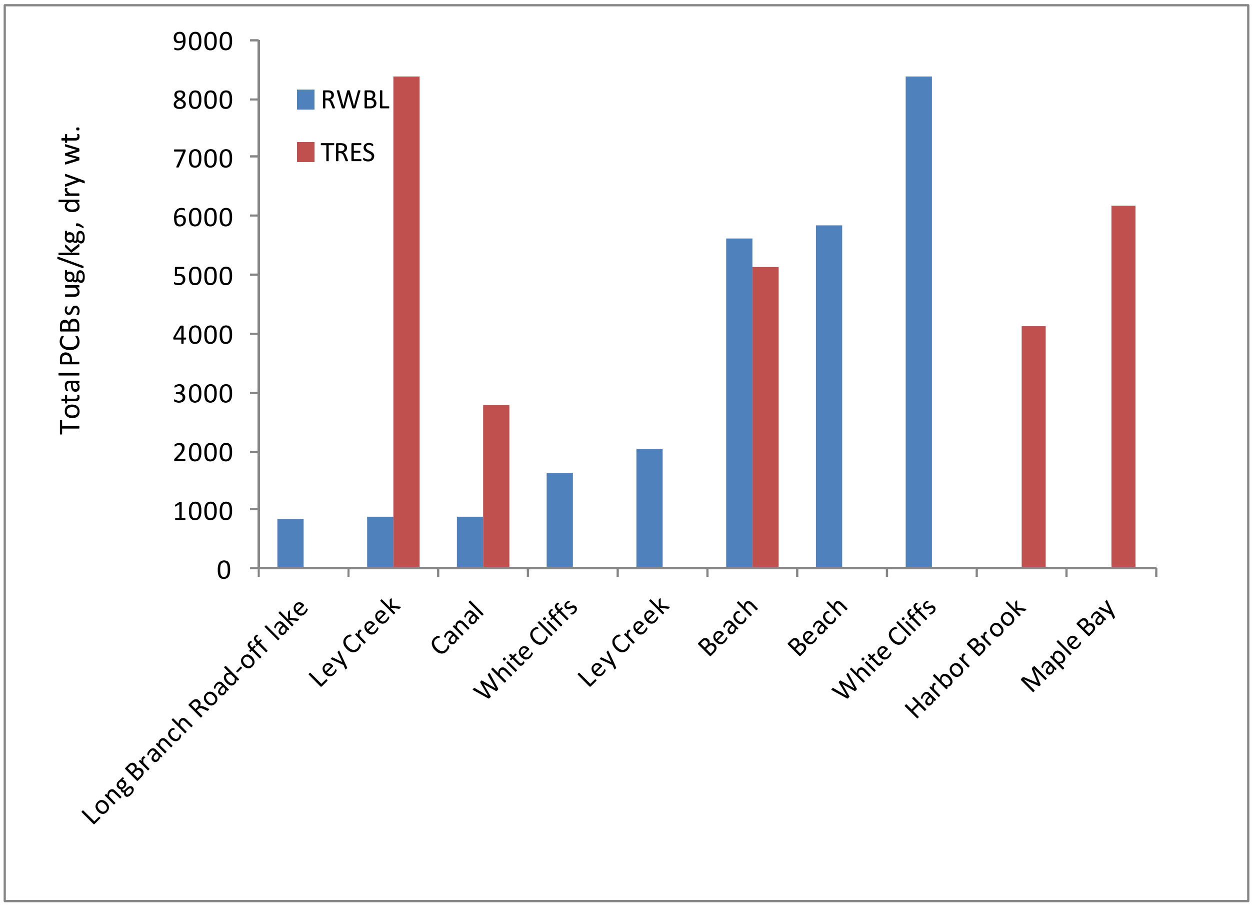

Figure 7. Total PCBs in eggs of red-winged blackbirds and tree swallows sampled on Onondaga Lake, 2008. (Concentrations are expressed in ppb, dry weight).

5.2.4 Feather mercury

Mean feather mercury concentrations in red-winged blackbird and common grackle sampled on Onondaga Lake were below 1.0 µg/g (Table 4). The mercury concentration in feathers from one belted kingfisher (35.7 µg/g fw) sampled was above the mallard critical level of 9.0 µg/g (fw) (Heinz 1979) and approached the level of concern for piscivorous birds of 40 µg/g fw (based on common loon; Evers et al. 2008) (Table 4).

Table 4. Mean feather mercury concentrations (µg/g, fw) in three avian species sampled on Onondaga Lake, 2008.

Site	Species	Feather Hg (µg/g, fw) Mean +/- stdev (n)
Maple Bay	Belted kingfisher	35.7 (1)
	Common grackle	0.33 +/-0.21 (4)
	Red-winged blackbird	0.36 +/-0.43 (7)
Ley Creek	Red-winged blackbird	0.30 +/-0.26 (7)

5.2.5 Stable isotopes of blood

A total of 83 blood samples from 19 bird species were analyzed for stable isotopes ($\delta^{13}C$ and $\delta^{15}N$), including 65 samples from Onondaga Lake sites and 18 samples from the reference site on Oneida Lake (Table 5). The $\delta^{13}C$ and $\delta^{15}N$ values for samples from the three target species are shown in Figure 8. Red-winged blackbirds from Onondaga exhibited the widest range of $\delta^{13}C$ values (-26.52 to -18.99‰) of the three target species, with song sparrows exhibiting the least variability of $\delta^{13}C$ values (range = -26.66 to -24.91‰) (Fig. 8). Red-winged blackbirds also exhibited the widest range of $\delta^{15}N$ values (6.31 to 15.70‰) while tree swallows varied little ($\delta^{15}N$ values between 10.93 and 13.05‰) (Fig. 8). Of the 13 red-winged blackbirds sampled for isotopes at Onondaga, 2 were female and 11 were male. The small sample size in this pilot study prohibits statistical testing, but the mean male and female red-winged blackbirds show some difference in $\delta^{13}C$ (male = -21.40 ± 2.04 (SD), female = -24.23 ± 1.45 (SD)) and almost no difference in $\delta^{15}N$ (male = 9.20 ± 2.57 (SD), female = 9.73 ± 3.20 (SD)). Without more samples, we cannot tell if these differences are meaningful or due to small sample size.

Table 5. Mean isotope values ($\delta^{13}C$ and $\delta^{15}N$) for all avian species sampled on Onondaga Lake, 2008.

	Onondaga			Oneida		
Species	# of samples	$\delta^{13}C$ (mean ± 2SE)	$\delta^{15}N$ (mean ± 2SE)	# of samples	$\delta^{13}C$ (mean ± 2SE)	$\delta^{15}N$ (mean ± 2SE)
American robin	3	-25.48 ± 1.62	9.85 ± 0.68			
Baltimore oriole	3	-24.94 ± 0.22	7.78 ± 1.04	1	-24.83	7.92
Belted kingfisher	1	-26.06	17.70			
Brown-headed cowbird	1	-19.85	7.36			
Common grackle				1	-22.86	8.52
Downy woodpecker	3	-25.05 ± 0.47	8.52 ± 1.03			
Great crested flycatcher	1	-24.93	9.16			
Gray catbird	2	-24.67 ± 1.00	9.89 ± 3.31			
Killdeer	2	-23.81 ± 0.73	10.45 ± 1.71			
Northern cardinal	1	-26.13	4.65			
Red-eye vireo	3	-24.75 ± 0.16	8.01 ± 0.25			
Red-winged blackbird	13	-21.84 ± 1.21	9.29 ± 1.41	10	-24.97 ± 0.79	10.79 ± 0.56
Song sparrow	12	-25.59 ± 0.29	11.62 ± 0.89	2	-25.97 ± 1.36	10.28 ± 1.08
Spotted sandpiper	1	-24.10	12.04			
Tree swallow	10	-27.47 ± 0.90	11.80 ± 0.47	2	-26.65 ± 0.05	12.42 ± 1.23
Traill's flycatcher	1	-24.54	9.62			
Warbling vireo	4	-25.77 ± 0.67	9.02 ± 0.81			
Wood thrush	2	-24.85 ± 0.12	7.18 ± 2.89	2	-24.66	8.49
Yellow warbler	2	-26.45 ± 2.16	11.06 ± 0.64			

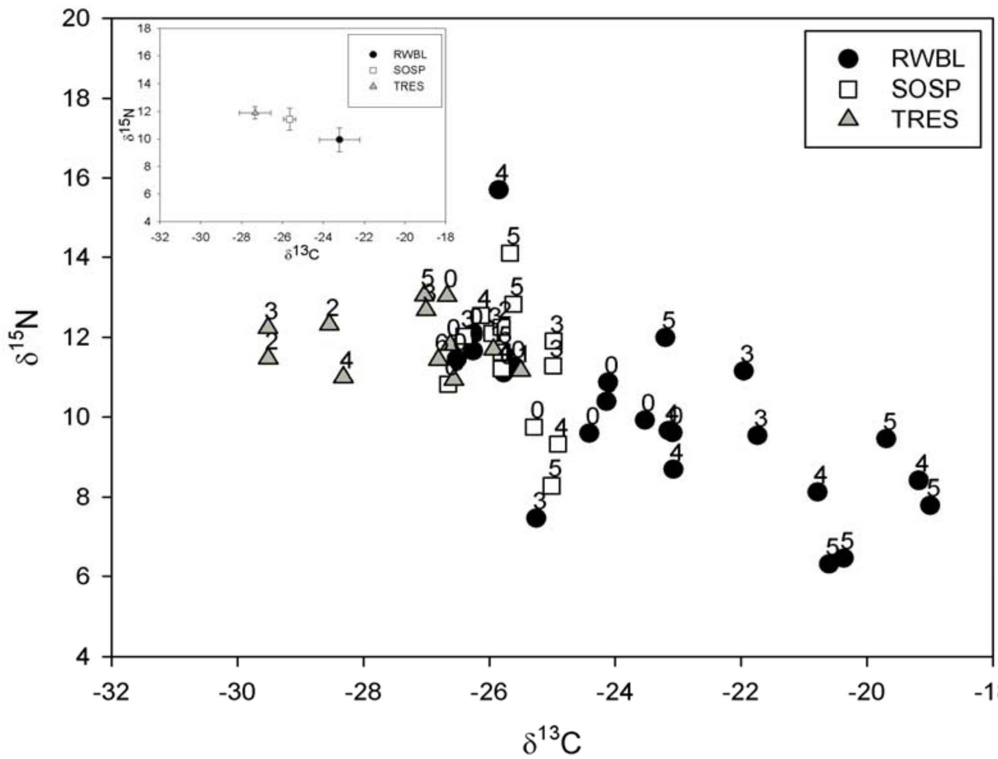

Figure 8. Stable isotope diagram of blood from select avian invertivores (RWBL = red-winged blackbird; SOSP = song sparrow; TRES = tree swallow). The inset figure shows the mean isotopic value from all sites for each species (± 2 SE). Numbers adjacent to symbols represent the six sampling sites (0 = Oneida Lake (reference site); 1 = Onondaga Canal; 2 = Maple Bay; 3 = White Cliffs; 4 = Beach; 5 = Harbor Brook; 6 = Ley Creek).

6.0 DISCUSSION

6.1 <u>Contaminant exposure in bird species</u>

6.1.1 Blood mercury

Based on the pilot sampling conducted in 2008 it is apparent that mercury concentrations in all target avian invertivore species tested were higher in birds sampled on Onondaga Lake than on Oneida Lake, the reference site. Where the sample sizes were sufficient to conduct statistical comparisons, we found that blood mercury concentrations were significantly higher in birds from Onondaga Lake than Oneida Lake.

It is unclear why blood mercury concentrations in female red-winged blackbirds were significantly higher than in males from Onondaga Lake but not from Oneida Lake. This finding suggests that male red-winged blackbirds captured on Onondaga Lake may have different habitat preferences than females and are foraging on different prey items containing lower mercury levels, possibly more of a terrestrial vs. aquatic origin.

Tree swallows tended to have lower blood mercury concentrations than red-winged blackbirds and song sparrows. This could be attributed to swallows' more aerial foraging habits. There may also be a difference in mercury levels between larval and adult (flying) stages of many insects. Elwood et al. (1976) demonstrated that gut contents of crane fly larvae could be a significant fraction of the total mercury in the larvae. When most insects and other invertebrates emerge, they molt their final exoskeleton, which includes the gut lining and the guts, leaving a significant portion of the mercury behind (Hildebrand et al. 1980). Sarica et al. (2005) showed that blowfly maggots accumulated mercury when feeding on fish carcasses and carried that mercury into the pupa stage, but then eliminated it when they emerged as adults. In addition, many adult insects do not feed and, therefore, lack a functional gut and consequently have lower mercury levels than the larval forms (C. Pennuto pers. comm.). Red-winged blackbirds and song sparrows tend to forage more on larval and "crawling" prey than flying insects (Piterman 1994, O. Lane pers. observ.).

Of all sites sampled on Onondaga Lake it appears that birds from Ley Creek, Harbor Brook, and White Cliffs have higher mercury levels in blood than birds from the remaining sites. Greater mercury exposure is likely due to point sources of mercury located near or upstream of these sites. The Canal site is the furthest downstream from the point sources of mercury and has the lowest mean blood mercury concentration of all sites sampled on Onondaga Lake.

We were able to sample several nesting female tree swallows in May and then again in June to determine if mercury exposure changed as the summer progressed. Based on a previous study with songbirds, blood mercury concentrations can double in a month (Lane and Evers 2007). We did not, however, observe a similar pattern in a small number of tree swallows sampled from Onondaga Lake. This is likely due to constant or stable prey mercury concentrations throughout the nesting period. Tree swallows captured later in May had been feeding in the area for over four weeks and mercury equilibrium may have been achieved.

We found that 100% of breeding shorebirds (killdeer and spotted sandpiper) sampled on Onondaga Lake exceeded the mercury LOAEL (0.63 µg/g, ww) that we have hypothesized for tree swallows and some exceeded the LOAEL for common loons (3.0 µg/g, ww) (see Appendix III for explanation).

Spotted sandpipers and killdeer feed on aquatic and terrestrial invertebrates (Oring et al. 1997). The spotted sandpiper diet includes midges-chironomids (Diptera), mayflies (Ephemeroptera) (Lank et al. 1985), grasshoppers, crickets (Orthoptera), beetles (Coleoptera), caterpillars (Lepidoptera), worms (Annelida), mollusks, crustaceans (amphipods), spiders (Aranea) (Cramp and Simmons 1983), and occasionally small fish and carrion in the form of dead fish (Oring et al. 1997). Onondaga Lake, including the shoreline, was littered with dead fish in 2008 (pers. observ.). It is likely that fish in Onondaga Lake have elevated mercury levels, potentially contributing to the spotted sandpipers' high blood mercury concentrations, if they are consuming those fish. Becker and Bigham (1995) found that mercury concentrations in chironomids and amphipods were highly correlated with the mercury concentrations in the contaminated sediments on Onondaga Lake, and likely contribute to spotted sandpiper's mercury loading. The lower blood mercury levels in the killdeer may reflect different foraging habits between the two shorebirds. Jackson and Jackson (2000) suggest that killdeer are less dependent on littoral zones for foraging and consume invertebrates such as grasshoppers and beetles in addition to snails, crayfish, and other crustaceans. However, stable isotope data from the 2008 season suggests that these two shorebirds are foraging on isotopically similar prey. Further research is needed on the foraging behavior and preferred prey items of shorebirds at Onondaga to better understand the high mercury concentrations in these birds.

6.1.2 Egg mercury

Concentrations of contaminants measured in eggs represent an important indicator of potential adverse reproductive effects in bird populations. It appears that mercury concentrations in tree swallow and red-winged blackbird eggs collected at Onondaga Lake are relatively low. Eggs from Oneida Lake were not tested because of funding limitations.

Because we do not know how long these birds have been on site prior to egg laying or the time it takes for mercury to build up in their body to be excreted into the eggs, it is possible that at the time of egg laying the female's mercury body burden was low enough and not a great deal of mercury was depurated into the eggs. As explained in Appendix III, the lowest observed adverse effect level (LOAEL) in tree swallow eggs from Heinz et al. (2009) is 0.2 µg/g (ww). Other studies (Custer et al. 2008, Bishop et al. 1995) also documented mercury exposure measured in tree swallow eggs that can provide further comparisons.

6.1.3 PCBs in eggs

In general, PCBs tended to be higher in tree swallow eggs than in red-winged blackbird eggs sampled on Onondaga Lake. The difference between egg PCB concentrations likely reflects the dietary differences of the two species on Onondaga Lake. Tree swallows nesting in an aquatic setting forage on prey items that are mostly aquatic in origin, prey that may reflect higher burdens of PCBs due to direct exposure to contaminated lake sediments. Red-winged blackbirds consume terrestrial prey as well as aquatic prey (Yasukawa and Searcy 1995). Sites further away (Long Branch Road and Canal) from the main body of Onondaga Lake had lower concentrations of PCBs than "Lake" sites. Tree swallows from Ley Creek had the highest levels of PCBs in eggs from Onondaga Lake. This is likely related to PCB releases along Ley Creek from an auto parts manufacturer and municipal landfill. Small sample sizes precluded statistical analyses.

Concentrations of PCBs were below levels reported to have significant adverse effects on tree swallow reproduction. For example, Custer et al. (2001) found no effects on tree swallow hatching success at egg concentrations of 4.2 µg/g (ww) PCBs. However, birds express different sensitivities to PCB exposure. PCB concentrations of 1.3 µg/g (ww) have affected hatchability in the chicken, one of the most sensitive species to the effects of PCBs (Chapman 2003). A NOAEC for the bald eagle was determined to be 4.0 µg/g (ww) (Bowerman et al. 2003). Kubiak et al. (1989) found Forster's terns nesting on Lake Michigan experienced reproductive failure associated with egg PCB concentrations ranging between 6.2 and 26.0 µg/g (ww).
Double-crested cormorants experienced egg mortality at egg PCB concentrations between 4.4

and 14.8 μg/g (ww) (Tillitt et al. 1992). In our study the highest concentration in swallow eggs was 1.7 μg/g (ww) (based on a conversion from dry weight to wet weight concentrations of PCBs assuming an 80% average moisture content).

While the concentration of PCBs in bird eggs from Onondaga Lake is relatively low, there is potential for additive or synergistic effects associated with PCBs and other contaminants (Blus 2003). Interactions between methylmercury and the PCB Aroclor 1260 resulted in less PCBs being accumulated in tissues than when only PCBs were administered to experimentally fed quail (Leonzio et al. 1996). However, liver monoxygenase activity, (i.e. enzyme activity associated with detoxification) was depressed 50% more in birds dosed with both methylmercury and PCBs than PCBs alone (Leonzio et al. 1996). In addition, low-dose treatments of methylmercury and PCB (food contaminated with 2.5 μg/g methylmercury and 10 μg/g Aroclor 1260) resulted in some DNA damage relative to the control birds, while high-dose treatments (25 μg/g methylmercury and 100 μg/g Aroclor 1260) caused significantly higher DNA damage than the control groups (Leonzio et al. 1996). It may be important to consider such synergistic effects when estimating the impact of mercury and PCBs on birds at Onondaga Lake.

6.1.4 Feather mercury

Feather mercury concentrations in common grackles and red-winged blackbirds sampled on Onondaga Lake were below 1.5 μg/g (fw). The mercury concentration in one female belted kingfisher sampled was 35.7 μg/g (fw), above the mallard critical level of 9.0 μg/g (fw) and approached the common loon level of 40 μg/g (fw) (Evers et al. 2008). Feather mercury reflects a bird's body burden at the time of feather growth. If this bird is older and spent several years nesting on the Onondaga Lake it would have had the time to bioaccumulate high levels of mercury in its system. This bird was nesting and was observed foraging on the lake, therefore, we can assume it is exposed to the local contamination.

6.1.5 Stable isotopes and mercury in bird blood

Contaminants that enter food webs are accumulated by organisms at lower trophic levels and then are magnified by consumers at higher levels in the food web. This process of bioaccumulation and biomagnification of contaminants represents a significant health risk for wildlife populations. Historically, food web studies have relied on labor-intensive gut content analysis to gain an understanding of predator-prey interactions across trophic levels. Such analyses provide a detailed "snapshot" of the diet of a particular organism at the time of capture but prohibit an understanding of trophic interactions that may vary across time and space. The ratio of stable isotopes of nitrogen (^{15}N and ^{14}N, reported as $\delta^{15}N$) and carbon (^{13}C and ^{12}C, reported as $\delta^{13}C$) measured in producers and consumers can help describe food web pathways leading from the base of the food web up to the top predators (Patterson and Fry 1987).

The combination of $\delta^{15}N$ and $\delta^{13}C$ analysis provides a two-dimensional interpretation of food web dynamics. Moving up through a food web, $\delta^{15}N$ values show a consistent enrichment of the heavier nitrogen isotope (^{15}N) because organisms preferentially excrete the lighter nitrogen isotope (^{14}N). This produces a trophic level shift of approximately 3.5 parts per million (ppm), allowing for trophic position of particular components of the food web to be determined quantifiably. By contrast, there is very little enrichment of $\delta^{13}C$ values through a food web (< 1.0 ppm is generally understood), but instead reflects the dietary preference at each trophic level (Patterson and Fry 1987).

Within contaminated landscapes, the combination of $\delta^{13}C$ and $\delta^{15}N$ analyses, in conjunction with contaminant chemistry, can provide a detailed assessment of the primary routes of contaminant transfer and biomagnification up to top-level predators (Rasmussen and Vander Zanden 2004).

Plots relating blood mercury concentrations to $\delta^{13}C$ and $\delta^{15}N$ from samples collected from Onondaga Lake (Fig. 9 and Fig. 10, respectively) vary across the three species. Red-winged blackbirds have a broad range of $\delta^{13}C$ value (-26.52 to -18.99‰), and those collected adjacent to Onondaga Lake have $\delta^{13}C$ values that are less negative than either of the other two bird species. This suggests that red-winged blackbirds are foraging within a food web that has different carbon sources than the other two species. Further research on emergent aquatic insects and other possible prey items for blackbirds will help identify the basal carbon sources within the red-winged blackbird food web.

The plot of $\delta^{15}N$ vs. mercury concentration shows variation between the three target avian invertivores (Fig. 10). The $\delta^{15}N$ values of song sparrows and tree swallows on Onondaga Lake do not have wide ranges (11.62 ± 0.89; n=12 and 11.80 ± 0.47; n=10, respectively). This suggests that mercury levels in these birds are not directly related to trophic level interactions but instead may represent site-specific contamination effects. This assertion is supported by the fact that birds collected from White Cliffs and Harbor Brook consistently have higher blood mercury concentrations relative to birds sampled from other sites (Table 1, Fig. 10). However, a positive relationship between mercury and $\delta^{15}N$ in red-winged blackbird blood is observed (Fig. 10). This positive relationship may be related to a shift in foraging behavior to higher trophic level organisms associated with increasing age. Of the 13 individual red-winged blackbirds represented in Fig. 10, 4 of them are after second year (ASY) birds (3 males and 1 female). Of these ASY birds, three (2 males, 1 female) have blood mercury concentrations above 1 µg/g (ww). These three ASY individuals also have $\delta^{15}N$ values that are higher than the range of all other individuals (11.15-15.69‰ compared to a range of 6.31-9.66‰ for all other individuals). These preliminary data suggest that a combination of mechanisms (i.e. shifts in foraging behavior and site-specific conditions) make avian insectivores at Onondaga susceptible to mercury contamination.

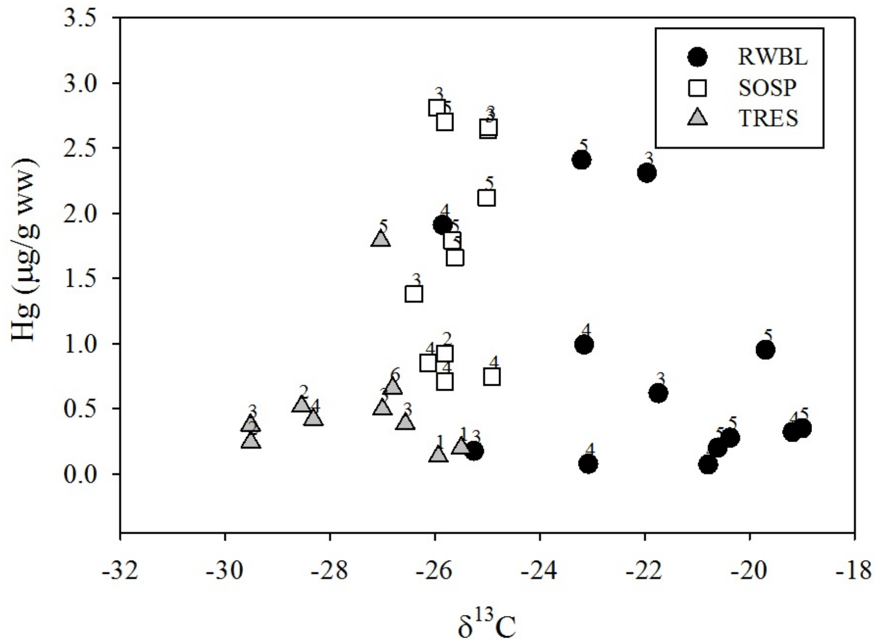

Figure 9. Isotopes (δ^{13}C) versus mercury concentration in blood of select avian invertivores from Onondaga Lake. The cattail (*Typha* spp.) has a mean δ^{13}C value of -27.5‰ (Chang et al. 2009). The stem of the common reed (*Phragmites australis*) has a mean δ^{13}C value of -25‰ (Balogh et al. 2006). Numbers adjacent to symbols represent the six sampling sites 1 = Canal; 2 = Maple Bay; 3 = White Cliffs; 4 = Beach; 5 = Harbor Brook; 6 = Ley Creek).

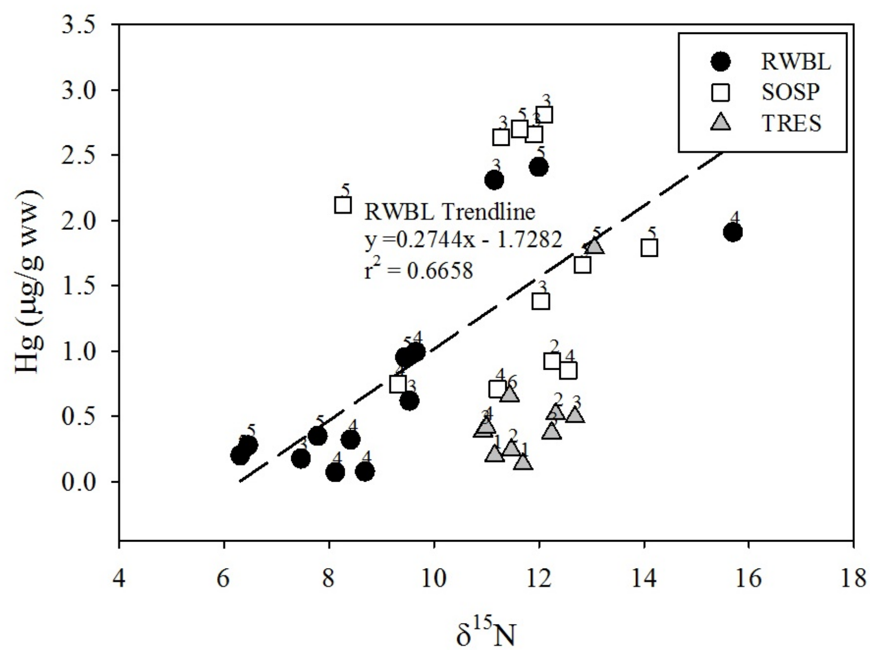

Figure 10. Total mercury concentrations versus δ^{15}N of blood samples for three avian invertivore species (RWBL – Red-winged blackbird; SOSP = song sparrow; TRES = tree

swallow). Numerical codes adjacent to each symbol correspond to sampling locations (1 = Canal; 2 = Maple Bay; 3 = White Cliffs; 4 = Beach; 5 = Harbor Brook; 6 = Ley Creek.

7.0 CONCLUSIONS

This 2008 pilot study demonstrates that mercury concentrations in all target species are significantly higher on Onondaga Lake than the reference site of Oneida Lake. Many individuals had blood mercury levels exceeding our calculated tree swallow LOAEL of 0.63 µg/g (ww); all five breeding shorebirds sampled had blood mercury levels above 0.63 µg/g (ww). Only a few songbird eggs exceeded the egg mercury LOAEL of 0.2 µg/g. Songbird feathers did not appear to generally have concentrations of mercury that would warrant concern, however, only a small number of feather samples were analyzed and mercury effects levels in feathers are still being developed. One belted kingfisher feather sample had mercury concentrations approaching the common loon critical body burden level of 40 µg/g (fw). Stable isotope data revealed differences in the foraging behavior between the three target songbirds and also highlighted the importance of understanding both site-specific processes and trophic level interactions that make songbirds susceptible to mercury bioaccumulation.

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APPENDIX I. MEAN BLOOD HG CONCENTRATIONS (µg/g, WW) IN ADULT BIRDS SAMPLED ON ONONDAGA LAKE AND ONEIDA LAKE IN 2008 (Data are arranged by site with species listed in increasing Hg blood concentration).

Site	Species	n	Mean +/- stdev	Range
Canal (Grenadier)				
	Song sparrow	1	0.06	
	Red-eyed vireo	2	0.12 +/-0.004	0.11-0.12
	Warbling vireo	1	0.14	
	Tree swallow	6	0.18 +/-0.03	0.13-0.22
	Gray catbird	1	0.18	
	Red-winged blackbird	2	0.23 +/-0.07	0.19-0.28
	Northern cardinal	2	0.06 +/-0.01	0.05-0.07
Maple Bay				
	Brown-headed cowbird	1	0.13	
	Wood thrush	1	0.16	
	Downy woodpecker	3	0.17 +/-0.04	0.13-0.21
	Common grackle	3	0.20 +/-0.13	0.12-0.35
	Yellow warbler	1	0.24	
	Gray catbird	2	0.25 +/-0.15	0.15-0.36
	Warbling vireo	9	0.28 +/-0.18	0.07-0.61
	House wren	1	0.34	
	Black-capped chickadee	1	0.37	
	American redstart	7	0.39 +/-0.15	0.19-0.57
	Tree swallow	5	0.40 +/-0.19	0.21-0.69
	Red-eyed vireo	1	0.46	
	Song sparrow	6	0.60 +/-0.20	0.31-0.92
	American robin	1	0.62	
	Red-winged blackbird	6	1.10 +/-0.90	0.07-2.21
	Belted kingfisher	1	1.84	
	Red-eyed vireo	1	0.12	
White Cliffs (Ninemile Creek)				
	Warbling vireo	2	0.28 +/-0.15	0.18-0.38
	Bank swallow	1	0.35	
	Tree swallow	4	0.42 +/-0.05	0.37-0.49
	Gray catbird	1	0.57	
	Wood thrush	1	0.57	
	Northern rough-winged swallow	2	0.65 +/-0.14	0.55-0.75
	Great crested flycatcher	1	0.65	

White Cliffs (cont.)				
	Red-winged blackbird	4	0.81 +/-1.03	0.13-2.31
	Yellow warbler	1	1.04	
	Killdeer	2	1.25 +/-0.01	1.24-1.26
	Song sparrow	4	2.37 +/-0.67	1.38-2.81
	Spotted sandpiper	1	6.42	
	Tree swallow	2	0.44 +/-0.04	0.42-0.47
Beach				
	Red-winged blackbird	5	0.67 +/-0.79	0.07-1.91
	Song sparrow	3	0.77 +/-0.07	0.71-0.85
	Traill's flycatcher	2	0.81 +/-0.05	0.77-0.84
	Yellow warbler	1	0.81	
	Gray catbird	1	1.11	
	Spotted sandpiper	1	1.56	
	Baltimore oriole	3	0.50 +/-0.26	0.31-0.80
Harbor Brook				
	Gray catbird	1	0.62	
	Red-winged blackbird	5	0.84 +/-0.93	0.20-2.41
	Tree swallow	2	1.61 +/-0.07	1.56-1.66
	Yellow warbler	2	1.98 +/-0.36	1.72-2.23
	Song sparrow	4	2.07 +/-0.46	1.66-2.70
	American redstart	2	2.34 +/-0.25	2.16-2.51
	Spotted sandpiper	1	3.61	
	House sparrow	1	0.07	
Ley Creek				
	Red-winged blackbird	7	0.37 +/-0.52	0.02-1.27
	Gray catbird	1	0.63	
	Tree swallow	2	0.76 +/-0.16	0.65-0.88
	Song sparrow	2	0.99 +/-0.88	0.37-1.61
Reference				
Oneida	Baltimore oriole	1	0.05	
	Song sparrow	3	0.06 +/-0.02	0.05-0.07
	Tree swallow	6	0.08 +/-0.03	0.06-0.13
	Red-winged blackbird	13	0.11 +/-0.03	0.08-0.17
	Wood thrush	1	0.15	
	Common grackle	1	0.16	

APPENDIX II. STABLE ISOTOPE (C=CARBON AND N=NITROGEN) DATA FROM BIRD BLOOD SAMPLED ON ONONDAGA (CONTAMINATED) AND ONEIDA (REFERENCE) LAKES, 2008. (Data are sorted by species).

Species	Site	$d^{13}C$	$d^{15}N$	Date
	Onondaga Lake			
American robin	Maple Bay	-27.07	9.55	06/24/2008
	White Cliffs	-24.42	10.53	06/20/2008
	White Cliffs	-24.95	9.47	06/20/2008
Baltimore oriole	Harbor	-25.06	8.63	06/24/2008
	Harbor	-25.04	6.84	06/24/2008
	Harbor	-24.73	7.86	06/24/2008
Belted kingfisher	Maple Bay	-26.06	17.70	06/06/2008
Brown-headed cowbird	Maple Bay	-19.85	7.36	06/24/2008
Downy woodpecker	Maple Bay	-24.77	9.26	06/24/2008
	Maple Bay	-25.52	7.53	06/24/2008
	Maple Bay	-24.87	8.78	06/24/2008
Great crested flycatcher	White Cliffs	-24.93	9.16	06/20/2008
Gray catbird	Beach	-24.17	11.55	06/10/2008
	White Cliffs	-25.17	8.23	06/20/2008
Killdeer	White Cliffs	-23.44	9.60	06/17/2008
	White Cliffs	-24.18	11.31	06/17/2008
Northern cardinal	Maple Bay	-26.13	4.65	06/24/2008
Red-eye vireo	Canal	-24.84	8.26	06/23/2008
	Canal	-24.59	7.91	06/23/2008
	White Cliffs	-24.83	7.87	06/20/2008
Red-winged blackbird	Beach	-23.08	8.68	06/10/2008
	Beach	-25.85	15.70	06/10/2008
	Beach	-20.79	8.12	06/10/2008
Red-winged blackbird	Beach	-19.18	8.41	06/10/2008

	Beach	-23.15	9.66	06/10/2008
	Harbor	-20.60	6.31	06/24/2008
	Harbor	-20.37	6.46	06/24/2008
	Harbor	-19.00	7.78	06/24/2008
	Harbor	-19.70	9.45	06/24/2008
	Harbor	-23.21	12.00	06/24/2008
	White Cliffs	-21.74	9.53	06/20/2008
	White Cliffs	-25.26	7.47	06/20/2008
	White Cliffs	-21.96	11.15	06/17/2008
Song sparrow	Beach	-25.81	11.21	06/10/2008
	Beach	-24.91	9.31	06/10/2008
	Beach	-26.13	12.56	06/10/2008
	Harbor	-25.62	12.83	06/24/2008
	Harbor	-25.01	8.27	06/24/2008
	Harbor	-25.81	11.63	06/24/2008
	Harbor	-25.67	14.10	06/24/2008
	Maple Bay	-25.81	12.25	06/24/2008
	White Cliffs	-26.40	12.03	06/20/2008
	White Cliffs	-25.96	12.10	06/20/2008
	White Cliffs	-24.99	11.28	06/17/2008
	White Cliffs	-24.98	11.91	06/17/2008
Spotted sandpiper	Beach	-24.10	12.04	06/10/2008
Tree swallow	Beach	-28.32	10.99	06/18/2008
	Canal	-25.94	11.69	06/9/2008
	Canal	-25.50	11.15	06/18/2008
	Ley Creek	-26.81	11.44	06/24/2008
	Harbor	-27.03	13.05	06/11/2008
	Maple Bay	-29.51	11.47	06/09/2008
	Maple Bay	-28.54	12.32	06/09/2008
Tree swallow	White Cliffs	-26.56	10.93	06/20/2008

	White Cliffs	-29.52	12.24	06/09/2008
	White Cliffs	-27.00	12.68	06/09/2008
Traill's flycatcher	Beach	-24.54	9.62	06/10/2008
Warbling vireo	Maple Bay	-24.85	8.13	06/24/2008
	Maple Bay	-26.34	8.79	06/24/2008
	Maple Bay	-26.19	9.07	06/24/2008
	White Cliffs	-25.70	10.08	06/20/2008
Wood thrush	Maple Bay	-24.79	5.73	06/24/2008
	White Cliffs	-24.91	8.62	06/20/2008
Yellow warbler	Beach	-27.53	11.39	06/10/2008
	White Cliffs	-25.36	10.74	06/20/2008
Baltimore oriole	*Oneida Lake*	-24.83	7.92	06/11/2008
Common grackle		-22.86	8.52	06/11/2008
Red-winged blackbird		-25.60	11.27	06/11/2008
		-24.14	10.39	06/11/2008
		-24.11	10.87	06/11/2008
		-23.53	9.92	06/11/2008
		-26.26	11.66	06/11/2008

Red-winged blackbird	*Oneida (cont.)*	-25.77	11.11	06/11/2008
		-26.27	12.09	06/11/2008
		-26.52	11.45	06/11/2008
		-23.09	9.60	06/11/2008
		-24.41	9.59	06/11/2008
Song sparrow		-25.29	9.74	06/11/2008
		-26.66	10.82	06/11/2008
Tree swallow		-26.67	13.04	06/10/2008
		-26.62	11.81	06/11/2008
Wood thrush		-24.66	8.49	06/11/2008