CAN MERCURY LEVELS IN BAT SPECIES ALONG THE ST. LAWRENCE RIVER IN ONTARIO BE USED AS AN EFFECTIVE BIOMARKER IN ASSESSING ECOSYSTEM HEALTH?

By

IDALIA M. MILAN

B.ASc., Mijail Lomonosov University, 1990

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
ENVIRONMENT AND MANAGEMENT

We accept this thesis as conforming to the required standard

Dr. Brian Hickey, Thesis Sponsor and Thesis Supervisor
St Lawrence River of Environmental Science

Graduate Committee Member
School of Environment and Sustainability

Dr. Anthony Boydell, Director
School of Environment and Sustainability

ROYAL ROADS UNIVERSITY

October 2009

© Idalia M. Milan, 2009
Can mercury levels in bat species be used as an effective biomarker?

Abstract

This pioneering investigation focused on the mercury bioaccumulation relationship of bats and insects. Identifying biomarkers that can be extrapolated to humans is necessary. Radio-transmitter-fitted bats were tracked to identify five of their preferred feeding sites within and outside the Cornwall Area of Concern. Bats, insects and guano were collected from the five sites.

High THg levels in bats (N= 80) were noted among species and locations but these levels were not correlated with insects. Some individual *Myotis lucifugus* and *Eptesicus fuscus* bats had concentrations (10 - 12 ppm and 15 - 26 ppm) that exceeded those from previous studies (7.6 ppm and 1.5 ppm) (Hickey et al., 2001). One-way ANOVA and *t*-test (two-tailed) established statistical significance among caddisflies by location (p= 0.0013), insect taxa (p <0.001), bat species (p =0.001) and *Eptesicus fuscus* by location (p= 0.004). Caddisflies were sampled for MeHg (> 50% Hg was MeHg).
Can mercury levels in bat species be used as an effective biomarker?

Acknowledgements

I would like to thank the following individuals and organizations for supporting this project: the St. Lawrence River Institute of Environmental Science, especially Dr. Brian Hickey, Education Program Leader and Research Scientist of the St. Lawrence River Institute of Environmental Science for his expertise relating to bats and their capture; the Eastern Ontario Health Unit for lending the black-light traps and GPS equipment; Emmanuel Yumvihoze for his guidance in mercury testing and his methylmercury sampling at the David Lean laboratory of the University of Ottawa; Dr. Frank Shi for his assistance in the statistical data analysis; St. Lawrence Parks Commission for its permission to install all the black-lights at the Upper Canada Village (UPV) and Crysler Marina (CM) facilities. Numerous evenings were spent travelling its campgrounds, properties, and even special tourist areas such as “Crysler’s Farm Battlefield”, in order to track bats. Gratitude also to my family for their patience and precious assistance during field trips and their enthusiasm for conservation of the natural environment.
# TABLE OF CONTENTS

Abstract .......................................................................................................................... 1  
Acknowledgements ........................................................................................................ 2  
List of Tables .................................................................................................................. 5  
List of Figures ................................................................................................................ 6  
List of Abbreviations, Acronyms and Symbols .............................................................. 8  
1. General Introduction and Literature Review .............................................................. 9  
  1.1 Mercury and Methylmercury in Wildlife .............................................................. 11  
  1.2 Mercury and Health Effects .............................................................................. 12  
  1.3 Overview of Local Levels of Mercury ................................................................. 14  
  1.3.1 Great Lakes and Cornwall-Massena Area of Concern .................................. 15  
  1.4 Bats and Mercury ............................................................................................... 17  
2. Methodology .............................................................................................................. 20  
  2.1 Study Sites ......................................................................................................... 20  
  2.2 Bat Capture ...................................................................................................... 22  
  2.3 Bat Tracking ..................................................................................................... 24  
  2.4 Insect Collection .............................................................................................. 25  
  2.5 Bat Guano Collection ........................................................................................ 26  
  2.6. Mercury Analysis ............................................................................................. 27  
  2.7. Quality Assurance/Quality Control of Mercury Analyses ............................... 27  
  2.8. Statistical Treatment of Data .......................................................................... 28  
3. Results ........................................................................................................................ 29  
  3.1 Bat Capture ...................................................................................................... 29  
  3.2 Bat Tracking and Feeding Habitats ..................................................................... 30  
  3.4 Bat Guano Collection ........................................................................................ 39  
  3.5. Mercury Concentrations in Target Species ...................................................... 40  
  3.5.1 Bat species .................................................................................................. 40  
  3.5.1.1 Bat Mercury Concentration over Time ..................................................... 40  
  3.5.1.2 Bat Mercury Concentration by Species .................................................. 41  
  3.5.1.3 Bat Mercury Concentration by Locations .............................................. 42  
  3.5.2 Insect Species .............................................................................................. 43  
  3.5.2.1 Insect Mercury Concentration by Insect Taxa ........................................ 43  
  3.5.2.2 Insect Mercury Concentration by Site .................................................... 44  
  3.5.3 Relationship among Mercury, Bats and Insect Prey ....................................... 46  
  3.5.4 Methylmercury Concentration by Caddisflies .............................................. 47  
4. Discussion ................................................................................................................... 48  
  4.1 Bat, Insect and Guano Collection .......................................................................... 48  
  4.2 Mercury Levels in Species of Concern ............................................................... 52  
  4.2.1 Bat Predators ............................................................................................... 52  
  4.2.2 Insect Prey .................................................................................................. 55  
  4.3 Relationship among Mercury, Bat Species, Insect Prey and Sites ...................... 57  
5. Conclusions ................................................................................................................ 60  
6. Recommendations ..................................................................................................... 65  
7. References .................................................................................................................. 74  
8. Appendix A: Bats, Insects, Guano and THg ............................................................. 85
Can mercury levels in bat species be used as an effective biomarker?

9. Appendix B: Bat Roosts Feeding Areas, Bat Tracking, THg and MeHg among all Species ................................................................. 93
Can mercury levels in bat species be used as an effective biomarker?

List of Tables

Table 1. *General Characteristic of Eptesicus fuscus (Big Brown bats) and Myotis lucifugus (Little Brown bats) Collected during 2006 – 2007 Period*.................................86-87

Table 2. *Amount of Insects captured by Site during 2006-2007 Period*.................................88

Table 3. *Percent of Insects collected by Site during Monitoring Season*.................................89

Table 4. *Guano Collections by Site accordingly with Rainfall*...........................................90

Table 5. *Mean THg Concentrations between Bats and Insects by Site*.................................91
Can mercury levels in bat species be used as an effective biomarker?

List of Figures

*Figure 1.* Cornwall Feeding Areas, Bat Roost, Bat Tracking and Black-Light Traps…93

*Figure 2.* Cooper Marsh Feeding Areas, Bat Tracking and Black-Light Traps……..94

*Figure 3.* Cornwall Recreation Centre Feeding Areas, Bat Roosts, Bat Tracking and Black-Light Traps………………………………………………………………….95

*Figure 4.* Upper Canada Feeding Areas, Bat Tracking and Black-Light Traps………..96

*Figure 5.* Crysler Marina Feeding Areas, Bat Tracking and Black-Light Traps…………97

*Figure 6.* Crysler Battlefield Farm Feeding Areas and Bat Tracking………………….98

*Figure 7.* Insect Black-Light Trap……………………………………………………….99

*Figure 8.* Cooper Marsh…………………………………………………………………….100

*Figure 9.* Cooper Marsh Visitor’s House………………………………………………….101

*Figure 10.* Upper Canada Village (Bat House)…………………………………………102

*Figure 11.* Cornwall Recreation Centre. ……………………………………………..103

*Figure 12.* Upper Canada Village Service Building………………………………….104

*Figure 13.* Crysler Marina ………………………………………………………………….105

*Figure 14.* Crysler Battlefield Farm…………………………………………………………106

*Figure 15.* Guano Collection……………………………………………………………….107

*Figure 16.* Summary of mean ± SD THg Levels among Bat Species…………………..108

*Figure 17.* Mean ± SD THg Concentrations *Eptesicus fuscus* (Big Brown bats) by Geographic Location………………………………………………………………………109

*Figure 18.* Mean ± SD THg Concentrations *Myotis lucifugus* (Little Brown bats) by Geographic Location……………………………………………………………………110

*Figure 19.* Mean ± SD THg Concentration Insect Species…………………………..111
Can mercury levels in bat species be used as an effective biomarker?

*Figure 20.* Mean $\pm$ SD THg Concentration Caddisflies Species by Site………………112

*Figure 21.* Mean $\pm$ SD THg Concentration Mosquito Species by Site………………113

*Figure 22.* Mean $\pm$ SD THg Concentration Moth Species by Site……………………………114

*Figure 23.* Mean $\pm$ SD MeHg Concentration Caddisfly Species by Site………………115

*Figure 24.* Percent of MeHg/THg for Aquatic Species (Caddisflies) by Site………………116
Can mercury levels in bat species be used as an effective biomarker?

List of Abbreviations, Acronyms and Symbols

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>AOC</td>
<td>Area of Concern</td>
</tr>
<tr>
<td>ATSDR</td>
<td>Agency for Toxic Substances and Disease Registry of Hazardous Substances</td>
</tr>
<tr>
<td>CORA</td>
<td>Cornwall Recreation Centre</td>
</tr>
<tr>
<td>EC</td>
<td>Environment Canada</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>Hg\textsubscript{0}</td>
<td>Mercury</td>
</tr>
<tr>
<td>Hg\textsuperscript{2+}</td>
<td>Elemental mercury</td>
</tr>
<tr>
<td>Hg\textsuperscript{2-2}</td>
<td>Inorganic mercury</td>
</tr>
<tr>
<td>IJC</td>
<td>International Joint Commission</td>
</tr>
<tr>
<td>LEL</td>
<td>Lowest Effects Levels</td>
</tr>
<tr>
<td>GIS</td>
<td>Geomatic Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>M</td>
<td>Mean</td>
</tr>
<tr>
<td>MHg</td>
<td>Methylmercury</td>
</tr>
<tr>
<td>MOE</td>
<td>Ministry of Environment</td>
</tr>
<tr>
<td>N</td>
<td>Number</td>
</tr>
<tr>
<td>N</td>
<td>North</td>
</tr>
<tr>
<td>RAP</td>
<td>Remedial Action Plan</td>
</tr>
<tr>
<td>RRCA</td>
<td>Raisin River Conservation Authority</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SEL</td>
<td>Severe Effects Level</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>THg</td>
<td>Total Mercury</td>
</tr>
<tr>
<td>UPV</td>
<td>Upper Canada Village</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>W</td>
<td>West</td>
</tr>
<tr>
<td>wt</td>
<td>Weight</td>
</tr>
</tbody>
</table>
Can mercury levels in bat species be used as an effective biomarker?

1. General Introduction and Literature Review

Mercury (Hg) is a persistent globally distributed toxin that accumulates in organisms. Mercury is in third place (highest rank) on the Agency for Toxic Substances and Diseases registry of hazardous substances (as cited in Risher & DeWoskin, p. 465). Environment Canada classifies mercury as a Priority Substance due its deleterious effects on biota.

The adverse consequences of mercury pollution continue to prompt scientific investigation (Hoffmann et al., 2004). Mercury is a pollutant of public concern due to its propensity to be converted to methylmercury (MeHg), the most deleterious form of mercury to living beings, (Morel, Kraepiel, & Amyot, 1998).

Mercury in nature is present mainly in the form of red sulphide (HgS) known as cinnabar, a mineral found in small concentrations in many rock formations (Gray, Theodorakos, Budahn, & O'Leary, 1994). Mercury exists in three oxidation states: \( \text{Hg}^0 \) (metallic), \( \text{Hg}^{2-} \) (mercurous) and \( \text{Hg}^{2+} \) (mercuric), and its properties and behaviour depend on the oxidation state (Schoeny, 1995). Degassing of the earth’s crust, the evaporation of ocean waters, volcanic releases and the weathering of rock formations and soils release mercury to the natural environment (Trasande et al., 2005; Nriagu, 1989; Schroeder & Munthe, 1998). Pirrone, Costa, Pacyna, & Ferrara (2000) stated that “natural and anthropogenic sources in the Mediterranean region release roughly 215 t of mercury annually, which represents a significant contribution to the total mercury (THg) budget in Europe and the global atmosphere” (p. B-14).

Organic mercury pollution is attributed mostly to anthropogenic activities (Hudson et al. 1995; Mason et al. 1994; Trasande et al., 2005). Mercury is released into
Can mercury levels in bat species be used as an effective biomarker?

Mercury levels in bat species can be used as an effective biomarker. The natural environment is contaminated by industrial and municipal discharges, combined sewer overflows, urban and agricultural non-point source runoff, and municipal landfill sites (Biberhofer & Rukavina, 2002). Since the mid-nineteenth century, mercury has been a major component of anthropogenic emissions (Schroeder & Munthe, 1998).

Municipal waste incinerators, gold and silver mines, and smelting operations (Malm, 1998; Pfeiffer & Lacerda, 1988; Lee et al., 2001) and coal-burning plants contribute to the presence of mercury in the natural environment. Chlor-alkali plants associated with the pulp and paper industry (Sherbin, 1979) are major contributors to the mercury content found in river systems. Mercury emissions in developed countries have increased at a rate of about 4.5–5.5% yr\(^{-1}\) up to 1989 and remained nearly constant since then; in the developing countries, the emissions continue to rise steadily at the rate of 2.7–4.5% yr\(^{-1}\) (Pirrone, Keeler, and Nriagu, 1995). The same researchers also determined that “solid waste disposal through incineration processes is the dominant source of atmospheric mercury in North America (~40%), Central and South America (~34%), western Europe (~28%) and Africa (~30%), whereas coal combustion remains the dominant source in Asia (~42%) and Eastern Europe and the former USSR (~40%)” (p. 3379).

Although the uses of mercury have been restricted, it persists as a global contaminant of consequence (Monteiro, 1997). Globally, mercury continues to be employed for chlorine-caustic soda production, in button-type batteries, cleansers, fireworks, folk medicines, and pesticides (Brooks, 2007).

Almost all mercury compounds are toxic. They can be dangerous in both aquatic and terrestrial ecosystems. Mercury compounds affect all living beings (Mierle, 2001).
Particular interest has been paid to the organic form of mercury, Methylmercury (MeHg), a compound easily absorbed and retained in the tissue of aquatic animals and fish that can biocumulate MeHg by a factor of $\sim 10^6$ (Gilmour, Henry & Mitchell, 1992). MeHg is a potential neurotoxin (Mahaffey, 1999) that has an effect on humans and wildlife and accumulates in the food web (Hightower, 2004; Mahaffey, 1999). Mercury can enter food chains through by the water column and sediments (Gilmour et al., 1992; Krabbenhoft et al., 1998). This process is called methylation, a process occurring in sediments where high levels of organic matter (Callister & Winfrey, 1986) and an adequate number of sulphate reducing bacteria are found (Gilmour et al., 1992; Brandfireun et al., 1999). Demethylation activity (chemical re-conversion of methylmercury to inorganic mercury) occurs in surface sediments (Korthals & Winfrey, 1987). This process is carried out by sulphate-reducing bacteria, nitrate-reducing bacteria, and methanogenic species (Spangler et al., 1973a, 1973b; Oremland et al., 1991).

1.1 Mercury and Methylmercury in Wildlife

Since mercury is a persistent substance it accumulates in living organisms resulting in increasing levels of harm on higher order species such as predatory fish (Hannah et al., 2003, de Souza Lima et al., 2000; Storelli et al., 2002), fish-eating birds (Burger et al., 1995) and mammals (Mierle et al., 1999) through a process known as biomagnification.

Canadian studies have revealed mercury contamination in seed-eating birds and their predators (Gurba, 1970; Fimreite et al., 1970). Elevated Hg levels in predatory mammals have been linked to premature mortality and behavioural changes in animals such as otters from South Central Ontario (Mierle et al., 1999).
Can mercury levels in bat species be used as an effective biomarker?

Maury-Brachet et al. (2006) found proportions of MeHg concentration in lake waters, and the bioaccumulation factor for phytoplankton and fish. They demonstrated that the safety limits in the United States, Canada, and Brazil of 500 ng/g (fresh weight) or 2,500 ng/g (dry weight) were being exceeded. Humans ingest mercury when they consume mercury-laden fish.

Physical, biogeochemical and seasonal factors can influence the bioaccumulation of mercury in aquatic biota (Babiarz et al., 1998). The acidity of the water (pH), the length of the aquatic food chain, temperature, dissolved organic material, and the physical and chemical characteristics of a given watershed (soil type and erosion) affect the amount of mercury that is transferred from soils to water bodies (Gabriel, Williamson, & Pitt, 2002).

1.2 Mercury and Health Effects

Mercury enters living tissue via inhalation, ingestion, or absorption through the skin (Kahn & Weis, 1987). Mercury adversely affects reproduction in fish-eating animals. Loon productivity decreased as Hg exposure increased in a study of 120 lakes in Wisconsin, New Brunswick and Nova Scotia (Burgess & Meyer, 2007). Loon Hg exposure, measured as Hg levels in female loon blood and their prey, appeared to impose an upper limit on loon productivity. Quantile regression analysis indicated that maximum observed loon productivity dropped 50% when fish Hg levels were 0.21 ug/g (wet wt), and failed completely when fish Hg concentrations were 0.41 ug/g” (p. 85).

Colborn and Clement (1992) suggested “health effects in wildlife related to mercury, were an early warning of health risk to humans” (p. 21).

“Potential population effects in fish and wildlife resulting from dietary MeHg
Can mercury levels in bat species be used as an effective biomarker? exposure are expected to vary as a function of species life history, as well as regional differences in fish-Hg concentrations which, in turn, are influenced by differences in Hg deposition and environmental methylation rates” (Scheuhammer, Meyer, Sandheinrich, and Murray, 2008, p.12).

A number of studies have been published on mercury toxicology including the work of Zelikoff, Bertin, Burbader, Hunte, Miller, & Silbergeld (1995). They discovered that mercury or MeHg is capable of causing learning disabilities and developmental delays in people. Total mean mercury concentration in cord blood was associated with some neurobehavioral and neurophysiological deficits in children in ranges of 0.5 to 35.6 microg/L (Murata, K., Dakeishi, M., Shimada, M., Saton, H., 2007).

MeHg is absorbed into the body nearly six times more easily than inorganic mercury and is rapidly and extensively absorbed through the gastrointestinal tract (Villas-Bôas, Beinhoff, & Da Silva, 2001); it is then distributed throughout the body where it easily penetrates the blood-brain and placental barriers of living beings (Hansen, Reske-Nielsen, Thorlacius-Ussing, Rungby, & Danscher, 1989). Mercury compounds migrate through cell walls and can damage the vulnerable fetal brain (Needham et al. 2005). Several studies emphasized that even short-term exposure to Hg can be transferred to young children since mercury passes through the placenta (Morissette et al., 2004 & Vahter et al., 2000). Stern and Smith (2003) noticed that MeHg concentration in the blood of the fetus is about 1.5- to 2-fold higher than that of the mother because of the active transport of MeHg to the fetus through the placenta, demonstrating that mercury crosses the blood-brain and placental barriers, and impacts brain and fetal cells. Mercury exposure during gestation (6 or 7 weeks) in groups of guinea pigs produced widespread
Can mercury levels in bat species be used as an effective biomarker?

degeneration of neurons in the neocortical region of fetal brains (Inouye & Kajiwara, 1988).

Elevated levels of MeHg can restrain development and cause damage to the brain in cases of adult poisoning (Clarkson, 1993). Mercury has been found in breast milk and is deposited in hair as it grows (as cited in Desjardins, 2004, p. 4). High mercury concentrations have been found in infants whose mothers are heavily exposed (Björnberg et al., 2003).

Neurological deficits occur at low-level long-term exposures to MeHg (Wheatley, 1979; Grandjean et al., 1998; Lebel et al., 1998; Dolbec et al., 2000). Mahaffey (1999) showed that motor function, language, speech and walking could be retarded. Deafness and seizures can also result. MeHg exposure in utero can result in impaired growth and diminished neuro-development in infants and children (Grandjean, Weihe, White, Debes, Araki, Yokoyama, et al., 1997; Kjellstrom et al., 1989; Schober et al., 2003; Murata et al., 2004).

Faroe Islands and New Zealand epidemiological studies done by Grandjean et al. (1997) and Kjellstrom (1989) demonstrated that MeHg in seafood consumed by pregnant women—even at low concentrations (about 10–20% of observed effect levels on adults)—had subtle, persistent effects on children’s mental development as observed at about age 4 to 7 (so-called cognitive deficits), as cited by Grandjean et al. (1997).

1.3 Overview of Local Levels of Mercury

More than 360 chemical compounds have been identified in the Great Lakes. Many are classified as persistent toxic chemicals (as cited in Morealle, 2002). Nearly one-third of these chemicals have been evaluated for their potential impacts on living
Can mercury levels in bat species be used as an effective biomarker?

beings and their human health effects as detailed by *An Inventory of Chemical Substances Identified in the Great Lakes Ecosystem* (as cited in (ECb, 2007 ¶ 1).

1.3.1 Great Lakes and Cornwall-Massena Area of Concern.

The International Joint Commission designated the Cornwall-Massena area as a Great Lakes-St. Lawrence River Area of Concern (AOC). The area is an 80 kilometre (km) stretch of the St. Lawrence River from the Moses-Saunders Power Dam just west of the City of Cornwall to the eastern outlet of Lake St. Francis in Quebec. This area is shared by Canada, the United States and the Mohawk Nation of Akwesasne (Dreier et al. 1997).

A Canadian and U.S. Government protocol for the Cornwall Massena AOC (International Joint Commission [IJC], Annex 2, 1987) highlighted the fact that contaminated sediments, inadequately treated waste water, non-point source pollution, inland contaminated sites or degraded habitat are more prevalent in this area than the rest of Great Lakes (IJC, 1989).

Studies have shown the presence of mercury in water, sediment and fish. (Dreier et al., 1997; Richman & Dreier, 2000; Fowlie et al., 2006). MeHg concentrations in water columns within wetlands (Holmes, 2005) were also noted and mercury has been released into bodies of water of the Upper St. Lawrence and Lake Ontario from industrial, municipal, urban storm water discharges and agricultural runoff (Dreier et al., 1997). Mercury levels in sediments along the Cornwall waterfront were recorded at levels ranging from 400 to 3000 ng/g (Grapentine, Milani, & Scott, 2003), exceeding the natural background levels of 10-700 ng/g of the Great Lakes (ECa, 1997).
Can mercury levels in bat species be used as an effective biomarker?

Industries such as Courtaulds (a Rayon producer), ICI (Forest Products), Domtar Inc. (pulp and paper mill) and Cornwall Chemicals (chlor-alkali plant) all contributed to the mercury contamination in the sediments of the St. Lawrence River near Cornwall (Dreier et al. 1997). These industries are gone, but evidence indicates that concentrations of mercury in river sediments remain above the Lowest Effects Levels (LEL) and Severe Effects Levels (SEL) of 200 ng/g and 2000 ng/g THg (dw), respectively (Ion et al., 1997).

Studies demonstrated that local Hg and Zn sources contributed to the contamination of littoral sediments and macro-invertebrates (Dreier et al., 1997; Richman & Dreier, 2000). For example, values of 0.02 µg/g, 0.03 µg/g and 0.06 µg/g of mercury were discovered within benthic organisms taken from the St. Lawrence River.

Mercury accumulates in benthic invertebrates at concentrations capable of inducing effects, biomagnifying up the food chain to produce adverse responses in higher trophic level organisms (Grapentine et al., 2003). Borgmann et al. (2001) cited “Measurements of contaminants in tissues of resident benthic fauna provide evidence of bioavailability and that the contaminants are responsible for observed effects on the organisms” (p. 956). Locally, THg concentrations in zooplanktons (4-36 µg/L) were higher in some areas of Zone 1 (Ridal et al., 2006) than in other areas sampled as well as upstream (Lake St. Lawrence). Consequently, benthic invertebrate communities are adversely impacted (Dreier et al., 1997). Ridal et al. (2006) reported average THg concentrations of zooplankton during the July period, with 594 ng/g dw in Zone 1 and 434 ng/g dw in Zone 2. These levels are considered high when compared to the mercury
levels detected in zooplankton taken from Illinois Lake in 1986 (0.01 ppm) (Ramelow, Webre, Mueller et al. 1989).

In the same way, Dreier et al. (1997) identified fish and wildlife health problems associated with exposure to mercury as one of the seven major environmental issues of concern in the Cornwall section of the St. Lawrence River AOC. Yellow perch (*Perca flavescens*) of the St. Lawrence River near Cornwall have been found to contain a mean of 0.27 ppm (Fowlie et al. 2007), exceeding Ontario Ministry of Environment consumption guidelines of 0.26 ppm (Yanch, 2007). These levels are high compared to the yellow perch concentrations of 0.25 ppm found in Michigan and Wisconsin (Grieb et al., 1990).

Additionally, since 1978 restricted consumption of some fish species has been recommended by the Mohawk Governments of Akwesasne. Women of child-bearing age and children under the age of 15 should not consume any fish taken from the St. Lawrence River due to mercury contamination (Dreier et al., 1997). The USA Food and Drug Administration recommends no more than 1 part of methylmercury in a million parts of seafood (1 ppm). For the general population Canadian guidelines for consumption restriction begin at levels above 0.61 ppm and for women of childbearing age and children under 15, consumption restriction begin at levels of 0.26 ppm (MOE, 2009).

1.4 Bats and Mercury

Most mercury research has focused on humans and animals that eat mercury-contaminated fish. Bats are top predators of a short food chain with fewer links compared to pike that are four steps above their prey on their food chain. Bats consume
Can mercury levels in bat species be used as an effective biomarker? 

many calories to fly, reproduce, grow and sustain their bodily functions. Their diet consists of a large variety and quantity of insects (Fenton, 1983) that develop in contaminated areas (wetlands). Bats can eat between forty and one hundred percent of their body weight in insects each night. Nursing mothers routinely ingest fifty percent of their body weight (Hickey & Fenton, 1996).

Bats are important ecosystem components. They can be impacted by persistent contaminants because of their top-level position in the food chain, their surprising longevity and consequent duration of exposure (O'Shea, Everette, & Ellison, 2001). There is little information relating to insect-eating bats. Only one Canadian research paper records mercury concentrations in hibernation sites (Hickey, Fenton, MacDonald & Soulliere, 2001). Their study within specific areas of Eastern Ontario revealed that some hibernating bats had great mercury concentrations. Mercury levels from Eastern Ontario and nearby Quebec ranged from 2.0 mg/kg to 7.6 mg/kg by site and 1.5 mg/kg for *Myotis lucifus* (*N* = 39) and *Eptesicus fuscus* (*N* = 3) respectively. However, these samples were done at hibernation sites without a connection to their habitats and feeding sites, which were unknown to the authors.

A study of the Rocky Mountain Arsenal National Wildlife Area, near Denver, Colorado, revealed that the resident Big Brown bat colony held higher Hg concentrations than most other mammals previously sampled at this site (O'Shea et al., 2001).

Despite the fact that bat fur holds high mercury concentrations relative to their position on the food chain, there are very few bat studies and none focused on the relationship of bat habitats and their prey.
Brigham and Fenton (1986) found that some bats cohabit with humans in urban and rural areas. Others often have their roosts hidden in attics, hollow trees or inaccessible caves (Fenton, 1983). In this study, bat samples were collected during their active period (summer). Insect collection occurred during the summer as well. The said factors combined were the greatest limitations encountered in this paper due to their short active life.

Currie, Fairchild & Muir showed “caddisflies and bats in urban environments may provide a pathway for the movement of contaminants from aquatic sediments to terrestrial ecosystems” (as cited in Hickey et al., 2001, p. 699). Caddisflies are exposed directly to Hg contamination (Bedard, 1999; Lawrence & Mason, 2001). Ultimately, bats eat the contaminated insects and absorb the mercury.

This project represents the first detailed study of mercury concentrations in bats and prey (from the Cornwall AOC and other areas of Eastern Ontario) at feeding sites. This study predicted that *Myotis lucifugus* (Little Brown bats) and *Eptesicus fuscus* (Big Brown bats) would have high mercury concentrations that should be correlated to environmental mercury concentrations in their habitats. Big Brown bat mercury concentrations would be greater since these bats eat greater amounts of insects because of their size. Their mercury concentrations would be greater than those of Little Brown bats, which are smaller. Although male bats eat less than female bats they could have higher mercury concentrations because females give birth to fetuses and thus give up some of the mercury concentration.

This research will seek to relate the mercury levels found in bat fur with the mercury concentrations within the insects consumed by bats from known feeding sites.
Can mercury levels in bat species be used as an effective biomarker?

Given that mercury could be found in insects, bats would accumulate even greater mercury concentrations. Consequently, the following questions were tested:

Question 1: Does mercury concentration differ between species (*Myotis lucifugus* and *Eptesicus fuscus*)?

Question 2: Does mercury concentration in bats differ among locations for *Myotis lucifugus* and *Eptesicus fuscus*?

Question 3: Does mercury concentration in insects vary among insect taxa?

Question 4: Does mercury concentration in insects differ among sites?

Question 5: If mercury in bats varies among sites and if insects vary among sites does insect mercury concentration correlate with bat mercury concentration?

Moreover, methylmercury concentration among caddisflies was examined tentatively. This study will provide useful baseline data for the evaluation of mercury concentrations in top predators, their prey and the bioaccumulation process.

2. Methodology

2.1 Study Sites

The bats were trapped from sites in the vicinity of the Cornwall waterfront and sites more than 10 km distant. Besides the City of Cornwall, Upper Canada Village (UPV), Cooper Marsh, Cornwall Recreational Centre (CORA) were sampled. Only a few Big Brown bats were captured during this study; therefore, I expanded my study to include another site (Pointe Fortune).

The five sites mentioned have different habitat conditions (Figure 8-14). The first two are significant wetlands and national historic sites. Upper Canada Village (45°01’ 23. 53” N, -74° 43’47. 34”) is a tourist attraction where the lives of United Empire
Can mercury levels in bat species be used as an effective biomarker?

Loyalist settlers are reenacted. The site lies near the Upper Canada Migratory Bird Sanctuary. An important waterfowl breeding and migratory bird staging area. Similarly, Crysler’s Farm Battlefield (44° 56’30. 57” N, -74° 04’12. 99” W) is a National Historic Site of a battle of the war of 1812. The battlefield lies just west of UPV. Both the village and battlefield lie along the shores of the St. Lawrence River. The sites were areas of prime bat activity during this research.

In contrast, Cooper Marsh (45°06’53. 64” N, -74° 30’52. 97” W) is a conservation area and a significant wildlife habitat. Cooper Marsh is a component of the larger Charlottenburg Marsh. The region had been settled and farmed by United Empire Loyalists in the 1780s. The marsh was created in the mid 1800s when flood control structures raised water levels to aid navigation along the St. Lawrence River (RRCA, n.d.). Cooper Marsh is located on the shores of Lake St. Francis, which is a portion of St. Lawrence River, about two kilometres west of the Village of South Lancaster on County Road number two and eighteen kilometres east of the City of Cornwall (RRCA, n.d.).

The City of Cornwall site (45°01'23. 53"N and 74°43'47.34"W) was chosen due to its proximity to the contaminated zones within Cornwall AOC boundary (around 2 km). These zones included Zone 1, which is located near the RCAF Boat Launch at the west end of Lamoureux Park; Zone 2 located in the area near the Port of Cornwall (Windmill Point to Pilon Island) and Zone 3 which extends from the former Courtaulds site to the Cornwall Wastewater Treatment Plant (Oil Tank Storage/ Tank Farm) (Richman, 1999; Dreier, 2000). Mercury analysis from this site could reveal high mercury concentrations in predators and their prey.
Can mercury levels in bat species be used as an effective biomarker?

The other sites away from the St. Lawrence River are the Cornwall Recreational Centre (CORA) and Pointe Fortune. CORA (45° 02’57. 02”N, -74°. 48’ 42. 44”W) is an abandoned sand pit northwest of the City of Cornwall. It is located away from the City of Cornwall at a distance of 2.5km. Over time the site has become a recreation area where diverse plants and wildlife can be seen while walking the nature trails. Artificial bat roosts were installed within the area to promote bat colony growth (Hickey, personal communication, 2006).

Finally, Pointe Fortune lies on the Quebec border along the Ottawa River just northwest of Montreal (45° 33’40” N, 74° 22’ 53” W). This site is north of the Trans Canada highway in the Montérégie region and at 5km from Voyageur Provincial Park.

A Global Positioning System (GPS) handheld navigation and positioning device (Mobile Mapper Device) was employed to record the feeding areas, bat colonies, black-light trap locations and bat tracking surveillance territories. Environmental conditions (e.g. precipitation, temperature) during the surveillance were noted as well.

For formatting and uploading the compiled data, Geographic Information System (GIS) software was used. To assist in the interpretation of all GPS coordinates taken for this study, main points were mapped and presented in Figures 1-6.

2.2 Bat Capture

Bats were captured while they were actively foraging during the period of May to September in 2006 and 2007. No more than fifteen bats were captured from any given colony. This quantitative research was conducted in accordance with the Animal Care requirements of University of British Columbia.
Can mercury levels in bat species be used as an effective biomarker?

Bats were captured with hand and mist nets. Each selected site was visited during the day to determine its accessibility and to install the mist nets. The mist nets used consist of four sections or shelves that are supported by cross lines. They were strung taut between two poles. The nets were positioned at various heights and took advantage of topographic and vegetative features in order to channel bats into the nets as Mills, Nortojn, Parnaby, Cunningham, & Nix (1996) suggested. This study considered the environmental factors that might influence the effectiveness of mist netting. Wind is certainly a factor affecting the success of a mist net since it will billow and move in the wind making it more detectable (Nyholm, 1965). Based on Nyholm’s suggestions (1965) about the optimal capture conditions, the mist nets during rainfall were not installed. Droplets adhere to the mist nets and make them more detectable to bats.

As Kunz and Kurta (1988) suggested based on site characteristics, the mist nets were placed frequently near roosts (UPV), near buildings (Cooper Marsh) and along the trails (CORA). Mist nets were set up between 6:00 p.m. and 7:00 p.m. just before dusk, thus preventing the capture of birds. The nets were constantly monitored before sunset and throughout the night. I avoided installing the nets in feeding areas where the illumination of the black-lights could interfere with bat collection.

The bats caught in the nets were quickly removed and placed in Cotton draw-string holding bags. General characteristics (sex, age, reproductive condition, etc.) were noted as factors that influence response to xenobiotics (Philip, 2001) as shown in Table 1. A sample of fur was clipped from the dorsal area where the fur is long and glossy (Nagorsen & Brigham, 1993). Fur samples were placed in small cap vials. Each bat captured was released without harm in close proximity of their roosts or feeding areas.
Can mercury levels in bat species be used as an effective biomarker?

2.3 Bat Tracking

Individual captured bats were fitted with colour coded bands and unique identification numbers. The bands were used in this study to determine if an individual was captured previously, and if so where it came from (roost). Certain individuals were captured more than once during the study. The UPV bats were tagged with a white band, CORA’s bats were tagged in green and Cooper Marsh bats were marked with a yellow band.

Each band was adjusted and placed on the individual’s wing. I banded females on the left side and males on the right side to identify them with a spotlight when they flew and fed at night. Individuals caught twice were banded on both wings. Wing movements were verified before the bats were released to ensure their well being. The bands could be seen under powerful light beams as they flew about feeding sites and their roosts.

Bat feeding sites were defined by fitting a few individuals with a very small battery powered radio-transmitter capable of emitting a specific frequency pulse signal detectable with a portable receiver and directional antenna (Nagorsen & Brigham, 1993). The transmitters used were LB-2N with a weight of 0.37g. These transmitters had a range greater than one kilometre and a battery life of 3 weeks, one week more than the battery life specified by Holohil System Ltd (12 days). The pulse signal revealed the direction of travel of the bats as they left the roost and flew towards their preferred feeding locations. The feeding behaviour of the transmitter-fitted bats within their preferred feeding areas was also monitored. Two bats from UPV, two from Cooper Marsh and two from the City of Cornwall were fitted with transmitters.
2.4 Insect Collection

Little Brown bats and Big Brown bats are insectivorous. They eat a great variety of insects including caddisflies and mosquitoes. Beetles, moths, and other kinds of flies were also taken (Nagorsen & Brigham, 1993). The target insects for this research were moths, caddisflies and mosquitoes.

Once the preferred feeding areas for bats were identified, insects were collected from these sites. Hand nets and miniature black-light traps were used to capture the insects. The black-light traps (UV, Model 1212) were developed by the American Centre for Disease Control. The traps consist of a fan, black-light, battery, collection bag and cup (Figure 7). The internal programmable photo-switch made it possible to have both the fan and light come on at dusk. The traps were connected to large 12 volt rechargeable batteries. The light source attracted insects near the trap where they were drawn into a fine mesh bag and holding cup by the fan. Only the fan remained active after sunrise to keep the insects inside the trap unharmed until they were collected. The small configuration of the trap made the capture of large insects impossible.

Insect traps were set up nearly every night regardless of weather conditions starting in early May and ending in late September during 2006-2007. Insect collection was not conducted on the Crysler’s battlefield site. I could not set up traps at this site because of the numerous tourists who visit this location daily. Tampering with the traps would have been too likely. Insects collected at UPV and CM were combined and analyzed as originating from a single site (UPV + CM) since the bats from the UPV colony patrolled both sites during an evening’s hunt.
Can mercury levels in bat species be used as an effective biomarker?

The insects captured were placed in a freezer soon after they were sorted and identified. The sorted insects were placed into 12 ml sample cap vials for mercury analyses.

Insect samples were dried on glass plates at 100\(^\circ\) C in an oven for 24 hours at the St. Lawrence River Institute of Environmental Science laboratory to ensure that water content was removed. All the instruments used in this procedure were washed with a nitric acid solution prior to their use.

2.5 Bat Guano Collection

Guano collection was undertaken once a bat roost was located. A mound of bat droppings (Fenton, 1983) is usually present at the base of a roost and is a clear indicator of an active colony.

During this study, guano collecting was achieved while insects were being trapped and bats were being tracked. Aluminium foil trays and/or plastic food wrap sheets were set under bat roosts (Figure 15). Guano was collected in this manner at Cooper Marsh (Visitor’s house, 45º 06’55. 23 N, 74º. 30’55. 10 W) and the UPV (Service building, 45º01’23. 53N, 74º43’47. 34W). Both roosts held large numbers of bats and offered suitable cover from the rain for the placement of the guano collection trays. The Visitor’s Centre at Cooper Marsh has a bat roost under a covered balcony (Figure 9), and the service building in UPV has a bat house attached to one of its gables (Figure 10). As illustrated by Figure 11, guano gathering from the CORA site located at 45º 03’02. 21N, 74º. 48’45. 77W) was limited by the very difficult access to the roost.

The guano samples collected were dried at room temperature then stored in paper envelopes. The identification of the guano content was preceded by the meticulous use
of tweezers to break up the guano pellets into fragments. The fractured matter was then observed under a microscope. Unused guano samples were frozen for future study, and to avoid the growth of tiny parasites and microorganisms that could be seen under the microscope.

2.6. Mercury Analysis

Insects and bats were captured during the years of 2006 and 2007 at the same locations. The bat fur samples collected during the summer of 2006 were associated with Big Brown bats from the City of Cornwall and Little Brown bats from Cooper Marsh. Bat fur and insect samples were also taken in 2007 from Cooper Marsh as well as from UPV, CORA, CM and Cornwall. Samples taken in previous years (2001-2005) were included in this study for better comparison between bat populations.

THg levels in insects and bats were related to one another and to known bat feeding sites. I gave particular attention to caddisflies collected during this study because their lives are loaded with mercury (Dreier et al., 1997). Consequently, caddisflies became the prime target species for MeHg testing. A modest MeHg analysis of insect samples collected in 2006 and 2007 was undertaken. The samples were first selected by their total Hg results and their proximity to known environmental mercury contamination.

2.7. Quality Assurance/Quality Control of Mercury Analyses

Bat fur was employed to determine mercury concentrations in bats. Insects collected in 2006 and 2007 were also analyzed for mercury concentrations. Fur and insect samples were assayed at the Mercury Laboratory of the University of Ottawa Campus. The laboratory specializes in trace mercury levels analyses. The majority of
Can mercury levels in bat species be used as an effective biomarker?

The samples were tested for THg only. A few insect samples (caddisflies) were analyzed for MeHg content at the same Laboratory.

Calibration of the machine was done before every mercury test. Standards and Blanks samples were run after three samples of bat fur and five samples of insects. The mercury testing range chosen for insects was 200 ng and for bats it was set at 1000 ng, in order to avoid mercury contamination from previous samples as per mercury equipment manual requirements. The Ottawa University Laboratory’s instruments were washed with soap and water then with distilled water and ethanol solutions before each batch analysis. A microscope, magnifying glass, scale, tweezers, dish and caliper as well as Mercury detector MD-1. NIC (Nippon Instruments) were also used to complete this study.

2.8. Statistical Treatment of Data

Data was analyzed by SPSS statistical software (SPSS Version 15 for Windows). Different approaches were used to determine the concentration of mercury within bats and insects. In order to test the difference among the means of groups (Kranzler, 2003) descriptive statistics, the one-way analysis of variance (ANOVA), t-test (two-tailed), and correlation methods were used to organize and summarize the data.

Once I determined the Hg concentrations in bats and insects collected at the bats’ feeding sites, I tried to correlate these two variables at diverse locations and determine the statistical significance between these two variables. All the insect species from CM and UPV were combined and analyzed by the t-test.

Because Hg concentrations in bats (Myotis lucifugus and Eptesicus fuscus) were significantly different, their Hg concentrations were analyzed separately with the Hg
Can mercury levels in bat species be used as an effective biomarker? However, the data available for *Eptesicus fuscus* were limited to two sites; consequently correlation method was inadequate to measure the strength of the linear relationship between insects and bats. Only *Myotis lucifugus* data were included in Pearson correlation.

### 3. Results

#### 3.1 Bat Capture

On the whole for this study, thirty-one bats were captured at three sites. Four were captured in 2006 and twenty-seven in 2007 respectively. Two bat species were collected at the sampling sites during nine nights of trapping: *Myotis lucifugus* (Little Brown bats, $N = 29$) and *Eptesicus fuscus* (Big Brown bats, $N = 2$).

Two Little Brown bats were captured in 2006 at the Cooper Marsh site then in 2007 nine more were captured at the same site. Three Little Brown bats were captured at the Cornwall Recreation Centre site in 2007, and fifteen bats of the same species were captured during the same season at Upper Canada Village. Two Big Brown bats were captured at the City of Cornwall site in 2006.

The proportions of females and males as well adults and juveniles caught were not equal among sites. Adult females ($N=30$) were more likely to be collected since they are the predominant gender in the roosts studied. Only one adult male and one female juvenile were captured from selected sites during 2006-2007. Overall there was a proportion of 97% of adult female bats captured. Only 3% of the captured were juvenile and male bats.

Bats are usually fairly abundant and widely distributed. As an illustration one mist nets trapping session resulted in the capture of 30 bats in less than 10 minutes as
they were leaving their little bat house. Only a few of them (15) were used for mercury testing purposes. The rest were released without delay. This episode took place at UPV (Figure 10) through bat collection in August 2007.

During this study certain banded individuals were recaptured in the mist nets on another evening. One pregnant Little Brown bat banded with number 26 was captured twice at the Cooper Marsh site. This event confirmed that banding did not impede that female’s activities.

Most of the sites surveyed were home to Little Brown bats. Big Brown bats were found within the town centre of the City of Cornwall. The captured Little Brown and Big Brown bats had arthropods or ectoparasites on their bodies (mites and fleas).

3.2 Bat Tracking and Feeding Habitats

During the surveillance effort all the Little Brown and Big Brown bats chose to live in summer roosts (i.e. old buildings). The bats monitored during this study began their nightly forays by leaving their roosts after 7:30 p.m. Their activities were monitored every night from 7 p.m. until 12 a.m. for two months. The numerous tracking sessions made it evident that the transmitter-fitted bats had preferred feeding sites.

To correlate the bat activity with weather conditions I obtained information relating to precipitation events and temperature. Monthly rainfall and temperature data was obtained from Climatological Station Reports (2006-2007).

The first transmitter put into use in this study was fitted to a Cooper Marsh bat. The transmitter emitted a signal for nearly three weeks between August 8th and August 26th of 2006. The bat in question was fitted with a transmitter with a frequency of
Can mercury levels in bat species be used as an effective biomarker?

173.1020. The very small transmitter signals were detected at distances greater than one kilometre.

Bat feeding sites varied from one colony to another in relation to the characteristics of the site (forest, swamp, watershed, etc.). Hunting territories remained remarkably constant from month to month and from one year to the next of this study (2006-2007). These territories include the wetland foraging range at Cooper Marsh (45°06'53.64"N and 74°30'52.97"W), the forest area near the storage building at UPV (45°01'23.53"N and 74°43'47.34"W) and the St. Lawrence River within city limits (45°01'20.72"N and 74°43'37.88"W).

The Cooper Marsh bats marked with coloured tags and transmitters were seen with a spot light feeding around their roost before they flew towards the Marsh. This was the case of bats caught in 2006 (N= 2) and the bats tagged in 2007 (N= 9), respectively.

Twenty evenings were spent tracking bats at Cooper Marsh. The bats flew out of their roost around 8:30 p.m. and flew about for ten to fifteen minutes. Thereafter, they flew southeast over the marsh where they remained for about two hours. They returned to the roost at around midnight. The same pattern was noted for fifteen days (75%) consecutively of the twenty days of surveillance.

I tracked bats from Cooper Marsh over the course of twenty days and during this time only five of the twenty times did they go far away from the marsh. The bat signal was lost after both bats tracked were detected feeding around the roost. Consequently, I decided to start far away from the roost and the marsh in the same direction (southwest) when the signal was lost the last time during bat tracking. Thus I could have more time (due to the bats’ speed during flight) to capture the signal and discover far feeding spots.
after the bats left their roost for feeding. As a result, bats were detected feeding far away (four times out of five) southeast, but within Cooper Marsh’s limits. On one occasion the signal was detected at the Village of Martintown (45° 09'34.82 N, 74° 40'56.41W), located at a distance greater than five kilometres from the St. Lawrence River.

During rain events the bats fitted with transmitters fed near their roost and a short distance to the west. This fact was confirmed three times especially on August 10th when a rainfall of 8.3 mm was recorded. Bats flew about the building until 9:45 p.m. then returned to their shelter.

Big Brown bats involved in this study were captured in a house in Cornwall. They were tracked from July 27th, 2006 to August 22nd, 2006. These bats had a frequency of 173.1814 and 173.1410 respectively. After this time, for unknown reasons, the signals ceased to be registered. The Big Brown bats were tracked for one hour before they would leave their roost (house). On most days, the bats flew about the neighbourhood for 15 minutes and then flew directly to the river to feed. When the signal was clear, the bats were down on the river at the geographic coordinates of 45°00'59.04"N, 74°43'24.87"W ; 45°00'55.25"N, 74°44'27.93"W ; 45° 01’20.72” N, 74°43’37.88”W, 45°00’57.34”N and 74°42’06.91”W. They returned around midnight from their hunting activities.

When temperatures hovered around 29°C (Climatological Station Reports, 2006) the bats flew directly to the river at about 8:15 p.m. - 8:30 p.m. This bat behaviour was reported for 6 days of tracking. During cooler temperatures such as 18°C (Climatological Station Reports, 2006), bats stayed inside the house until 9:30 p.m., then flew off. These
activities were observed on four occasions at City of Cornwall site. After the second week of surveillance I lost the signal of the bat with frequency of 173.1410. Based on a resident’s testimony, apparently the bat had been captured in another house within the neighborhood near its day roost.

The second bat fitted with a transmitter was also captured and released a great distance away at the homeowner’s request on August 20th of 2006. The bat (with frequency of 173.1814) returned to the house 10 days later, providing further evidence that bats have what might be called a familiar area. This area is the range they regularly patrol and know intimately (Fenton, 1983). I resumed tracking the returnee for two days until the signal was gone.

Upper Canada Village bats were tracked from the roost to feeding sites along the river merely seven hundred metres to one and a half kilometres distant. The bat tracking surveillance with radio-transmitters at this site started August 18th, 2007 and finished September 5th, 2007. The bats (N = 15) from this site were tagged with bands from numbers 5 to number 19. The bats surveyed in this case were the ones with the transmission number of 173.0210 (Tag #5) and 173.0598 (Tag #7) correspondingly.

The tracking quickly revealed that CM and the Crysler Farm Memorial Battlefield site were the preferred feeding sites of the transmitter-fitted individuals. The calm waters of the numerous inlets and ponds are perfect breeding grounds for aquatic insects. The location’s coordinates are 44°56’30.34”N and 75°04’16.62”W. Bats left their roosts after 8 p.m. and were occasionally seen flying over their roosts and feeding along the edge of the surrounding woodlands. After some time they would fly to CM or the battlefield site
Can mercury levels in bat species be used as an effective biomarker?  

Tracking was conducted for twelve days. Bats went directly to Crysler’s Farm Battlefield Memorial five times of twelve and to CM on the other days. 

Heavy rain and cold temperatures (17°C) reduced the time bats spent hunting insects. Guano was scarce after evenings of cold and rain. One evening in August a rainfall of 8 mm was recorded. That evening bats flew only for a few minutes and then quickly re-entered their roost. August 24th saw 15.4 mm of rainfall (Climatological Station Reports, 2007), and bats exhibited the same behaviour. Interestingly, the smaller transmitter-fitted bat flew further from the roost than its larger roost companion. She did not stray more than fifty metres from the roost.

Bats from Cornwall Recreational Centre were surveyed for two weeks. A bat captured and banded with tag number 4 at this site was seen feeding over the swamp on two occasions before disappearing into the forest. This sighting confirmed that the bats at the CORA site also began their evening hunts in the vicinity of their roosts. Unfortunately, surveillance efforts at this site were hampered and soon suspended since the woodlands surrounding the CORA bat house were submerged by a metre of water. The path through the woodlands became impassable.

The Big Brown bats roosting in an old house within the city (45° 01’23. 53” N, 74° 43’47. 34” W) and the Little Brown bats found at Cooper Marsh and UPV always returned to their roosts at the end of every night-hunt (between 11 p.m. and 12 a.m.). This behaviour was confirmed 18 days (90%) out of the 20 days of surveillance for Cooper Marsh and 16 days (89%) out of 18 days of bat tracking at UPV. The latest time for bats returning was reported on one occasion at 1 o’clock in the morning from an
individual bat from UPV. The same prototype was noted 19 days (95%) consecutively out of the 20 days of surveillance for the bat tracked at the Cornwall site.

The Little Browns from UPV, tagged with numbers 5 and 7 and radio-transmitter frequencies (173.0210 and 173.0598 respectively), often left from one roost and returned to a different building to sleep during the day. The shelter’s coordinates are 44°56'51.82"N and 75°04'59.00"W. Five times of 18 days of tracking (28%), the bats were detected at that day roost next day, when the insect traps were picked up in the morning.

3.3 Insect Collection

The greatest number of insects captured were mosquitoes, caddisflies, moths, and beetles. The insect collection period yielded approximately 8326 insects as shown in Table 2. The percentage of insects caught per site is noted in Table 3. Adult mosquitoes were collected during the months of June to September. The most abundant mosquitoes collected were *Culex* and *Aedes*. Both types are enzootic and bridge vectors that transmit West Nile virus.

Three hundred caddisflies were captured at the CORA site and four hundred and fifty at the CM sites throughout the season. Forest beetles covered my clothing, hands and work surfaces while I tagged and measured the bats I captured at Cooper Marsh in June of 2007. Forested areas yielded more moths and mosquitoes, as was the case at the CORA and UPV sites with 2275 and 1138 mosquitoes collected. 630 and 490 moths were also captured at the same sites. Mosquitoes predominated at all the sites and throughout June, July and August of 2007. 5615 mosquitoes were captured in total. Mosquitoes captured included *Aedes sollicitans, Aedes stimulants, Culex pipiens* and
Can mercury levels in bat species be used as an effective biomarker?

*Anópheles punctipennis*. Caddisflies were collected in greater abundance at CM (450) and at CORA (350).

Moreover, Table 3 validates that moths and mosquitoes (*Aédes sollícitants* and *Anópheles punctipennis*) dominated the Cooper Marsh site with percentages of 25% and 65% respectively. Caddisflies amounted to only 9% of the catch.

Insects caught within forested areas as at UPV were mostly mosquitoes, namely *Anópheles punctipennis, Aédes stimulants* and *Aédes sollícitants* (65%) followed by moths (34%) and caddisflies (1%). The same mosquito types were collected at the CM site, where they dominated the catch with 66% of the species collected, followed by caddisflies (28%), and moths (6%), as shown in Table 3. Likewise, less than 0.5% of the insects collected with the traps were beetles, stoneflies, mayflies and crane flies. These insects are not noted in Tables 2 and 3.

Mosquitoes were the predominant taxa, comprising 67% of all insects captured at all the sites (Table 3). Moths ranked second with 21% and caddisflies third with 12% of all insects captured.

Greater numbers of caddisflies were captured at the CM site because of the many inlets and ponds, as well as its proximity to the shoreline (about 100 metres). The number of caddisflies (4.3%) from the City of Cornwall site (situated about 2 km from the river) was less than the number caught near the CM (47%). Once again, the proximity of the St. Lawrence River explains their prevalence.

The flooded woodlands of the CORA site meant that mosquitoes predominated at 71% of the total capture (Table 3), followed by UPV (65%) and Cornwall (57%) respectively.
Can mercury levels in bat species be used as an effective biomarker?

The UPV site had the highest percentage of moths collected (34%) followed by Cooper Marsh (26%), CORA (20%), the City of Cornwall (11%), and CM (6%) (Table 3). The remaining 3% belonged to other insects such as stoneflies, beetles and crane flies.

The insects collected varied in size and species depending on weather conditions, habitat (rural or urban) and season. Rising temperatures (~14°C, Climatological Station Reports, 2006-2007) aroused the bats from hibernation at a time when insects became available. Trapping ceased in late September when temperatures cooled (~10°C, Climatological Station Reports, 2006-2007) and insects became scarce.

During rain events the black-light traps were placed under the cover of trees to facilitate insect collection. Nonetheless, the number of insects captured always decreased during rain events. During the month of July in 2006, 127.2 mm of rain fell on Cooper Marsh. The mean temperature was 23.4°C. The number of caddisflies collected at Cooper Marsh decreased by 36% during this time. Only 16 types of insects were collected in comparison to the 25 types of insects captured at Cooper Marsh in June of 2006, when 98.7 mm of rainfall and a mean temperature of 19.7°C were registered respectively.

Fewer caddisflies were collected in July of 2007 (N= 12) than in June of the same year (N= 31) at the Cooper Marsh site. The rainfall reported for July of 2007 was 169.5 mm with a mean temperature of 21.1°C. In June 2007, 48.2 mm of rain fell and a mean temperature of 21°C were recorded (Climatological Station Reports, 2007).

The number of mosquitoes of all types increased following heavy sustained rain events and when temperature remained above 22°C. Mosquito populations increased by
Can mercury levels in bat species be used as an effective biomarker?

25% after rain episodes. Mosquitoes were collected in large numbers after a rainfall (N= 88), while fewer moths were collected (N= 13) for 2006. *Aedes sollicitans* mosquitoes were caught in large numbers (N= 212) and moths in smaller numbers (N= 45) after rainfall periods in 2007. Other types of insects captured (i.e. Beetles) were few in number, at less than 10 for both years.

On September 7th of 2007 a heavy rainfall occurred. During the night the black-light traps at CM site captured a tremendously large number of insects. The traps had been set under trees and bushes to shelter them from the heavy rain. Perhaps the insects were also seeking shelter or hiding from nocturnal predators (i.e. Bats). In the morning, the traps were filled to the brim inside and out with a thick layer of mosquitoes and small beetle like insects. A very strong fish-like odour was emanating from the small green beetles. Insects were more attracted to the lights of the traps during the new moon or when the traps were installed under the shelter of the trees. The influence of light was illustrated during the full moon episodes of June 2007. During a period of hot weather at the end of September 2007 (from CM area) caddisflies and a type of trichoptera with a strong fish smell were especially abundant. “When some species of caddisflies move from an aquatic to a terrestrial phase, then they develop a defensive mechanism of abdominal secretions of p-cresol (indole and skatole are the principal forms) that have this type of smell” (Boydell, personal communication, 2009).

The average temperature during those days was 27º C, with a reported maximum temperature for certain days of 30ºC and 32.5ºC, respectively (Climatological Station Report, 2007). Moths at UPV were especially abundant during the twenty-four clear evenings in the month of August 2007 (Climatological Station Report, 2007).
3.4 Bat Guano Collection

Guano samples mainly came from UPV (1.2 g) and Cooper Marsh (2.3 g) sites due to their settings for guano collection. Cooper Marsh site (Figure 9) had better shelter conditions to collect guano than UPV (Figure 12) during rainfall periods. Little guano was collected (0.3 g) from the Cornwall Recreational Centre because of the flood conditions. The bat guano revealed that caddisflies and moths were the favoured insects at these sites.

Bat droppings diminished during rainy periods. When bat activity decreased guano production diminished accordingly. This proportion is illustrated in Table 4 (Guano Collection by site accordingly with rainfall). As well, when cool temperatures (p.m.) and episodes of heavy rain coincided, guano production decreased even further because bats remained in their roosts. Table 4 illustrates some samples used for insect identification at UPV during the months of July, August and September. The weather conditions shown (Climatological Station Report, 2007) belong to the evenings before the guano collection activities.

Thousands of chewed-up fragments found in the dried guano pellets were in fact bits of insect legs, wings and other body parts. Many of these parts provided effective clues to identify insect types.

The insects captured near the river and the guano samples gathered at the UPV site both held a strong fish odour. The bats whose guano was collected were tracked to feeding areas in the vicinity of the CM during September 2007.

All the guano was collected under optimal conditions. Freshness was a primary consideration since we were able to track the bats to feeding sites and back to the roosts.
The guano contained the remnants of the insects eaten by bats the night before. Only fresh guano was collected and stored for analysis.

Guano collecting led to the conclusion that caddisflies of various types were the most prevalent of all the insects consumed by bats (~40%), followed by moths (~30%) and mosquitoes (~25%). The rest (~5%) corresponded to a mix of other insect types that were not analyzed.

3.5. Mercury Concentrations in Target Species

This section summarizes the mercury concentrations of the bat and insect species. Additionally, it shows the results of the process of monitoring data for mercury, at different locations, time (including yearly values), means and standard deviations. All results are reported as ppm (mg/kg).

The next step incorporated statistical models that were used to see Hg uptake and to appraise the relative importance of Hg exposure routes for the chosen species.

3.5.1 Bat species

3.5.1.1 Bat Mercury Concentration over Time

To assess mercury contamination in the Big Brown and Little Brown bats, their mercury levels were evaluated by site and between both bat species.

I supplemented the existing fur samples from 2006 and 2007 ($N=31$) that I collected, with fur samples collected by Dr. Hickey (St. Lawrence River Institute of Environment Science) between the 2001-2005 period ($N=33$). I analyzed their mercury concentrations. Mercury concentration results from bat fur ($N=22$) previously measured by Hickey (1999-2005) were included in this study.
Based on the 1998-2007 results, THg levels remain at high concentrations in bats species. I compared the Hg concentrations for each bat species tested among these years. There was no significant difference for Little Brown bats ($p = 0.34, F = 1.15, M = 3.56$ ppm (mg/Kg), $N = 54$) among the years. Regarding Big Brown bats, there was a significant difference among the years based on the one-way ANOVA test ($p = 0.03, F = 2.84, M = 4.79$ ppm (mg/Kg), $N = 26$). It is likely that for Big Brown bats, 2000 and 2001 were the years when mean mercury concentrations peaked. The mean for 2001 the period had a value of 10.55 ppm (mg/Kg), $N = 2$, $SD = 7.44$, and the 2000 period had a mean value of 9.28 ppm (mg/Kg), $N = 4$, $SD = 1.82$ respectively.

The comparison among years (1998-2007) showed that contaminant concentrations in bat colonies have increased at some sites and decreased at others without a constant pattern. For further analysis, the data was combined regardless of the years the samples were collected.

3.5.1.2 Bat Mercury Concentration by Species

This study documents the extent of mercury bioaccumulation in bats collected along the St. Lawrence River in Eastern Ontario. Mercury concentrations were high within both bats types (Figure 16). Big Brown bats held the most elevated THg concentrations with a mean equal 5.42 ppm (mg/Kg), $SD = 4.79$ in $N = 26$ and Little Brown bats held a mean equal 3.56 ppm (mg/Kg), $SD = 2.49$ in $N = 54$. Mercury concentrations in both Big Brown and Little Brown varied widely among individuals. The highest concentration in Little Brown bats were 12 ppm and 10 ppm in individual samples; but those found in Big Brown bats were as high as ~16 ppm to ~26 ppm. On
average Big Brown had the highest Hg concentrations. A significant difference between bat species ($p = 0.001$, $F=11.82$) was discovered when used a one-way ANOVA test.

3.5.1.3 Bat Mercury Concentration by Locations.

On the subject of the geographical location factor in mercury concentrations obvious trends were discovered in both bat species. This study reports Hg concentrations of bats living in colonies at five locations (Cornwall, Cooper Marsh, CORA, Pointe Fortune and UPV).

Big Brown bat samples were collected at two sites (Pointe Fortune and Cornwall). The samples gathered from Pointe Fortune held significantly higher Hg concentrations ($M = 12.58$ ppm (mg/Kg), $SD= 5.47$, $N= 3$) than the Hg concentrations of Big Brown bats sampled in Cornwall ($M = 4.49$ ppm (mg/Kg), $SD = 3.94$, $N= 23$) as Figure 17 illustrates. Consequently, $t$-test (two-tailed) revealed a statistically significant difference ($p = 0.004$, $t = -3.219$) for Big Brown bats by site.

The THg mean of Little Brown bats did not differ significantly among sites based on the one-way ANOVA test ($p = 0.653$, $F= 0.615$), as Figure 18 illustrates. However there are trends of Hg concentrations between sites. The Little Brown bats of Cornwall held the highest mercury concentrations among all the bats captured ($M = 4.41$ ppm (mg/Kg), $SD = 2.99$ and $N = 15$). UPV and Cooper Marsh sites followed. UPV and CM are located 40 km west of the AOC. These sites had a recorded mean of 3.35 ppm (mg/Kg), $SD= 2.50$ and $N=16$. Cooper Marsh is situated 20 km east and downstream of the Cornwall AOC, and it had $M = 3.19$ ppm (mg/Kg), $SD = 2.42$ and $N = 12$.

Sites distant from the contaminated zones near the St. Lawrence River held the lowest mercury concentrations among Little Brown bats. The Cornwall Recreation
Can mercury levels in bat species be used as an effective biomarker?

Centre held levels of $M = 3.17$ ppm (mg/Kg), $SD = 1.72$ and $N = 3$. Pointe Fortune held levels of $M = 3.08$ ppm (mg/Kg), $SD = 1.75$ and $N = 8$ respectively.

THg levels in certain individuals were high at upstream sites. In fact, one Little Brown bat from UPV held the highest THg levels found with 10 ppm (mg/Kg), whereas a Little Brown bat captured at the Cooper Marsh site had THg levels of 8.67 ppm (mg/Kg), and an individual captured in Cornwall (AOC site) held a THg level of 8 ppm (mg/Kg).

Certain Big Brown bats held remarkably high THg levels. One of Cornwall’s Big Brown bats held a mercury level of 25.5 ppm (mg/Kg). A mercury level of 20.26 ppm (mg/Kg) was recorded in a Pointe Fortune Big Brown.

3.5.2 Insect Species

In this analysis the $N$ value for insect species refers to a batch and not to the number of insects per sample. The insects are very light. Consequently, many are needed to form a viable sample. The mercury machine requires such a sample to achieve an accurate result.

3.5.2.1 Insect Mercury Concentration by Insect Taxa

Caddisflies held a higher mean mercury concentration than mosquito and moth species regardless of the collection period or geographical location. As illustrated in Figure 19, caddisflies had the highest THg concentrations at all the sites with a mean of 0.15 ppm (mg/Kg), $SD = 0.10$ with $N = 61$. Within most sites the THg concentrations in mosquitoes ($M = 0.07$ ppm (mg/Kg), $SD = 0.03$, $N = 30$) were lower than the mean of the caddisflies, but they were greater than those uncovered in moths. Moths held the lowest mercury concentrations of all the three target insect species ($M = 0.04$ ppm (mg/Kg),
Can mercury levels in bat species be used as an effective biomarker?

$SD = 0.05, N = 41)$. Consequently, significant difference between each insect species was discovered ($p < .001, F= 25.48$) when using the one-way ANOVA test.

### 3.5.2.2 Insect Mercury Concentration by Site

Mercury levels within insect groups differed significantly, depending on the site. Figures 20-22 indicate obvious trends by insect types and geographical locations. All the insect species from CM and UPV were combined after it was determined that there was no significant difference among them. Insect species from these spots had $p$ and $t$ values of 0.864 and 0.174 for Caddisflies, $p = 0.080$ and $t = -2.007$ for mosquitoes and $p = 0.319$ and $t = 1.040$ for moths respectively.

There was a significant difference among caddisflies by site ($p = 0.001, F= 5.94$). The highest mercury concentrations uncovered for caddisflies was detected within the CORA site (Figure 20). This site had a mean of 0.225 ppm (mg/Kg), $SD = 0.13$ with $N = 13$. The Cornwall site was identified as having a mean mercury concentration of 0.170 ppm (mg/Kg), $SD = 0.12$ and $N = 14$. The Cooper Marsh site came in third place with a mean mercury concentration of 0.163 ppm (mg/Kg), $SD = 0.08$ and $N = 18$. The UPV site combined with the CM was the site that held the lowest mean mercury concentration with a value of 0.07 ppm (mg/Kg), $SD = 0.03$ in $N = 16$.

The data for mosquito species was collected using the one-way ANOVA test, having no significant difference ($p=0.158, F= 1.880$). However, it was revealed that mercury concentration testing of the mosquitoes by location (Figure 21) in the north western part of the Area of Concern (CORA) held mercury concentrations of $M = 0.082$ ppm (mg/Kg), $SD = 0.046$ in $N = 9$. Cooper Marsh was next with a mean mercury concentration of 0.069 ppm (mg/Kg), $SD = 0.014$ in $N = 7$. The Cornwall site followed
with a mean mercury concentration of 0.056 ppm (mg/Kg), \( SD = 0.03 \) in \( N = 4 \). Last were the upstream areas (UPV and the beach area of the CM site) with \( M = 0.05 \) ppm (mg/Kg), \( SD = 0.013 \) in \( N = 10 \).

The comparisons made between all the sites for moths in this study revealed that there was no significant difference (\( p = 0.66, F = 0.533 \)). The distribution of mean mercury concentration of moths is illustrated in Figure 22. Cooper Marsh had the highest mean among other sites (\( M = 0.062, SD = 0.09 \) in \( N = 8 \)). It was followed by UPV site (including CM) which had a mean of 0.043, \( SD = 0.06 \) in \( N = 14 \); then by Cornwall (\( M = 0.04, SD = 0.024 \) in \( N = 8 \)), and then CORA (\( M = 0.026, SD = 0.02 \) in \( N = 7 \)), in that order.

Certain individual samples held elevated mercury levels, such as individual moth and caddisfly samples with Hg levels of 0.240 ppm and 0.160 ppm respectively, which were collected at the CM site.

Mean Hg concentrations in caddisflies within my research at different sites had values of 0.21 \( \mu g/g \) (ppm), 0.17 \( \mu g/g \) (ppm) and 0.16 \( \mu g/g \) (ppm) greater than those discovered previously in Eastern Ontario in benthos (0.055 \( \mu g/g \) (ppm) from St. Lawrence River (Richman, 1994) and around the Gulf of Mexico (between 1986 and 1989) that had mean of 0.127 \( \mu g/g \) (ppm) as Presley, Taylor & Boothe (1990) demonstrated.

The levels found within my study in benthic samples were much higher in the St. Lawrence River area. Individual samples from different sites had THg of 0.56 \( \mu g/g \) (ppm), 0.32 \( \mu g/g \) (ppm), 0.29 \( \mu g/g \) (ppm) and 0.17 \( \mu g/g \) (ppm) respectively.
3.5.3 Relationship among Mercury, Bats and Insect Prey

The fur THg concentrations of individual bats from various colonies were analyzed by type of bats and by geographical locations; then these Hg levels were compared with the mercury concentrations of the insects sampled. In order to determine if a significant relationship existed between mercury in Little Brown and Big Brown bat and insect species, correlation Pearson test analyses were applied.

The Mean mercury concentrations from the bats and insects by locations are summarized in Table 5. Overall THg concentrations in insects were greater in sites close to downstream areas (CORA) than any other areas. The insects with the highest levels of mercury at the CORA site were caddisflies followed by mosquitoes. CORA’s mean concentration of mercury in the Little Brown bats did not have greater THg concentrations when compared to the other sites. CORA’s bats ranked fifth among the Little Brown’s sampled and analyzed.

Mercury levels in insects were consistently high at the Cornwall site (AOC), where caddisflies ranked first, followed by mosquitoes, then moths. A comparison of the THg concentrations of all sites revealed that bats of the Cornwall site held greater THg concentrations.

Further, Pearson correlation was calculated to find a relationship among species (bat and insects). The mercury concentrations in Little Brown bats were not significantly correlated with mercury concentrations in caddisflies, mosquitoes and moths (Pearson Correlation Coefficient for all variables was close to zero). In this case, Pearson Correlation Coefficient and their p value using 2-tailed were equal 0.08, \( p = 0.92 \) for
Can mercury levels in bat species be used as an effective biomarker?

Biomagnification factor was not correlated when looking at bats and their insect prey.

3.5.4 Methylmercury Concentration by Caddisflies

Patterns for THg concentrations were significantly higher in caddisflies compared to the rest of the insects collected. Individual caddisflies had THg levels of 0.56 ppm (mg/Kg), and 0.41 ppm (mg/Kg) respectively with a total average of 0.15 ppm (mg/Kg). Methylmercury sampling was performed on a few caddisfly samples in an attempt to determine the percentage of MeHg in insects and to demonstrate any potential relationship within the bat colony. Perhaps the findings could be used for future studies.

MeHg concentrations for caddisflies are summarized in Figure 23- 24. The upstream site of Upper Canada Village had the highest MeHg mean concentration of all five sites tested with 0.28 ppm (mg/Kg). Insect samples gathered at CM and UPV were combined because the bats were feeding in both areas every evening. CORA, Cooper Marsh and Cornwall sites followed with mean MeHg concentrations of 0.23 ppm (mg/Kg), 0.15 ppm (mg/Kg) and 0.14 ppm (mg/Kg) respectively (Figure 23).

Using a one-way ANOVA test, it would seem that the MeHg concentrations in caddisfly species revealed no significant differences by site. In this case $p = 0.798$, $F= 0.338$.

More than 49 percent of the MeHg was present of THg tested at any study site for the species tested. Consequently, it was concluded that MeHg levels in caddisfly species were present an average in a range of ~ 49% to ~ 90 % of THg tested.

The CORA site had the greatest average percentage of MeHg/THg (~ 90%) followed by the upstream sites of Upper Canada Village and CM with ~ 89%. Next was
the downstream site of Cooper Marsh with ~ 58%. Finally, the Cornwall (AOC) site had a percentage of ~ 49.34% (Figure 24).

4. Discussion

4.1 Bat, Insect and Guano Collection

Bat detectors helped me build a general picture of bat distribution, activity and habitat preferences (Nagorsen & Brigham, 1993) with at least some indication of the species present, as Hooper (1966, 1969a, 1969b) demonstrated previously.

At the start of the study it was suspected that bats had preferred feeding locations. Few bats were captured while they fed. Secondly, bats were captured near their roosts and colour tagged them. Tracking them revealed their preferred feeding sites or hunting territories. That was not a surprise since most predatory mammals exhibit such behaviour. Females tend to congregate in nursery colonies that may contain hundreds or more bat individuals, as Nagorsen and Brigham (1993) cited. Both authors added that nursing females roost in almost any natural site that offers the environmental conditions that will promote the rapid growth of young.

Cold and wet weather conditions resulted in light or sporadic activity. Under appropriate temperature conditions (above 10°C), bats usually left their day roosts at dusk. Few bats left their roost to fly about in cool fall temperatures. Only large, strong, pregnant or nursing females who need to eat prodigiously in order to rear their offspring will routinely leave the roost and fly into adverse conditions. This behavior was confirmed in this study during a thunderstorm at the UPV site. Bats at the UPV site flew about near their roost during a heavy rainfall. Nonetheless, numerous tracking events were accomplished during light rain periods. Bat activity declined during rain events,
just as Fenton (1970) demonstrated when he used a Holgate ultrasonic receiver to count the number of ‘passes’ made by bats flying by. His work denoted a significant decrease during rainstorms.

Several studies suggest that changes in light levels govern the nightly departure of bats from their roosts (Fenton, 1983), a behaviour mentioned by Fenton (1983) when predators such as owls and hawks take advantage of the moonlight to hunt bats. Even bats in areas where no predators were seen are less active in bright moonlight.

Bat activity levels varied from one bat to another within the same colony. Adult females, nursing mothers and juveniles all act differently. They use diverse patterns of feeding activity based on their own needs and demands (Fenton, 1983; Hickey, 1992 & Hickey et al., 1996).

Banding allows the discovery of feeding sites and movement among roosts (Constantine, 1967; Cockrum, 1970; Glass 1982). Consequently, using this technique, researchers can gain a great deal of information about bats’ life history, habitats and movements regardless of time of capture, habitats and lifetime (Yalden and Morris, 1975).

Additionally, as Griffin noted “findings from banding studies also documented other aspects of natural history, the annual cycle of reproduction and movements, and regional migrations to hibernacula of bats in the eastern United States, particularly in New England and New York” (as cited in O’Shea et al. 2001, p. 300). Comparatively, Pearson et al. (1952) used banding to show that certain bat species (e.g., Corynorhinus townsendii) made only seasonal movements.
Many bats prefer man-made structures. The UPV colony was established in a bat house purposely installed to discourage bats from entering the storage buildings on the property. The Big Brown bats (females) that were tracked as a part of this study roosted in an older home in downtown Cornwall (Zone 1) in close proximity to an area that Richman (1999) and Dreier (2000) revealed was contaminated with environmental THg and MeHg in sediments.

Many types of bats occupy the same roosts day after day, year after year (Fenton, 1983). The Cooper Marsh colony is an example of such a colony. Day roosts are used to pass daylight hours, and night roosts serve as refuges for eating and digesting between bouts of foraging (Fenton, 1983). Certain factors will encourage bats to modify their roosting behaviour such as temperature and humidity of the site (Richardson, 2002).

“Bats must consume great quantities of food to have the energy, minerals and vitamins to fuel flight” (Nagorsen & Brigham, 1993, p. 13). Large bats usually eat larger insects than smaller bats, as Yadden and Morris cited (1975). Bats acquire their food near lights (Beier, 2006; Rydell, 1992; Blake, Hutson, Racey, Rydell, & Speakman, 1994) and forage over water, where they take in aquatic insects. This latter fact is based on bat tracking surveillance done in this study for the two bat species monitored. Diurnal insects such as butterflies, damselflies and wasps (Yalden & Morris, 1975) do not figure in a bat’s diet. Some insects that did not belong to my group of interest were attracted to the traps. These insects were carefully removed and released.

Likewise, Fenton and Morris (1976) and Bell (1980) indicated that with their experimental ultraviolet lights set up in dark areas insects were attracted and bats came to feed. Illumination (lunar cycle) and whether the night sky was clear or covered were
Can mercury levels in bat species be used as an effective biomarker?

Factors considered when planning insect captures. Success is dependent on background illumination as mentioned by Beier (2006).

The insect trapping efforts revealed a decrease in insects captured during brighter evenings possibly due to decreased flight activity during this phase of the lunar cycle, or from a decreased attraction to artificial lighting as Eisenbeis & Hassel (2000) cited. Evidently, during bright moonlit nights insects do not decrease their activities, as Negraeff & Brigham (1995) and Hecker & Brigham (1999) cited. Moths, in particular, are more active and abundant when the night is brighter (Beier, 2006).

The number of insects captured per trap per night also varied according to weather conditions. Insects were scarce during heavy rains. Equipment malfunction, strong winds and curious animals occasionally left the traps empty.

Great quantities of mosquitoes were present at all the targeted sites. Caddisflies were present at city limits (Cornwall site) probably because caddisflies are attracted to streetlights. Moths were present in less proportion than the rest of insects collected. The abundance or absence of moths in the traps or in the guano could be due to the black-light traps configuration, seasonal abundance or bat feeding preferences.

The percentages of insects captured with the traps did not mirror the percentages of insect body parts found in the bat guano collected during the same period. Mosquito species dominated the insect collection but were third by volume in the guano collection followed by moths in second place. Caddisflies were found in higher proportions than the other two insects.

Previous studies demonstrated that guano provides the researcher with a precise identification of the insects eaten by bats (Tuttle, Benson, & Sparks, 2006). When a
Can mercury levels in bat species be used as an effective biomarker? collector tray is placed under the roost, the droppings of the previous evening contain the remnants of the insects consumed.

Useful insight can sometimes be gained from the odour of the fresh guano. The guano collected at UPV had a very strong fish odour sometimes. The days when the guano had this particular odour the insects captured in the traps emanated the same odour. Insects utilize odour as an attractant for mates and a repellent to predators. Perhaps bats who consume large numbers of a certain type of insect will have its guano marked by the insects’ specific odour. Guano sample odour might be an indication of the bats’ preferred seasonal prey. Perhaps this question could be pursued in future studies (i.e. Pheromones markers in guano).

4.2 Mercury Levels in Species of Concern

This study is the first of this type conducted to date within the province or country. One of this project’s objectives was to shed light on the relationship between mercury concentrations within bats, their feeding sites and within the insects they eat.

The potential transfer of mercury from the local environment to aquatic species then to top predators were factors considered to determine the timing and locations of insect and bat fur collecting efforts, using group comparisons and statistical analysis. In addition, the fact that the samples were randomly selected does give the data statistical validity. Statistical analysis of test results helped to uncover any existing relationship for insects, bat species and their feeding areas.

4.2.1 Bat Predators

Bats are impacted by persistent contaminants because of their position in the food chain and their potential longevity and consequent exposure duration (O’Shea et al.,
2001). Both bat types of this study had elevated mercury concentrations that coincide well with the findings of a study conducted in 2001 by Hickey et al. The bat data collected during previous studies was appropriate for inclusion and comparison to the bat samples of this study (2006-2007).

These results are presented by the graphical representations of mean concentrations of THg in insect prey and bat predators. Mercury moved up the food chain beyond fish-eating wildlife such as loons to levels high enough to compromise and threaten population health. This is cause for concern if bats are as sensitive to Hg as aquatic insects.

THg levels differed significantly depending on the kind of bats and the locations involved. As Philp (2001) and Kamrin (2000) noticed, additional factors influencing susceptibilities comprise characteristics of the chemical (the chemical form of mercury) and the individual exposed, the total dose, the age, the route of exposure, and the time of exposure.

Data showed that mercury concentrations in bats uncovered within this study are greater than the mercury concentrations discovered previously within the region. The mercury levels in bat species were up to ~8 times higher than previous rates. Sample sizes used in my study were much bigger than those employed earlier. That could be a point to consider when doing further bat research.

Mercury concentrations differed between Big Brown bats and Little Brown bats within this research. Big Brown bats had greater levels of mercury concentrations than Little Brown bats as it was predicted. This could be due to their needs to eat insects in greater proportions due to their bigger size. Feeding habitats could be another potential
cause that influenced their mercury intake from zones near AOC. At the same time at these sites Big Brown bats could catch more contaminated insects that have their habitats within the same polluted spots. An alternative explanation for their Hg intake could be that Big Brown bats come back every time to the same contaminated spots near AOC (used as day or night roosts) during their active life, thus being more exposed to local Hg contamination. The current Hg contaminations in Big Brown bats among their sampling sites are significant different.

However, for Little Brown bats the feeding habitats did not alter their mercury concentrations to have a significance difference among sites sampled. Environmental and anthropogenic influences could affect at the same levels the Hg intake, however, the conditions might be similar at these habitats and feeding sites. Still, bat tracking efforts have indicated that concentrations of THg were greater in Little Brown bats captured at Cornwall, when compared with those of upstream sites far removed from known point and non point sources of contamination. Cornwall provided the greatest levels of mercury among bat colonies (Little Brown bats), followed by Pointe Fortune. That could be because the conditions of this contaminated site are ideal and tend to determine bat-feeding preferences.

Additionally, it was discovered that the high Hg concentrations in Little Brown bats collected at upstream areas such as UPV (that encompasses Crysler’s Farm Battlefield memorial and the CM) and a relatively uncontaminated site (Cooper Marsh) were observed at these sites. However, upstream sample areas were discovered with Hg levels higher than those recorded in a downstream site at Cooper Marsh. Conditions in this area may have favoured THg production. For instance, the UPV site is upstream of
known point sources of mercury pollution. The site is located 40 km west of the AOC region. UPV had a recorded mean of 3.35 ppm (mg/L), \( N = 16 \).

It seems that these sites have special characteristics that could be the reason for high Hg levels. For example, contaminated sediment and Hg concentrations in pore water could be potential sources of high mercury levels, and might have significant effects on inputs of Hg affecting the river system, and be a link in the transfer of Hg to higher trophic levels as was noted previously by Delongchamp (2006). Consequently, remedial action should be taken. This demonstrates that at present, mercury accumulation at these two spots needs to be measured using a variety of new biomarkers such as wildlife animals (bats). These issues could be significant to find any differences in bat species at each target site and uncover bat Hg concentrations.

4.2.2 Insect Prey.

During the 2-year period of analysis, concentration of THg at all sites by year decreased with time for insects. Mercury concentrations were highest among caddisflies. Huckabee’s et al. (1979) remarked that the mercury content of aquatic organisms varies greatly among species from the same location and within species from different locations. Contamination of these aquatic species could be attributed to the variety of conditions that induce aquatic species to prefer one habitat over another.

The mean mercury concentration for caddisflies collected near the downstream areas such as Cornwall Recreation Centre, Cornwall city and Cooper Marsh in this order, were particularly high. Moths captured at Cooper Marsh (downstream site) had the greatest mercury loading of all the capture sites. Mercury concentrations in other insects gathered at Cooper Marsh were lower than the upstream areas, but they were still
Can mercury levels in bat species be used as an effective biomarker?  

significantly high. Mercury levels found in the caddisflies could correspond with the mercury levels in the natural and built environment, as previous researchers suggested. Holmes (2005) did a detailed mercury study in the region. His findings were validated from samples taken at Cooper Marsh where high levels of THg and MeHg were recorded in pore water and sediments.

Mercury concentrations in mosquito species were also high within the downstream areas of CORA, Cooper Marsh and Cornwall, followed by the upstream areas of UPV and CM.

In general, mercury concentration in insects vary among insect taxa due to their diverse feeding habitats, where environmental Hg pollution (contaminated sediments) remain a potential source of Hg intake in the river impacting certain species such as benthic invertebrates more than moths that are more abundant at forested areas. Accordingly, these species have being more exposed to higher THg and MeHg levels at these habitats. Therefore, the environmental surrounding will give higher Hg levels to the food web (to top predators as bats).

MeHg analysis revealed high levels in caddisflies. Many parameters need to be taken into consideration to arrive to a definitive conclusion about the factors that could influence mercury contamination in these aquatic insects and/or biota. Some of them could be metabolic rate, feeding habits, mercury speciation and chemical process such as the interaction of mercury with other contaminants in the natural environment (Richman, 1994).
4.3 Relationship among Mercury, Bat Species, Insect Prey and Sites

The variability of mercury concentrations between bat and insect populations was described within this research. One-way ANOVA test analysis was applied to determine if a relationship existed between bat predators and insect prey at all the study sites. The hypothesis validated in this research was the Null hypothesis. No linear association between levels of mercury in bats and mercury levels in insect prey was established. As a result, the possible independent variable (mercury levels in insects) cannot presently predict the dependent variable (mercury levels in bats).

Some individual bats had mercury concentrations great enough to expect toxic effects similar to the ones found in large epidemiologic human studies of mercury excess (Fukuda et al., 1999, Harada, 1995). Levels were similar to those found within carnivores and humans that eat large amounts of contaminated fish that exceed 10 mg/kg (Halbrook et al., 1994; Kehrig et al., 1997). Benthic organisms exposed to high levels of mercury could be affected as well, and their growth rates reduced (by 79% and 80%) as Richman (1994) previously noted. That could be due to their individual habitats and the levels of prevalent mercury contamination. Any of these bat species could be more or less susceptible because of their own specific metabolic rate to the mercury accumulation. Furthermore, the conditions for THg production may have been more favourable at some sites than others, and within species of concern from the same or different sites as trends revealed.

Of particular significance in the Eastern Ontario region are the findings in relation to high levels of mercury contamination (including THg and MeHg) found in insect prey. As noted earlier, the samples tested for MeHg were not numerous, but could be used as
Can mercury levels in bat species be used as an effective biomarker? baseline data or a starting point for further research. The existence of MeHg exposure on all target species could not be determined during this study because time for testing in the laboratory with the testing equipment was not available. More research needs to be conducted for MeHg on all the species.

In short, the existence of environmental mercury contamination, the possible presence of other organic (organisms) contaminants which transform mercury to organic mercury (MeHg), the interaction of mercury with other metals (Richman, 1994), the competing metal and organic material (Luoma, 1977; Bartlett & Graig, 1981), as previous researchers have observed, could be factors that influence mercury contamination in biota and wildlife.

Mercury concentrations found in bats were not related to the levels of Hg in the insects they consume. It was first suspected that the biomagnification process would be explained by the Hg intake by bat predators, but this does not appear to be the case. Therefore biomagnification process alone cannot explain bat and insects Hg contamination at this time. It is difficult to determine whether bat mercury bioaccumulation is caused by feeding habits or if there are other factors or sources of mercury exposure (that were not seen within this study) that affect these species. Attention should be directed in the future to selection of insect species and their habitats that are or could be potentially impacted by mercury pollution that impacts bat species.

The lack of correlation is an indication of other possible factors that are critical in the bioaccumulation of Hg by prey and predators. These factors could influence and impact these species differently. It is possible that some bats were feeding on insects that are more loaded with Hg or the bat feeding sites are more contaminated with Hg.
Can mercury levels in bat species be used as an effective biomarker?

pollution. At these sites could be larger releases of Hg into the adjacent environment and deposited into the water, air and then bioaccumulated at more concentrated levels, being the local species potentially exposed to these conditions.

Alternatively, some bats captured might feed in different spots (relatively uncontaminated spots) and are thus exposed to less Hg. In this case these bats could be less representative of local environmental conditions than the bats that feed within AOC. The possibilities of reveal site-Hg contaminations and as a result demonstrate greater differences in Hg concentration could be incomplete and could not reflect the real conditions. Consequently, any analysis done based on mercury levels of these individual bats could be inaccurate; any possible trend and correlation will be difficult to assess and identify based on these conditions. The insects collected are not a significant predictor of Hg bat contamination at this time. So there are some variations that need to take into account to find spatial patterns to predict the correlation between target species by any of these factors. Any supplementary approach needs to be taken to arrive at a better risk assessment and understand the sources and pathways of Hg to wildlife and their prey.

Based on these results it appears that insect and bat mercury concentrations vary among sites. Possible reasons for the observed patterns include difference among target species in feeding habits, habitats, prey contamination, environmental contamination, and local source of Hg as well as bat traveling behaviours within and away of contaminated areas. In general, there were seasonal differences in abundance and/or scarcity of insect preys that could influence bat feeding preferences and feeding habitats.

In summary even if there is a lack of data relating to mercury concentrations in
Can mercury levels in bat species be used as an effective biomarker?

Sediments, air, water and soil in the upstream reference area; the possibility of a source of Hg contamination among the upstream site (that could magnify Hg concentrations in bat colonies and their insect prey) should not be disregarded. All are possible reasons for the greater Hg concentrations among target species.

While the source of the high concentrations of mercury in insect and bat species cannot be determined at this time, the high mercury concentrations in species detailed in this study are likely a result of mercury environmental contamination from known sources, and not only by possible biomagnifications of the food chain. The number of samples is not as big as other studies of top predators done previously. Still, it is useful to obtain a general idea of the mercury levels of contamination within local wildlife species. Especially when the information relates to a top of the food chain predator, such as a bat.

Having this kind of surveillance on local bat colonies and prey could prevent to conduct the same studies at the identical colonies raising the risk of species and their habitat. This study can be used for comparison purposes and can serve as a basis for expanding research and statistical analysis.

5. Conclusions

Bats are very sensitive to disturbances around their roosts. This fact imposes limitations on those wanting to study them (Nagorsen & Brigham, 1993). No endangered insects or other species at risk were captured or harmed during this research.

During this study it was demonstrated that pregnant females and other adults live with their young and gather in nursery groupings usually close to the roof, as Fenton (1983) cited previously. Males rarely occupy nursery colonies. Females of various ages
Can mercury levels in bat species be used as an effective biomarker?  

were mostly captured.

Radio tracking quickly made evident that bat activity levels are tied to seasonal changes, and that levels drastically decline during cooler evenings. This fact is somewhat expected since the number of flying insects will decline at temperatures below 10°C (Fenton, 1983). Although lactating females often leave roosts in search of food even during thunderstorms (Fenton, 1983), levels of activity decline under these conditions. The number of bats captured during warm weather episodes was eight times greater than the numbers captured during cool temperatures.

During periods of bright moonlight the bat detectors, insect trapping and radio tracking confirmed that bats curtail their hunting activities. Banding and tracking bats with radio-transmitters allowed me to follow them to their preferred feeding sites or hunting territories.

Bats respond to thermal challenges by exploiting different roosts as explained by Fenton (1983). The reduction of bat activity during bright moonlight may be related to a decline in the abundance of insects during bright moonlit evenings (Fenton, 1983).

Bright conditions reduced the effectiveness of the black-light traps as my research revealed during insect collection. During very bright nights or in bright areas, the amount of insects caught with black-light traps decreased probably because the traps went unnoticed by nocturnal insects.

Insect captures were small when temperatures were cool and when it rained heavily. Traps were nearly empty in such conditions. The quantity and variety of insects collected differed from site to site. Moths were found mostly in forests and marsh areas.
Can mercury levels in bat species be used as an effective biomarker?

Mosquito species were abundant in woodland settings and in the proximity of ponds within city limits. Caddisflies were more abundant at woodland and river -front areas.

Early guano collection efforts and the initial microscope observations of insect body parts guided the selection of the insects that would be captured and analyzed for THg content (moths, caddisflies and mosquitoes). Mosquitoes were the most important component of the bat guano samples collected during 2006 and 2007. The abundance of mosquitoes, their rapid reproductive cycle and the configuration of the traps might have contributed to this greater proportion.

These findings support the hypothesis that bat colonies and their prey are exposed to the higher levels of mercury in Eastern Ontario. Findings from this study provided sufficient evidence to confirm that mercury levels in bat colonies (fur) are very elevated at diverse sites, times and species. As well, graphical representation revealed that THg within bat and insect populations showed similar trends in the study period at certain sites. Accordingly, it has to be presumed that mercury levels found in bat hair and insects, gave some indication of the degree of risk that each individual species is exposed to. This would also indicate the possibility of a need to eliminate or at least reduce the exposure to mercury for both predators and their prey.

Big Brown bats had greater mercury concentrations than Little Brown bats. Big Brown bats might be impacted by their environmental surroundings as well as their voracious feeding habits and capacity to absorb heavy metals (THg) as previously cited. This fact was particularly present in the vicinity of the Cornwall site. THg concentrations in both bats sampled and collected near to or downstream of known mercury sources (Cornwall) were higher than upstream areas, suggesting the presence of a source of Hg
Can mercury levels in bat species be used as an effective biomarker?

The mercury levels recorded during this study (10 ppm and 12 ppm, and 15 ppm and 25 ppm) were greater than the levels previously recorded in earlier studies involving local bat colonies done by Hickey et al. (2001) (i.e. 2.0 ppm and 7.6 ppm, and 1.5 ppm for *Myotis lucifus* and *Eptesicus fuscus* respectively).

Mercury concentrations found in mosquito species were higher at downstream sites than upstream areas. Hg concentrations in moths and caddisflies were greater at downstream areas as well. Mercury concentrations in caddisfly species had significant differences among insects collected, and by sites. Based on the positive correlation between mercury found in insect populations gathered from diverse sites, and the environmental mercury contamination present at these locations, it could be postulated that there is a definite link between mercury exposure and levels of Hg in insect populations.

The evidence uncovered in this study suggests that THg and MeHg are prevalent in the natural environment and have the potential to threaten aquatic species, insects and bat colonies. The consistent correlation between mercury in insect species and their habitat is a strong indication that species with mercury-laden habitats are in fact more vulnerable to mercury contamination.

The potential for contaminant concentrations of mercury and MeHg within an aquatic community depends on the prolonged presence of mercury in sediments deposited in the river, environmental Hg and its place in the food chain. Overall, the analysis of MeHg in caddisflies did shed some light on the process of mercury bioaccumulation in insect prey. Even though sample sizes used for MeHg analysis may not be representative of the actual conditions of some areas tested, the MeHg results
Can mercury levels in bat species be used as an effective biomarker? Presented are useful to provide an indication of current conditions within target species and to encourage more research in this area.

Even though this research did not statistically reveal a significant relationship between mercury concentrations in bats and their insect prey, bat colonies are loaded with high levels of mercury from sources other than the insects they consume. The levels of mercury concentration found in bats captured during this study were proportional to the known mercury concentration found in the natural environment for the Cornwall area of concern. Accordingly, it was concluded that the bio-magnification process couldn’t be the only factor that influences mercury contamination in these populations. Mercury levels found in the environment may be another factor that influences the mercury concentrations found in bat colonies. Hence, there is no clear link between mercury in bat colonies and mercury in aquatic insects. More research is needed to make any relationship evident.

Based on research findings, it is possible to conclude that both predator and prey in this research hold elevated levels of mercury within their bodies. All things considered, it appears that the association between exposure to Hg contamination and Hg levels found in these species reflects the influence of local environmental pollution. Local point sources contribute to the formation of MeHg thereby increasing its concentration in the natural environment where bats and insects gather their food, implying an association between mercury levels in living organisms and their respective habitats.

Knowing mercury concentrations in top predators (bats) could help us determine with more precision the mercury concentrations in our natural environment, thereby
Can mercury levels in bat species be used as an effective biomarker?  

Lending support to the assertion that bat species could be used as an effective biomarker in assessing ecosystem health. This study could serve as base for expanding bat and prey research to higher levels of comprehension and statistical analysis.

High levels of local mercury pollution, the bats’ capacity to absorb mercury, repetitive contacts with environmental mercury pollution and consumption of contaminated prey could explain the contamination of the bat with high levels of mercury. Monitoring of bats could provide a first alert of adverse effects from exposure to chemical contaminants in the environment. Findings attributed to bats are more easily extrapolated to humans. More effective monitoring techniques for pollutants and a more in-depth understanding of potential chemical adverse effects (Chapman, 2002) might be achieved.

6. Recommendations

The recommendations in this research were developed from the analysis of issues identified, and analysis of trends with the view to develop resource management strategies. Forming implementation committees and partnerships to conduct comprehensive and sustained monitoring efforts will ultimately provide a clear analysis of ecosystem health. All of the recommendations are focused on utilizing bat colonies as biomarkers to assess the ecosystem’s health status. In this case, these species could provide evidence of increased exposure to contaminants and therefore of possible increased health risk.

Essentially, current research examined the levels of mercury contamination within bat species. The same study proposes expanding research into the field to assess ecosystem health. The additional resources that could be applied in this area of research
would increase the assessment of bat colony risks in the field. Special consideration would be given to monitoring their mercury intake and comparing findings to known environmental mercury concentrations, effectively establishing bat colonies as sensitive biomarkers to particular chemical exposures (THg and MeHg). Further investigation is needed to determine possible factors (e.g. changes in local upstream and/or downstream contaminant loadings) that regulate Hg contaminant concentrations. As well, increasing the size of target sites or other areas where Hg exposure is suspected may determine with more certainty whether there is any correlation between bats and their insect prey by the biomagnification factor.

The use of definitive dose-response relationship that considers any possible confounding factors (complex nature of environmental contaminants) will help to quantify risks. Furthermore, designing effective computer models (Cronin, 2003) could better determine toxic response (s) in a living animals thereby reducing test duplication. It is advised to use the statistical extrapolation method rather than uncertainty or safety factors, when sufficient data are available (Chapman et al., 1998).

In a future surveillance program, particular attention needs to be paid to MeHg testing, especially for aquatic species living near known contaminated sediment zones (caddisflies). Other insects could be taken as controls from diverse sites to see if differences or similarities exist between these levels of mercury and the environmental mercury concentrations (i.e. in sediments), as Nagorsen and Brigham (1993) suggested in their study. Insects could serve as biomarkers of MeHg toxicity. We must consider biological factors, multiple stressors and their interactions to examine the differences in
Can mercury levels in bat species be used as an effective biomarker?

the susceptibilities of target species to the effects of mercury exposure or environmental exposure in general.

On the other hand, further research is needed to determine background mercury levels in the local environment such as upstream areas that are not included in the benchmark research program relating to the Cornwall AOC. Disturbances of these natural backgrounds by toxic contaminants and long-range air transportation of mercury may be one of the sources of environmental mercury contamination.

Moreover, due to insufficient data to adequately assess the effects on the St. Lawrence River ecosystem, much more work and more studies are needed in this area to confirm the actual judgments and assumptions and to protect human beings, wildlife and our ecosystem in general. In spite of this difficulty, carefully designed and properly conducted studies need to be prepared to validate and identify adverse health effects from exposure to chemical contaminants in the environment. A more comprehensive assessment of toxic contaminants in the water column, sediments, bat colonies and their prey is a key part of the monitoring strategy.

Accordingly, these results could be used to design future investigations of chemical sources and their effect on wildlife populations, in order to decrease or eliminate the pathways of mercury exposure. In essence, new epidemiological and toxicological research should seek to define the relationship between exposure and contaminants in media. Guano collection should be undertaken to assess the degree of direct exposure of bat populations and insect preys (Clark et al. 1981).

Outcomes should reveal the associations between diseases and high potency substances thereby reinforcing the scientific underpinning of health risk assessment.
Can mercury levels in bat species be used as an effective biomarker?

The weight of evidence resulting from this study shows that health effects may result from exposure to environmental contaminants such as THg and MeHg. For this reason, more research needs to be made in order to uncover the possible long-term additive effects of toxic contaminants such as MeHg on bats and their prey.

Another goal would be to establish a mercury risk assessment study in wildlife populations and a benchmark research program to examine the levels of contaminants in wildlife species and the biochemical effects of these contaminants (Dreier et al., 1997). As previously stated, there is need for ongoing programs in areas where risks have been identified from environmental data showing high mercury levels in species tested. As Nagorsen and Brigham (1993) noted, high levels of mercury and lead have been found in several bat colonies but their significance is unknown.

In essence, surveillance in areas of concern and areas where high levels of Hg have been found should be pursued, with suitable follow-up action where necessary. Further research that considers multiple exposure and determinants, and which develops new biomarkers that are more sensitive and specific to particular chemical exposures to standardize the environmental exposure databases are needed. Studies must be tailored to geographical regions, incorporate animal welfare and favour multi-species tests (Linthurst, Bourdeau, & Tardiff, 1995).

Generally, the assessments of the levels of total and MeHg were conducted in the targeted locations, where bat and insect populations were monitored during the study period. Therefore, this research distinguished target sites that constitute important roosts to regional bat species. As Fenton (1983) cited, “the speed at which they find new roosts, often to the despair of homeowners, suggests that the availability of roosts can affect the
Can mercury levels in bat species be used as an effective biomarker? 69

The adaptations of bats provide strong evidence of the vital importance of roosts to their survival” (p. 91). For instance, the UPV site is a part of the cultural Heritage of Eastern Ontario. The site is assigned Eco-tourism and economical marketplace values. Another site assigned value within the study area is the Canadian Historical Site known as Crrysler’s Farm Battlefield. Other recreational and tourist spots were vital feeding areas for local bats (i.e. Pioneer Village at UPV, CM and Crrysler Beach Park). Indeed, any development or alteration of these sites will impact the habitat of the bats inhabiting them. Preservation of bat habitats could preserve and maintain the diversity of bat populations and their prey. These insectivorous bats keep the natural environment in balance and reduce local insects such as mosquitoes (recognized as a vector of West Nile virus) and make the historical and tourist sites more appealing.

Decision makers need to be adequately provided with all available information in order to increase their knowledge and influence their decisions in favour of bat and other wildlife populations. Consequently, they could generate new decisions based on risk management, including the protection of bat habitats and foraging areas, and incorporating an adaptive management system for ecosystem restoration that encompasses all phases of a bat’s life history. As well, policies need to be put in place as part of a comprehensive wildlife-protection legislation to legally defend these bat colonies.

For instance, the adaptive ecosystem management system should set priorities and establish strategies for addressing mercury contamination, based on regular and ongoing reviews of scientific information, reports, and any other available information, to diminish uncertainties. As Ahearne (1989) mentioned, “Data gap and areas of significant
disagreement among experts should be disclosed” (as cited in Elliot et al., 2002, p.13). Otherwise, based on knowledge about the risk and benefits that might be changed if the risk is decreased, it may be possible to encourage recovered alternatives ensuring completeness on uncertainty in knowledge about risks and benefits and on management issues as Ahearne et al., noted (as cited in Elliot et al., 2002, p. 156). Nevertheless, these findings need to be shared between interested groups (such as conservation authorities) in order to continue the evaluation of the health risk of wildlife, and then extrapolate the result to humans.

In particular, the adaptive ecosystem management plan should be focused on diverse areas such as natural sites of Hg methylation like wetlands that are sources of MeHg to downstream river and lake ecosystems (Holmes, 2005). Consequently, this information will provide more details and better comprehension about chemical interactions, exposure routes besides food sources such as environmental sources and new pathways.

In general, development and documentation methods should be available to appropriate provincial and local agencies, as well as to the general public in order to implement community- based economic development and biodiversity protection programs emphasizing management at the local (urban and rural) levels, and facilitating the free exchange of information to ensure the effective coordination of actions.

Similarly, a detailed investigation is required to determine the status of wildlife and insect population contamination so the appropriate remedial action can be planned. Remedial action may include regulating the use of pesticides (i.e. organochlorines) for spraying forest and agricultural crops that ultimately diminish bat food supplies, putting
Can mercury levels in bat species be used as an effective biomarker? 71

them and the entire wildlife at risk of ingesting contaminated food. It may also address habitat loss and degradation such as forestry operations, renovation of old buildings that harbour bats (Fenton, 1983) and streetlight intensity that negatively affect bat colonies (Jones & Morton, 1992).

Another issue that urban planners and politicians need to consider is new developments and their role in the sustainability of cities and environmental changes that could fatally affect local bat colonies by destroying their preferred habitat, as mentioned by Fenton (1983).

Above all, assistance must be given to the bat and wildlife populations in order to limit their mercury intake, having a minimal effect on wildlife lifestyle, and thus safeguarding the environment by preserving biodiversity and protecting wetlands and regional Cultural Heritage. Moreover, it is critical to increase awareness on the potential dangers to bat colonies and their prey, as well as expose the surveillance of wildlife population and change humanity’s negative perception of bats to ensure the survival of these nocturnal creatures (Nagorsen & Brigham, 1993).

Incorporating educational strategies and informing the community of the value of biodiversity protection of large and small animals is important for instance, creating awareness that bat colonies can decrease insect pests such as moths that attack gardens, lawns and shrubs. Educational strategies such as these will in the long run, enhance the ability of groups and individuals to understand and participate in risk management activities (Elliot et al., 2002).

Likewise, more detailed examination of these key issues will help identify the science and its role in decision-making; it is necessary to examine the implications of
Can mercury levels in bat species be used as an effective biomarker?  

These findings for ecosystem and contaminant management (i.e., how the science informs management issues/policy). However, as McLain and Lee (1996) and Johnson (1999) point out, there may be “challenges of too much scientific emphasis on models and data acquisition and not enough effort on partnerships, collaboration and communication to make the systems work” (p. 438). Subsequently, it is essential to first identify the key stakeholders (federal, provincial and local governments, first nations, private landowners, and nongovernmental organizations such as conservation authorities) and define their implications. Establishing new incentive programs, coordination and consultation with these key players would be the result.

Involving decision makers and the community, as well as conducting frequent and ongoing public consultation in a bid to find a reasonable compromise to limit mercury intake (Yalden & Morris, 1975) might arise.

Accordingly, enhancements to public awareness to devise local solutions after recognizing the potential dangers arising from mercury contaminations to wildlife, human health, and the environment must be made. As a result, follow up the needs for an ongoing program in areas where risks have been identified.

Assessment of habitat preferences such as roosting and feeding areas throughout monitoring programs, must, therefore, continue in areas where a significant problem has been detected (i.e. the upstream areas of the Cornwall AOC) in order to take corrective actions and initiate mercury surveillance on wildlife population and environment.

Applying the findings of this research to new areas of risk management might protect wildlife, as well as human and environmental health, from the exposure to environmental hazards. Mercury emissions should be reduced with more advanced, safer
energy and disposal technologies, and mercury free consumer products should be encouraged. Focus should also be on developing reliable and widely applicable or transferable approaches and estimates of values for ecological benefits and human health benefits, with particular emphasis on children's health issues and risks from mercury and/or MeHg contamination.
Can mercury levels in bat species be used as an effective biomarker?

7. References


Can mercury levels in bat species be used as an effective biomarker?


Climatological Station Reports. (2006). City of Cornwall Water Filtration Plant. Via email

Climatological Station Reports. (2007). City of Cornwall Water Filtration Plant. Via email

Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Can mercury levels in bat species be used as an effective biomarker?


Wheatley, B. (1979). Methylmercury in Canada: exposure of Indian and Inuit residents to methylmercury in the Canadian environment. Department of National Health and Welfare, Medical Services Branch, Ottawa, Canada.


Yanch, L. (2007). MSc Thesis. Assessing the Spatial and Temporal Patterns of Total Mercury, δ 15N and δ13C in Yellow Perch and their Prey Items form a Contaminated Site, St. Lawrence River, Cornwall, ON.

Can mercury levels in bat species be used as an effective biomarker?

8. Appendix A: Bats, Insects, Guano and THg
Can mercury levels in bat species be used as an effective biomarker?

Table 1

**General Characteristic of Bat collected during 2006 – 2007 Period**

<table>
<thead>
<tr>
<th>Site</th>
<th>Bat caught ID</th>
<th>Year</th>
<th>Tag #</th>
<th>Sex</th>
<th>Mass</th>
<th>Forearm</th>
<th>Transmitter #/Frequency</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooper Marsh</td>
<td># 1</td>
<td>2006</td>
<td></td>
<td>F</td>
<td>7</td>
<td>38.39</td>
<td>111033/173.102</td>
<td>8-May-06</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 2</td>
<td>2006</td>
<td></td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td>8-May-06</td>
</tr>
<tr>
<td>Cornwall</td>
<td># 1</td>
<td>2006</td>
<td></td>
<td>F</td>
<td></td>
<td></td>
<td>111034/173.1410</td>
<td>28-July-06</td>
</tr>
<tr>
<td>Cornwall</td>
<td># 2</td>
<td>2006</td>
<td></td>
<td>F</td>
<td></td>
<td></td>
<td>111035/173.1814</td>
<td>28-July-06</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 1</td>
<td>2007</td>
<td>26</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td>23-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 2</td>
<td>2007</td>
<td>27</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td>23-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 3</td>
<td>2007</td>
<td>28&amp;29</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td>23-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 4</td>
<td>2007</td>
<td>30</td>
<td>F</td>
<td>4.9</td>
<td>37.7</td>
<td></td>
<td>27-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 5</td>
<td>2007</td>
<td>31</td>
<td>F</td>
<td>5.2</td>
<td>36.4</td>
<td></td>
<td>27-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 6</td>
<td>2007</td>
<td>32</td>
<td>F</td>
<td>6.7</td>
<td>40.7</td>
<td></td>
<td>27-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 7</td>
<td>2007</td>
<td>33</td>
<td>F</td>
<td>7</td>
<td>40.6</td>
<td></td>
<td>27-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 8</td>
<td>2007</td>
<td>34</td>
<td>M</td>
<td>4</td>
<td>40.5</td>
<td></td>
<td>27-Jun-07</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td># 9</td>
<td>2007</td>
<td>35</td>
<td>F</td>
<td>5.5</td>
<td>40.7</td>
<td></td>
<td>27-Jun-07</td>
</tr>
<tr>
<td>CORA</td>
<td># 2</td>
<td>2007</td>
<td></td>
<td>F</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CORA</td>
<td># 3</td>
<td>2007</td>
<td></td>
<td>F</td>
<td>8.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CORA</td>
<td># 4</td>
<td>2007</td>
<td></td>
<td>F</td>
<td>12.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPV</td>
<td># 1</td>
<td>2007</td>
<td>5</td>
<td>F</td>
<td>5.7</td>
<td>38.7</td>
<td>#31/173.0210</td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 2</td>
<td>2007</td>
<td>6</td>
<td>F</td>
<td>4.5</td>
<td>36.8</td>
<td></td>
<td>18-Aug-07</td>
</tr>
</tbody>
</table>
Can mercury levels in bat species be used as an effective biomarker?

Table 1 Cont’

<table>
<thead>
<tr>
<th>Site</th>
<th>Bat caught ID</th>
<th>Year</th>
<th>Tag #</th>
<th>Sex</th>
<th>Mass</th>
<th>Forearm</th>
<th>Transmitter #/Frequency</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPV</td>
<td># 3</td>
<td>2007</td>
<td>7</td>
<td>Female</td>
<td>7.1</td>
<td>42</td>
<td>#32/173.0598</td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 4</td>
<td>2007</td>
<td>8</td>
<td>Female</td>
<td>6.7</td>
<td>37.5</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 5</td>
<td>2007</td>
<td>9</td>
<td>Female</td>
<td>5.5</td>
<td>39.6</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 6</td>
<td>2007</td>
<td>10</td>
<td>Female</td>
<td>5.8</td>
<td>38.4</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 7</td>
<td>2007</td>
<td>11</td>
<td>Female</td>
<td>5.5</td>
<td>39.2</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 8</td>
<td>2007</td>
<td>12</td>
<td>Female</td>
<td>5.4</td>
<td>39.2</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 9</td>
<td>2007</td>
<td>13</td>
<td>Female</td>
<td>6.9</td>
<td>37.5</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 10</td>
<td>2007</td>
<td>14</td>
<td>Female</td>
<td>5.9</td>
<td>39.4</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 11</td>
<td>2007</td>
<td>15</td>
<td>Female</td>
<td>5.6</td>
<td>38.6</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 12</td>
<td>2007</td>
<td>16</td>
<td>Female</td>
<td>6.1</td>
<td>39.4</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 13</td>
<td>2007</td>
<td>17</td>
<td>Female</td>
<td>7.9</td>
<td>37.7</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 14</td>
<td>2007</td>
<td>18</td>
<td>Female</td>
<td>5.6</td>
<td>38.4</td>
<td></td>
<td>18-Aug-07</td>
</tr>
<tr>
<td>UPV</td>
<td># 15</td>
<td>2007</td>
<td>19</td>
<td>Female</td>
<td>5.3</td>
<td>38.7</td>
<td></td>
<td>18-Aug-07</td>
</tr>
</tbody>
</table>
Can mercury levels in bat species be used as an effective biomarker?

Table 2

*Amount of Insects captured by Site during 2006-2007 Period*

<table>
<thead>
<tr>
<th>Site</th>
<th>Caddisflies N</th>
<th>Moths N</th>
<th>Mosquitoes N</th>
<th>Total N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornwall</td>
<td>42</td>
<td>14</td>
<td>73</td>
<td>129</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td>150</td>
<td>420</td>
<td>1079</td>
<td>1649</td>
</tr>
<tr>
<td>Cornwall Recreation Centre</td>
<td>300</td>
<td>630</td>
<td>2275</td>
<td>3205</td>
</tr>
<tr>
<td>Chrysler Marina</td>
<td>450</td>
<td>98</td>
<td>1050</td>
<td>1598</td>
</tr>
<tr>
<td>Upper Canada Village</td>
<td>17</td>
<td>590</td>
<td>1138</td>
<td>1745</td>
</tr>
<tr>
<td>Total</td>
<td>959</td>
<td>1752</td>
<td>5615</td>
<td>8326</td>
</tr>
</tbody>
</table>
Can mercury levels in bat species be used as an effective biomarker?

Table 3

*Percent of Insects collected by Site during Monitoring Season*

<table>
<thead>
<tr>
<th>Site</th>
<th>Caddisflies</th>
<th>Moths</th>
<th>Mosquitoes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornwall</td>
<td>33</td>
<td>11</td>
<td>57</td>
</tr>
<tr>
<td>Cooper Marsh</td>
<td>9</td>
<td>25</td>
<td>65</td>
</tr>
<tr>
<td>Cornwall Recreation Centre</td>
<td>9</td>
<td>20</td>
<td>71</td>
</tr>
<tr>
<td>Chrysler Marina</td>
<td>28</td>
<td>6</td>
<td>66</td>
</tr>
<tr>
<td>Upper Canada Village</td>
<td>1</td>
<td>34</td>
<td>65</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>21</td>
<td>67</td>
</tr>
</tbody>
</table>
Can mercury levels in bat species be used as an effective biomarker?

Table 4

**Guano Collections by Site accordingly with Rainfall**

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample number</th>
<th>Date</th>
<th>Total Weight used</th>
<th>Total of weight collected mg</th>
<th>Rainfall mm</th>
<th>Temperature p.m. max.-min / Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Canada</td>
<td># 1</td>
<td>13-Jul-07</td>
<td>0.055</td>
<td>0.140</td>
<td>24-14/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 2</td>
<td>21-Jul-07</td>
<td>0.085</td>
<td>0.230</td>
<td>24.5-13.5/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 3</td>
<td>22-Jul-07</td>
<td>0.185</td>
<td>0.530</td>
<td>26-15/Clear</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 4</td>
<td>5-Aug-07</td>
<td>0.035</td>
<td>0.120</td>
<td>2.8</td>
<td>25.5-14/Clear</td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 5</td>
<td>12-Aug-07</td>
<td>0.075</td>
<td>0.600</td>
<td>30.5-19.5/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 6</td>
<td>17-Aug-07</td>
<td>0.050</td>
<td>0.125</td>
<td>23.5-13.5/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 7</td>
<td>19-Aug-07</td>
<td>0.060</td>
<td>0.155</td>
<td>20-11/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 8</td>
<td>21-Aug-07</td>
<td>0.100</td>
<td>0.275</td>
<td>23.5-8/Clear</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.275</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 9</td>
<td>14-Sep-07</td>
<td>0.165</td>
<td>0.470</td>
<td>26-14/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 10</td>
<td>16-Sep-07</td>
<td>0.135</td>
<td>0.380</td>
<td>17-5/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 11</td>
<td>17-Sep-07</td>
<td>0.09</td>
<td>0.175</td>
<td>20.5-7/Clear</td>
<td></td>
</tr>
<tr>
<td>Upper Canada</td>
<td># 12</td>
<td>18-Sep-07</td>
<td>0.025</td>
<td>0.075</td>
<td>22.5-6.5/Clear</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1.060</td>
<td>3.275</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Can mercury levels in bat species be used as an effective biomarker?

Table 5

<table>
<thead>
<tr>
<th>Site</th>
<th>Cooper Marsh</th>
<th>Cornwall</th>
<th>CORA</th>
<th>Point Fortune</th>
<th>UPV+CM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caddisflies</td>
<td>0.16</td>
<td>0.17</td>
<td>0.21</td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>Mosquitoes</td>
<td>0.07</td>
<td>0.06</td>
<td>0.08</td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>Moths</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td><em>Eptesicus fuscus</em></td>
<td>4.49</td>
<td></td>
<td></td>
<td>12.58</td>
<td></td>
</tr>
<tr>
<td><em>Myotis lucifugus</em></td>
<td>3.19</td>
<td>4.42</td>
<td>3.17</td>
<td>3.08</td>
<td>3.35</td>
</tr>
</tbody>
</table>
Can mercury levels in bat species be used as an effective biomarker?

9. Appendix B: Bat Roosts Feeding Areas, Bat Tracking, THg and MeHg among all Species
Can mercury levels in bat species be used as an effective biomarker?

Figure 1. Cornwall Feeding Areas, Bat Roost, Bat Tracking and Black-Light Traps.
Can mercury levels in bat species be used as an effective biomarker?

Figure 2. Cooper Marsh Feeding Areas, Bat Tracking and Black-Light Traps.
Figure 3. Cornwall Recreation Centre Feeding Areas, Bat Roosts, Bat Tracking and Black-Light Traps.
Can mercury levels in bat species be used as an effective biomarker?

Figure 4. Upper Canada Feeding Areas, Bat Tracking and Black-Light Traps.
Can mercury levels in bat species be used as an effective biomarker?

*Figure 5.* Crysler Marina Feeding Areas, Bat Tracking and Black-Light Traps.
Can mercury levels in bat species be used as an effective biomarker?

Figure 6. Crrysler Battlefield Farm Feeding Areas and Bat Tracking.
Can mercury levels in bat species be used as an effective biomarker?

Figure 7. Insect Black-Light Trap.
Can mercury levels in bat species be used as an effective biomarker?

Figure 8. Cooper Marsh.
Can mercury levels in bat species be used as an effective biomarker?

Figure 9. Cooper Marsh Visitor’s House.
Can mercury levels in bat species be used as an effective biomarker?

Figure 10. Upper Canada Village (Bat House).
Can mercury levels in bat species be used as an effective biomarker?

Figure 11. Cornwall Recreation Centre.
Can mercury levels in bat species be used as an effective biomarker?

Figure 12. Upper Canada Village Service Building.
Can mercury levels in bat species be used as an effective biomarker?

Figure 13. Crysler Marina.
Can mercury levels in bat species be used as an effective biomarker?

Figure 14. Crysler Batterfield Farm.
Can mercury levels in bat species be used as an effective biomarker?

Figure 15. Guano Collection.
Can mercury levels in bat species be used as an effective biomarker?

Figure 16. Summary of Mean ± SD THg Levels among Bat Species.

Note. a indicates that the p < 0.05.
Can mercury levels in bat species be used as an effective biomarker?

**Figure 17.** Mean ± SD THg Concentrations *Eptesicus fuscus* (Big Brown Bats) by Geographic Location.

*Note.* a indicates that the p < 0.0.5.
Can mercury levels in bat species be used as an effective biomarker?

Figure 18. Mean ± SD THg Concentrations *Myotis lucifugus* (Little Brown Bats) by Geographic Location.

Note. b indicates that the p > 0.05.
Can mercury levels in bat species be used as an effective biomarker?

**Figure 19.** Mean ± SD THg Concentration Insect Species.

*Note.* a indicates that the p < 0.05.
Can mercury levels in bat species be used as an effective biomarker?

Figure 20. Mean ± SD THg Concentration Caddisflies Species by Site.

Note. a indicates that the p < 0.05.
Can mercury levels in bat species be used as an effective biomarker?

**Figure 21.** Mean ± SD THg Concentration Mosquito Species by Site.

*Note.* b indicates that the p > 0.05. ±
Can mercury levels in bat species be used as an effective biomarker? 115

Figure 22. Mean ± SD THg Concentration Moth Species by Site.

Note. b indicates that the p > 0.05.
Can mercury levels in bat species be used as an effective biomarker?

Figure 23. Mean ± SD MeHg Concentration Caddisfly Species by Site.

Note. b indicates that the p > 0.05.
Can mercury levels in bat species be used as an effective biomarker?

Figure 24. Percent of MeHg/THg for Aquatic Species (Caddisflies) by Site.