An examination of mercury concentrations in white perch, yellow perch, and white sucker in Cumberland and Guysborough Counties in Nova Scotia

By
Carolyn Stevens

A Thesis Submitted to
Saint Mary's University, Halifax Nova Scotia
In Partial Fulfillment of the Requirements for
the Degree of B.Sc. Honours in
Environmental Science.

April 22, 2014, Halifax, Nova Scotia

Supervisor: Dr. Linda Campbell

Reader: Dr. Colleen Barber

Abstract

An examination of mercury concentrations in white perch, yellow perch, and white sucker in Cumberland and Guysborough Counties in Nova Scotia
By: Carolyn Stevens
Date: April 22, 2014

Mercury concentrations in the environment have been a growing concern globally due to the inherent health risks associated with mercury exposure. Concentrations are of importance due to the impacts on the natural environment and the eventual impact on human and wildlife health. An organic form of mercury, methylmercury, is able to easily bioaccumulate and biomagnify in tissues of organisms. In Nova Scotia, much research has been done in the Kejimkujik National Park on fish and waterfowl; however, relatively little has been done to further an understanding of mercury concentrations in aquatic food webs throughout the rest of the province. For this study, we focused on mercury concentrations in three species of freshwater fish from four lakes which were Gilbert and Mattatall (Cumberland County), and Lochiel and Pringle (Guysborough County). *Perca flavescents* (yellow perch), *Morone americana* (white perch), and *Catostomus commersoni* (white sucker), were analyzed to determine the mercury concentrations of these species and compare how they differed among species and lakes.

Mercury concentrations in all three species exceeded Health Canada's marketing limit of 0.5 ng/g. The trends for white perch and yellow perch remained fairly consistent with significant and positive correlation between length and THg concentrations. These trends occur as the species grows and begins consuming other fish and elevating its position in the food chain. However, white sucker did not show a significant relationship between length and THg concentrations which may be due to consistent diet throughout its life regardless of its size. The THg-length trends differed significantly among lakes, meaning that other variables, such as the complexity of the food web and availability of food, could play a role.

Acknowledgements

I would like to start by thanking my supervisor Dr. Linda Campbell. She was very patient, kind, and supportive throughout the process and worked with me to overcome challenges both within the project and outside. I was lucky to have such an understanding and positive individual to support me through this process and allow me the chance to apply my skills and broaden my field of knowledge. Thank you for allowing me this opportunity.

I must also extend my sincere thanks to Jason LeBlanc and the staff at Nova Scotia Fisheries and Aquaculture. The help provided with collecting the fish species and providing information about each lake was invaluable to this project.

Finally, the research for this paper would not have been possible without the funding from the Nova Scotia Fisheries and Aquaculture Freshwater Fisheries Research Cooperative (FFRC) Funding program), an National Science and Engineering Research Council (NSERC) Discovery Grant, and the Student Employment and Experience Program (SEEP) summer stipend funding from Saint Mary's University.

Tables of Contents

Introduction

Mercury Sources:

Mercury (Hg) is an element that occurs naturally in the environment with much of the global mercury sequestered in rock formations and soils. Processes such as weathering and erosion will lead to the release of mercury from geological and soil sources. However, humans have escalated this process exponentially.

It is believed by some that atmospheric concentrations of mercury have been increasing by approximately 0.6% over the century (Fitzgerald, 1995; O' Driscoll et. al., 2005) while others believe that number is closer to 1% (Watras and Huckabee, 1994; O' Driscoll et. al., 2005). Certain forms of mercury, such as Hg(0), can have an approximate lifetime in the atmosphere of one year (Selin et. al., 2007; Sunderland et. al., 2008) allowing ample time for mercury deposition to occur far from the original source as it travels within the atmosphere. This deposition is triggered through oxidation processes and returns to the land in a wet or dry form (Ethier et. al., 2008). As a result of this ongoing deposition, "the atmospheric emissions of mercury have a direct link to the cycling of mercury in watersheds" (O' Driscoll et. al., 2005). With the increases in atmospheric mercury, regions that were not prone to higher mercury concentrations from bedrock geology and mining have seen large increases in recent decades.

Mining is a globally widespread common point source for release of anthropogenic mercury into the environment due to the extraction of ore containing mercury, and the use of mercury in the extraction of specific types of elements. The main example is artisanal and small-scale mining (ASM) for gold. Mercury amalgamation through adding mercury to the creushed ore to extract gold is one of the most common ways utilized by ASM to obtain the gold ore. (Veiga et. al., 2006). In the process, mercury is combined with ore to create an amalgam that

dissolves to remove the gold from the ore and silt. The mixture is heated to evaporate the mercury leaving the gold behind. This can be used as an inexpensive and simple process, which makes it ideal for ASMs (Zolnikov, 2012; Veiga et. al., 2006). After the extraction, the mercury has either been burned off or left in tailings piles. If not properly secured, covered, or contained, mercury compounds after extraction can easily enter the surrounding environment as leachate from the tailings pile as a result of an introduction of water to the pile, or by the processes of weathering and erosion. These processes allow the toxic mercury to seep into the soil, enter aquifers, and become a part of run-off into surface water bodies.

Nova Scotia had numerous gold mines in operation from the 1860s to approximately 1945. Elemental mercury was used in the process of extraction of gold from mined ore. During this time, it is estimated that there was approximately 6800kg of Hg left in tailings piles as a result (Wong, Gauthier & Nriagu, 1999). Over time, the mercury was able to enter into the surrounding environment and contaminate the water, soils, and harm and kill living organisms (Wong, Gauthier & Nriagu, 1999). The majority of gold mining occurred in the Meguma Terrane of Nova Scotia, which spreads from the southern tip to the Cobequid-Chebucto Fault (Ryan & Smith, 1998). However, in this particular study the lakes were selected away from any documented gold mine sites, meaning that the majority of observed mercury levels would be related to atmospheric deposition as opposed to mining operations.

Types of Mercury and Bioaccumulation:

Mercury can exist in either an inorganic or organic form. The majority of the mercury found in biological organisms would be methylmercury. Methylmercury (MeHg) is an organic form of mercury which is toxic and bioaccumulates in living cells and tissues (Environment

Canada, 2013). The term "total mercury" (THg) is used to indicate the total amount of mercury, which includes all mercury compounds analyzed within environmental matrices. In tissue of an organism, the proportions of inorganic mercury is typically low enough (5 to 10%), such that THg in biological tissues consists mostly of MeHg (Wiener et. al., 2003; Wyn et. al., 2010; Chumchal et. al., 2011; Depew et. al., 2013). THg analyses are relatively inexpensive and straightforward relative to MeHg analyses, so often is used more often in the scientific literature.

Bioaccumulation occurs when a substance, such as mercury, accumulates in the living tissue of biological organisms. The process of bioaccumulation depends on the organism, chemical make-up of the organism and substance. The process of bioaccumulation can lead to biomagnification when an organism with bioaccumulated mercury is ingested by another organism higher in the trophic level, resulting in increased mercury concentrations in that higher-trophic organism (Environment Canada, 2013). Methylmercury biomagnifies depending on the initial concentration entering the food web and the trophic position of organisms (Environment Canada, 2013). As a result, mercury concentrations that may have been at a tolerable level in a lower trophic level organism may exceed recommended guidelines organisms at higher trophic levels.

Health Impacts:

When MeHg enters aquatic food chains, aquatic species and subsequent predators become at risk from elevated mercury via bioaccumulation and biomagnification. Due to the highly toxic nature of methylmercury, increased MeHg can lead to a wide array of negative health impacts on the living organisms. Mercury in the water and sediments of water bodies can be toxic to the benthic communities, cause a loss of habitat and abundance of fish species, and

have a resulting negative impact on humans ingesting fish from these contaminated areas (Wong, et. al., 1999).

There are a variety of negative impacts that can befall organisms in an aquatic setting. Mercury can remain associated with suspended particulates in the water column or settle into the sediment. When in the sediment, Hg can impact benthic species that lay their eggs in these areas (Akearok, et. al., 2010). MeHg can be taken up by plants and fish species. Elevated MeHg can then affect reproduction rates and health of many species. Bird species may consume fish species containing large amounts of mercury which then biomagnifies in their own bodies and can be transferred to their eggs (Akearok, et. al., 2010).

Impacts of higher concentrations of mercury in humans and wildlife can be divided into acute and chronic symptoms. For humans, after three to five hours of high exposure, several negative symptoms can develop such as coughing, lethargy, fever, and more (Langford & Ferner, 1999). When chronic exposure at sufficiently high concentrations occurs, changes are seen mainly in the nervous system and the kidney. Tremors begin at a smaller scale and continue until it affects handwriting and causes the individual to have little control of their limbs to perform even the simplest of tasks (Langford & Ferner, 1999).

Perhaps the most well-known example of the negative impacts of methyl mercury contamination in humans would be in Minamata Bay in Japan where effluent contaminated with mercury from an acetaldehyde factory was discharged over a thirty year period until 1965 (Tomiyasu et.al, 2014). Ocean water, sediments, and marine species along the Minamata Bay coast were heavily contaminated by the factory discharges. When the aquatic species that were contaminated by the ocean water and sediments were consumed by humans, it had terrible consequences. People living in fishing villages and the City of Minamata have diets high in fresh

seafood, so mercury accumulated to the extent that severe birth defects and neurological effects were among the consequences. This was termed "Minamata disease". As of 2000, the number of individuals affected by the methyl mercury from the Minamata Bay region was recorded at 2264; however, it is believed that approximately 200,000 individuals have had some form of mercury poisoning (Ekino et al, 2007).

The Minamata disaster led to increased global awareness of the impacts of elevated mercury concentrations and sparked many regulations and policies. Due to the involvement of fish in most Canadian, and especially Nova Scotian, diets, Health Canada has recommended a "marketing limit" of 0.5ppm total mercury in fish fillets (0.5mg/kg) (Health Canada, 2007).

Study Lakes

While much mercury research has occurred in the southern section of Nova Scotia, with emphasis on Kejimkujik National Park in Yarmouth County (d'Entremont et. al., 1998; Carter et. al., 2001; O'Driscoll et. al., 2005; Wyn et. al., 2009; Burgess et. al., 2005), the rest of the province remains relatively understudied. We examined mercury trends for key fish species from three lakes in the northern portion of the province (Figure 1), Lochiel (LO) and Pringle (PG) lakes located approximately 10km from each other in Guysborough County in the Meguma terrane, and Mattatall (MA) and Gilbert (GI) lakes located in Cumberland County in the Avalon terrane (Figure 1). Due to the different geological terranes in Nova Scotia, knowing where the lakes are located and which bedrock geology each lake is situated upon is of great importance (Figure 1).

Mattatall has one invasive species. Smallmouth bass were introduced into Nova Scotia waterways back in 1942. Over the years the species has spread throughout the province to

occupy all but five of the eighteen counties (LeBlanc, 2010). Smallmouth bass have become a popular sport fish (Halfyard, 2008).

Species of Interest:

The white perch (WP) *Morone americana* is found throughout Nova Scotia living in fresh water; however, observations have been made of the white perch migrating towards the sea in the summer (Livingstone, 1951). In general, white perch have a broad diet and are often opportunistic with feeding habits ranging from plankton, to invertebrates, and other fish species (Zuerlein, 1981; Stanley & Danie, 1983; Parrish & Margraf, 1990) including eggs of other fish species (Schaeffer & Margraf, 1987). While the preference of the white perch appears to be benthic organisms, older and larger fish can be piscivorous should the opportunity arise (Parrish & Margraf, 1990).

The yellow perch (YP) *Perca flavescens* is found throughout Nova Scotia and lives in freshwater bodies. This species has a similar diet to that of white perch (Prout et. al., 1990). Yellow perch consumes zooplankton, benthic organisms, and other fish species (Parrish & Margraf, 1990). This species is a popular sport fish (Livingstone, 1951).

The white sucker (WS) *Catostomus commersoni* is found throughout Nova Scotia and lives in freshwater bodies. It feeds off of benthic organisms such as molluscs and insect larvae by using its large mouth to strain organisms from the benthic zone. White suckers are deemed mature after reaching 10-13cm in length (Livingstone, 1951).

Objectives:

The purpose of this analysis is to focus on three resident native species that remain in the lake year-round: yellow perch *Perca flavescens* (YP), white perch *Morone americana* (WP), and

white sucker *Catostomus commersoni* (WS), to determine the THg concentrations in muscle tissue, and how levels compare with other areas of the province.

Methods

Study Sites:

Lochiel (45.345631,-62.059193) and Pringle (45.376267,-61.950631) are both located in the Horton Group along the pre-existing fault line. Lochiel has a surface area of approximately 129.2 ha while Pringle is 62.7 ha. Mattatall (45.696948,-63.47198) is a part of the Pictou Group's Balfron Formation with fluvial sandstone, conglomerates, floodplain mudstone, and rare lacustrine limestone (Figure 1). Mattatall has a surface area of 106.8 ha. Finally, Gilbert (45.47542,-64.341223) is a part of the Cumberland Group where the bedrock consists of fluvial sandstone, calcrete limestone, conglomerates, and mudstone (Keppie, 2000) and has a surface area of 22.7 ha. All of these lakes have a relatively higher pH (7.0 to 7.4; Table 1) in contrast with the acidic pH concentrations reaching 4.5 in some lakes of Kejimkujik NP. Bathymetry maps can be found for Gilbert, Lochiel, Pringle, and Mattatall (Figure 2).

In Guysbourgh, Pringle Lake has many new cottages built right along the shoreline with the majority of the vegetation removed. As a result, there appears to be an issue with severe erosion. There was a small park with some picnic tables nearby along one of its shores, indicating human activity. Lochiel was located next to a highway and had several gravel roads surrounding the lake (Figure 2). In addition, there is some development around one shoreline, with a small protected park along the other shoreline next to the road. In Cumberland, Mattatall is quite developed and is highly popular with recreational anglers. However, most properties preserved shoreline plant cover with many trees along the shoreline. Gilbert likely experienced the greatest anthropogenic effects, as it was surrounded by a large blueberry farm, ATV trails and cottage development.

Field Sampling:

Lakes Lochiel and Pringle were sampled on May 30th and May 31st respectively while Mattatall and Gilbert were sampled on June 10th and June 11th in collaboration with the Nova Scotia Department of Fisheries and Aquaculture. The fish were collected by various means including overnight monofilament gill nets with 1", 1.5", and 2" mesh sizes, as well as single and double wing fyke nets placed in the evening and retrieved in the early morning.

While the nets and fish were collected, a clean area was prepared for processing. Sheets of aluminum foil were cut beforehand and the cutting boards and knives were cleaned in a laboratory using soapy water, followed by reverse osmosis (RO) type 3 water and type 1 ultrapure water. Aluminum foil was used in order to allow fish samples to be tested for other elements and components in the future as desired. Clean unused garbage bags were placed on a flat surface to reduce contamination and provide a clean work space.

Collected fish were initially weighed to the nearest gram and measured for total length with a fish measuring board (Table 2 and Table 4). Once measured, each fish was checked for gender and stomach contents, and then filleted using sterilized stainless steel disposable safety scalpels. The fillets for each fish were laid on a sheet of aluminum foil with the muscle tissue touching and skin and scales on the outside touching the aluminum foil. Care was taken to reduce the contact of muscle tissue with aluminum foil as it was wrapped into the aluminum foil. Finally, each sample was placed in a labelled, sterilized whirl-pak sample bag and placed on ice until transfer to laboratory freezers.

Sample Preparation:

In order to reduce contamination of the samples, clean laboratory procedures were followed. Prior to sampling, laboratory spaces were cleaned from the topmost shelves to the ground to remove dust and dirt. Clean, closed-toed footwear was required to enter the laboratory and access was restricted to reduce outside contaminants. Borosiliciate 20-mL scintillation vials, cutting boards and non-metallic instruments needed for sample processing were placed for 24 hours in an acid bath with approximately 20% nitric acid in ultrapure water, then a secondary bath of ultrapure water, and rinsed three times each with ultra-pure and RO water, then dried overnight in a reserved drying oven. Cutting implements and the cutting board used to process fish samples were rinsed between samples with approximately 20% nitric acid and ultrapure water using an ultra-trace quality polyester knit cloths. Fish were processed by lake, then by species to minimize cross contamination. Species were processed in ascending order through the food web, starting with the smaller fish and ending with the largest. This was done to reduce the risk of carryover of elevated mercury from the higher to lower trophic levels.

After the muscle tissue was removed from each fillet, all muscle tissue were dried in a drying oven at low temperatures (between 50°C to 57°C) for approximately two – five days, depending on the number of samples in the oven at once, and the level of fattiness in the muscle tissue.

Once dried, the tissue was broken down further into smaller pieces to fit inside 2.0mL trace-metal quality microcentrifuge tubes. These were filled approximately halfway, depending on the amount of sample within the scintillation vials. The 2.0mL vials were then placed in the drying oven again for one day to ensure that the tissue was thoroughly dried and easier to grind. When the samples had been fully dried, they were prepared for grinding. Each 2.0mL tube had

two 5-mm ultra-trace-quality zirconium oxide balls added and ground using a Retsch MM400 mixer mill. The samples were run at 25.0 hertz per second for 10 minutes. If many unground pieces remained after the first round of grinding, the samples were ground again at the same rate for the same time interval. The zirconium oxide balls were removed from the powdered samples and washed using water and soap, then tap water, RO water, and finally ultrapure water before using for the next set of samples.

Ground samples were taken to a separate lab and placed in a dessicator with anhydrous "Drierite" brand desiccant crystals with ≥98% $CaSO_4$ and <2% $CoCl_2$. The caps were left open for one or two days to reduce the moisture content in the samples. Once dried, samples were left in the desiccator until analysis through the DMA-80 (Direct Mercury Analyzer).

Analysis of Samples:

A "run" on the DMA-80 machine consists of 40 slots, which hold quartz "boats" which are sample containers. Approximately 0.01 mg of sample or quality control materials were weighed out in each boat for analyses by combustion in the DMA. Quality control protocols included standards, blanks, duplicate samples and certified reference materials (CRM). Several CRMs were used at the beginning of the runs including lobster hepatopancreas for trace metals (TORT-2), dogfish protein for trace metals (DORM-3), and dogfish liver for trace metals (DOLT-4). In-house fish sample replicates from Lake Ontario (10307 and 11142a), Pringle lake white sucker 7 (PGWS7), Mattatall brown bullhead 4 (MABB4), DORM-3, and DOLT-4 were used at the beginning, end, and throughout the run to act as a way of monitoring any fluctuations within the system and mercury levels (Appendix Table 5). Trace metal protocols were observed throughout all laboratory processing and analyses.

Statistical Analysis:

The data was analyzed by comparing the THg concentrations (mg/kg) and length (cm) for each species across each lake. A linear regression was taken for each set of data for each lake to determine the change in mercury levels with increasing fish size. The regression gave the equation for the trend line to determine its slope, as well as providing an r^2 value to establish how accurately the trend line fit the data points. Finally, an analysis of variance (ANOVA) was run for each species to determine how similar the trend lines were within each species among the four lakes. A p-value of less than 0.05 would show a significant difference between the trend lines for each lake within the same species.

Results

Mercury concentrations in all sampled fish (Table 2) exceed the 0.5 mg/kg guideline for commercially sold fish (Health Canada, 2007), and are within similar ranges to those sampled in Kejijumjuk National Park (d'Entremont et. al., 1998; Carter et. al., 2001; Wyn et. al., 2009; Burgess et. al., 2005).

Mercury concentrations tended to increase with length for white perch and yellow perch in all lakes (Table 3), indicating that larger fish of both species are consistently higher in THg (Figures 4 and 5). Both white perch and yellow perch showed an increase in total mercury as the length increased and a linear regression showed the increasing slopes of the trend lines (Table 3, Figures 4 and 5). This is the expected trend for the bioaccumulation of mercury within the muscle tissue. There was a lack of significance for among-lake trends for white perch. For yellow perch, there was a significant difference among lakes, due to the steep slopes (slope value = 0.2882 and 0.3060) present in Gilbert and Pringle, with more shallow slopes (slope value = 0.1360 and 0.1731) for Lochiel and Mattatall (Figure 5).

Data for the white sucker proved to have very different trends from those observed in the other two species. While the white suckers of Lochiel and Mattatall followed the normal trend of increasing THg with length, Pringle's trend line lay almost flat and Gilbert saw a decrease in THg with an increase in total length (Figure 6). Therefore, significant differences for mercury versus length regressions between the lakes were observed.

Discussion

Each fish species did not show consistent differences in average THg concentrations between each lake: yellow perch did have consistent increasing trends and white sucker often followed opposing patterns relative to that of white perch (Figure 4). There are a number of key factors which could contribute to those patterns. The significant trends in mercury with the total length of the fish follow a standard assumption of increasing mercury concentrations with size. White perch and yellow perch will often undergo dietary shifts to consume more and larger fish as they grow larger (Zuerlein, 1981; Stanley & Danie, 1983; Parrish & Margraf, 1990). As this happens, the larger fish is able to occupy a higher level in the food chain of the ecosystem compared to smaller individuals of the same species. This can lead to increased biomagnification rates and lead to higher concentrations of mercury and trends towards increasing mercury with fish size (Environment Canada, 2010). On the other hand, white sucker does not exhibit these same trends for each lake, and in fact appears to have steady mercury concentrations regardless of size. This could be due to differing dietary habits and the different food chains present in each of the lake settings. An in-depth analysis into the structure of the food web in each of the lakes would have the potential to reveal the cause for these differences (L. M. Campbell, pers. data).

Lochiel and Pringle lakes are located within ~10km of each other and share the same bedrock geology; however, Lochiel tended to have much higher concentrations of THg than Pringle for white perch and white sucker (Table 2). One possible cause could be due to anthropogenic impacts. As mentioned earlier, Lochiel may potentially have a greater amount of exposure to anthropogenic effects than Pringle. Lochiel has a highway along one shoreline and several gravel roads surrounding its shore with little to no tree cover between the roads and the water surface. Pringle on the other hand only had only had a small park with a sitting area by one

of the shorelines; however, it still had substantial tree cover surrounding the lake. Another possibility could be eutrophication resulting in algal biodilution of mercury prior to transfer up the food chain in Pringle Lake which was much more eutrophic than Lochiel Lake with higher chlorophyll concentrations (Table 1) (Pickhardt et. al., 2002). In Nova Scotia, a similar study in Kejijumjik National Park showed that mercury biomagnified at slower rates in more eutrophic lakes (Wyn et. al., 2009).

Gilbert and Mattatall are located in the same county; however, they are on opposites sides of the county (~93km apart) and in different geologic areas. For white perch the two lakes share a similar trend of increasing THg with length (Figure 4). With yellow perch, the trendline is shallower for Mattatall than for Gilbert by 0.2374 (Figure 4 and Table 3). Finally, the opposite occurs for white sucker with Mattatall having a steep upwards slope and Gilbert showing a decrease in THg with length. This could be due to the dietary habits of the white sucker species within Mattatall Lake; however, an in-depth food web analysis would need to be done to determine this and is in the process of being analyzed (LM Campbell, pers. data).

Most mercury research in Nova Scotia been conducted in Kejimkujik National Park with long-term studies of mercury trends in Common loon and yellow perch since the 1990's (Wyn et. al., 2010; Burgess, Evers & Kaplan, 2005). In addition to this, Kejimkujik lies in the Meguma terrain which tend to have lakes with higher acidity, and had gold mining occurrences and activities in the past (Ryan & Smith, 1998) raising concerns about elevated mercury concentrations in that region. However, comparatively little data have been gathered on other areas in Nova Scotia with only a few exceptions (Parsons et. al., 2012), making the data collected in this study of great importance to better understand mercury trends for the rest of the province.

The yellow perch is one of the most studied fish species in Kejimkujik National Park. The mercury concentrations for yellow perch in this study are well within the range of data collected in Wyn et. al., 2009. The concentrations range from an average of 0.96 mg/kg, like Mattatall, to 2.26 mg/kg like Gilbert and Pringle (Table 2). Alternatively, older datasets from Kejimkujik lakes (Carter et. al., 2001) indicate substantially lower fish THg concentrations with an average across all the Kejimkjik lakes of 0.25 mg/kg and no value reaching above 0.46 mg/kg. This indicates that the fight THg concentrations from Cumberland and Guysborough (Table 2) may be significantly higher than some of the water bodies in Kejimkujik, which is a surprise because the higher pH of those lakes had led to the hypothesis that mercury concentrations would be lower than those from Kejimkujik..

The mercury concentrations in white perch were also studied in Kejimkujik National Park and like for yellow perch, a similar pattern emerged. Average THg concentrations for Kejimkjuik white perch ranged from 0.78mg/kg – 1.22mg/kg (d'Entremont et. al., 1998), which is much lower than the more elevated concentrations (1.77mg/kg – 3.56mg/kg average) for the four lakes in this study. Those trends for yellow perch and white perch indicates that there may be other factors contributing to the higher concentrations of mercury found in the white perch in the other half of the province other than acidity increasing the bioavailability of mercury.

Conclusion

Mercury contamination is a growing concern in the world as humans develop a better understanding on its effects in the environment and to the human species. It is for this reason that greater amounts of time and research are being placed on better understanding the movement of mercury through the food chain and throughout the environment. This underlies the necessity of continuing this important research by expanding available databases and spreading the focus of mercury analysis.

While a lot of research has been conducted in Kejimkujik National Park, there are other areas of Nova Scotia that differ greatly from Kejimkujik, and have different geologies, acidities, and species. For this reason, it is necessary to continue to expand the research other regions of Nova Scotia to hopefully create a dataset for the province that will aid in the understanding of mercury flows in Nova Scotia.

Due to the risks involved with consuming large concentrations of mercury, having a firm grasp on the expected concentrations in fish across the province would not only help to understand and assist native species, but will also help to protect humans and wildlife from the negative consequences inherent in mercury poisoning. Many Nova Scotians enjoy fishing and sport fishing is popular in the region. Having a better understanding of what is in the species that are being fished for will help to protect fishers and their families from unknown contaminants.

Gaining the knowledge of mercury content in aquatic species would also aid in creating new policies to make the necessary changes to further reduce mercury pollution and ensure that mercury levels stay within safe levels for humans and the natural environment.

References

Akearok, J. A., Hebert, C. E., Braune, B. M., & Mallory, M. L. (2010). Inter- and intraclutch variation in egg mercury levels in marine bird species from the Canadian Arctic. *Science of the Total Environment*, 408, 836-840.

Alexander, D., Kerekes, J., & Sabean, B. (1986). Description of Selected Lake Characteristics and Occurrence of Fish Species in 781 Nova Scotia Lakes. *Nova Scotian Institute of Science, 36*, 63-106.

Burgess, N. M., Evers, D. C., & Kaplan, J. D. (2005). Mercury and other contaminants in common loons breeding in Atlantic Canada. *Ecotoxicology*, 14, 241-252.

Carter, J., Drysdale, C., Burgess, N., Beauchamp, S., Brun, G., & d'Entremont, A. (2001). Mercury concentrations in yellow perch (*Perca flavescens*). *Parks Canada-Techincal Reports in Ecosystem Science*, 031.

Chumchal,M.M.;Rainwater,T.R.;Osborn,S.C.;Roberts,A.P.; Abel, M. T.; Cobb, G. P.; Smith, P. N.; Bailey, F. C. Mercury speciation and biomagnification in the food web of Caddo Lake, Texas and Louisiana, USA, a subtropical freshwater ecosystem. *Environmental Toxicology and Chemistry*. 2011, 30, 1153−1162.

d'Entremont, A., Carter, J., Burgess, N., Drysdale, C., Brun, G., & Beauchamp, S. (1998). Mercury concentrations in brook trout and white perch from Kejimkujik National Park, Nova Scotia. Report to Parks Canada.

Depew, D. C., Burgess, N. M., & Cambell, L. M. (2013). Spatial Patterns of Methylmercury Risks to Common Loons and Piscivorous Fish in Canada. *Environmental Science and Technology, 47*, 13093-13103.

Ethier, A. L. M., Mackay, D., Toose-Reid, L. K., O'Driscoll, N. J., Scheuhammer, A. M., & Lean, D. R. S. (2008). The development and application of a mass balance model for mercury (total, elemental and methyl) using data from a remote lake (big dam west, Nova Scotia, Canada) and the multi-species multiplier method. *Applied Geochemistry*, 23, 467-481.

Ekino, S., Susa, S., Ninomiya, T., Imamura, K., & Kitamura, T. (2007). Minamata disease revisited: An update on the acute and chronic manifestations of methyl mercury poisoning. *Journal of Neurological Sciences*, 262, 131-144.

Environment Canada. Environment Canada, (2013). About Mercury. Retrieved from website: http://www.ec.gc.ca/mercure-mercury/default.asp?lang=En&n=D64997D2-1

Fitzgerald, W. P. (1995). Is mercury increasing atmosphere? The need for an atmospheric network (AMNET). *Water Air Soil Pollution*, 80, 245-254.

Halfyard, E. A. (2008). Smallmouth Bass Report: Shubenacadie (Grand) Lake. Report to: Nova Scotia Fisheries and Aquaculture, Inland Fisheries Division. Retrieved from website: https://novascotia.ca/fish/documents/special-management-areas-reports/GrandLakeBassRpt265911.pdf

Health Canada, (2007). Human Health Risk Assessment of Mercury in Fish and Health Benefits of Fish Consumption. Report to Health Canada from the Bureau of Chemical Safety Food Directorate Health Products and Food Branch. Retrieved from website: http://hc-sc.gc.ca/fn-an/pubs/mercur/merc_fish_poisson_e.html

Keppie, J.D. (compiler) 2000: Geological Map of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Map ME 2000-1, scale 1:500 000.

Langford, N. J., & Ferner, R. E. (1999). Toxicity of mercury. *Journal of Human Hypertension*, 13, 651-656.

LeBlanc, J. E. 2010. Geographic distribution of smallmouth bass, *Micropterus dolomieu*, in Nova Scotia: history of early introductions and factors affecting current range. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/028. iv + 25 p

Livingstone, D. A. (1951). The Fresh Water Fishes of Nova Scotia. *Nova Scotian Institute of Science, 23*, Retrieved from http://dalspace.library.dal.ca/handle/10222/13619

Nova Scotia Lake Survey Program. (2014). *Lake chemistry data*. MS Excel Spreadsheet. Retrieved from website: http://www.novascotia.ca/nse/surface.water/lakesurveyprogram.asp

O' Driscoll, N. J., Rencz, A. N., & Lean, D. R. S. (2005). Mercury cycling in a wetland-dominated ecosystem: A multidisciplinary study. North Carolina, USA: SETAC Press.

Parrish, D. L., & Margraf, F. J. (1990). Interactions between white perch (*Morone americana*) and yellow perch (*Perca flavescens*) in Lake Erie as determined from feeding and growth. *Canadian Journal of Fisheries and Aquatic Sciences*, 47, 1779-1787.

Parsons, M.M., LeBlanc, K.W.G., Hall, G.E.M., Sangster, A.L., Vaive, J.E., and Pelchat, P., 2012. Environmental geochemistry of tailings, sediments and surface waters collected from 14 historical gold mining districts in Nova Scotia; Geological Survey of Canada, Open File 7150.

Pickhardt, P. C., Folt, C. L., Chen, C. Y., Klaue, B., & Blum, J. D. (2002). Algal blooms reduce the uptake of toxic methylmercury in freshwater food webs . *Proceedings of the National Academy of Sciences of the United States of America*, *99*(7), 4419-4423.

Prout, M. W., Mills, E. L., & Forney, J. L. (1990). Diet, growth, and potential competitive interactions between age-0 white perch and yellow perch in Oneida Lake, New York. *Transactions of the American Fisheries Society*, *119*(6), 966-975.

Ryan, R. J., & Smith, P. K. (1998). A review of the mesothermal gold deposits of the Meguma group, Nova Scotia, Canada. *Ore Geology Reviews*, 13, 153-183.

Schaeffer, J. S., & Margraf, F. J. (1987). Predation on fish eggs by white perch, *Morone americana*, in western Lake Erie. *Environmental Biology of Fishes*, *18*(1), 77-80.

Selin, N.E., Jacob, D.J., Park, R.J., Yantosca, R.M., Strode, S., Jaegle, L., Jaffe, S., 2007. Chemical cycling and deposition of atmospheric mercury: Global constraints from observations. *Journal of Geophysical Research: Atmospheres* 112, D02308 (online only).

Service Nova Scotia. Service Nova Scotia, (2012). Nova Scotia counties colour (CMC-240-02). Retrieved from website: http://www.novascotia.ca/snsmr/land/pdf/ans-land-counties-colour-CMC240-02.pdf

Stanley, J. G., & D. S. Danie. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic - White perch). USFWS, Div. of Biol. Serv., FWS/OBS-82/11.7. U.S. Amy Corps of Engineers, TR EL-82-4.

Sunderland, E. M., & Chmura, G. L. (2000). An inventory of historical mercury emissions in Maritime Canada: implications for present and future contamination. *The Science of the Total Environment*, 256, 39-57.

Sunderland, E. M., Cohen, M. D., Selin, N. E., & Chmura, G. L. (2008). Reconciling models and measurements to assess trends in atmospheric mercury deposition. *Environmental Pollution*, 156, 526-535.

Tomiyasu, T., Takenaka, S., Noguchi, Y., Kodomatani, H., Matsuyamab, A., Oki, K., Kono, Y., Kanzaki, R., & Akagi, H. (2014). Estimation of the residual total mercury in marine sediments of Minamata Bay after a pollution prevention project. *Marine Chemistry*, 159, 19-24.

Veiga, M. M., Maxson, P. A., & Hylander, L. D. (2006). Origin and consumption of mercury in small-scale gold mining. *Journal of Cleaner Production*, 14, 436-447.

Watras, C. J., Huckabee, J. W. (1994) Mercury pollution: Integration and synthesis. Boca Raton (FL): CRC/Lewis. (As cited by O'Driscoll et. al., 2005).

Wiener, J. G.; Krabbenhoft, D. P.; Heinz, G. H.; Scheuhammer, A. M. Ecotoxicology of mercury. In Handbook of Ecotoxicology,2 nd ed.; Hoffman, D. J., Rattner, B. A., Burton, G. A., Cairns, J., Eds.; Lewis Publishers: Boca Raton, FL., 2003; pp 409−463

Wong, H. K. T., Gauthier, A., & Nriagu, J. O. (1999). Dispersion and toxicity of metals from abandoned gold mine tailings at Goldenville, Nova Scotia, Canada. *The Science of the Total Environment*, 228, 35-47.

Wyn, B., Kidd, K. A., Burgess, N. M., & Curry, R. A. (2009). Mercury biomagnification in the food webs of acidic lakes in Kejimkujik National Park and national historic site, Nova Scotia. *Canadian Journal of Fisheries and Aquatic Sciences*, 66(9), 1532-1545.

Wyn, B., Kidd, K. A., Burgess, N. M., Curry, A. R., & Munkittrick, K. R. (2010). Increasing mercury in yellow perch at a hotspot in Atlantic Canada, Kejimkujik National Park. *Environmental Science & Technology*, 44(23), 9176-9181.

Zolnikov, T. R. (2012). Limitations in small artisanal gold mining addressed by educational components paired with alternative mining methods. *Science of the Total Environment*, 419, 1-6.

Zuerlein, G. 1981. The white perch in Nebraska. Nebraska Game and Parks Commission. Tech. Ser. 8. Lincoln, NE. (As cited by Parrish & Margraf, 1990).

Figures

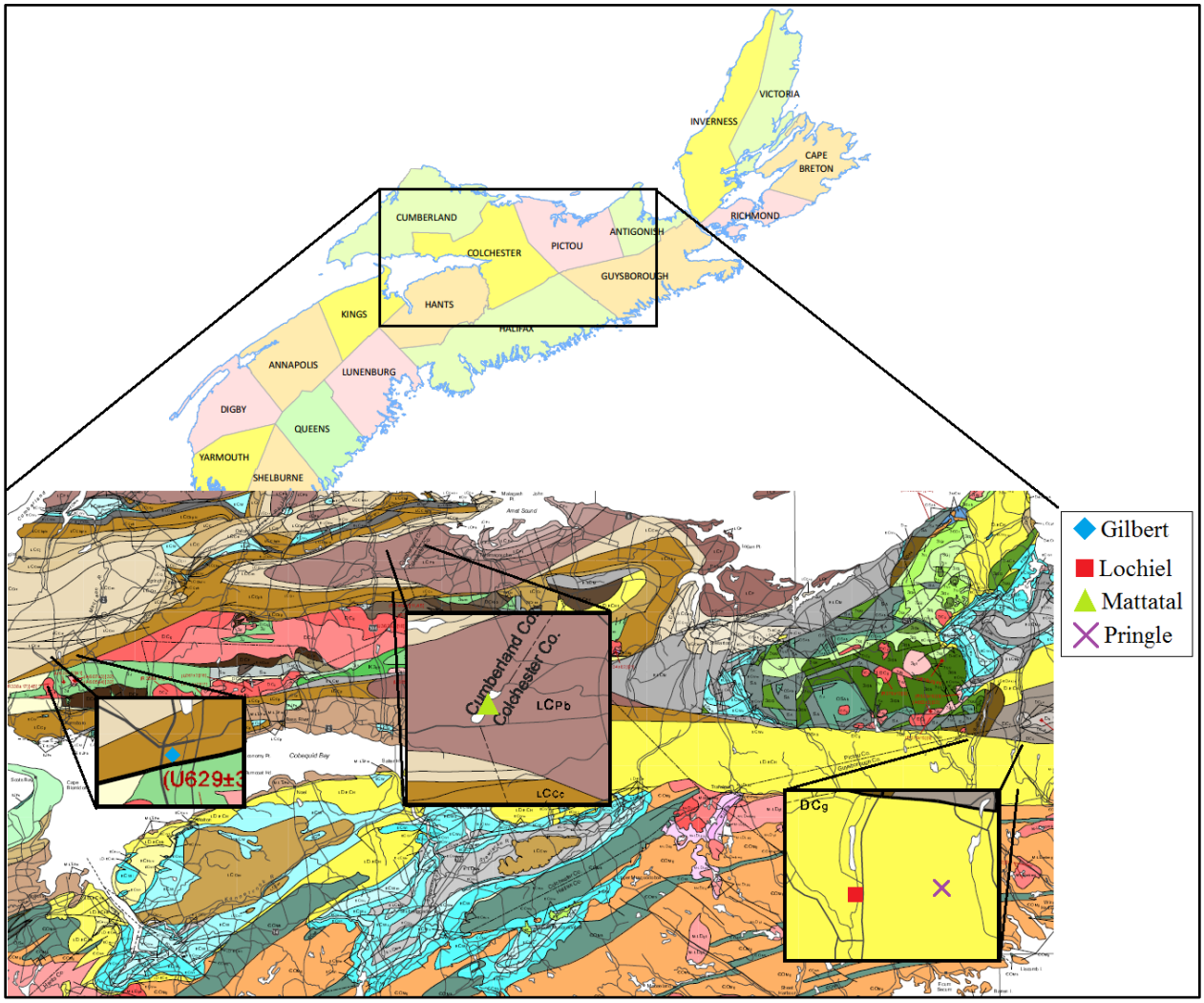

Figure 1: Lake locations and bedrock geology for each of the four lakes (Keppie, 2000; Service Nova Scotia, 2012; edits by Carolyn Stevens).

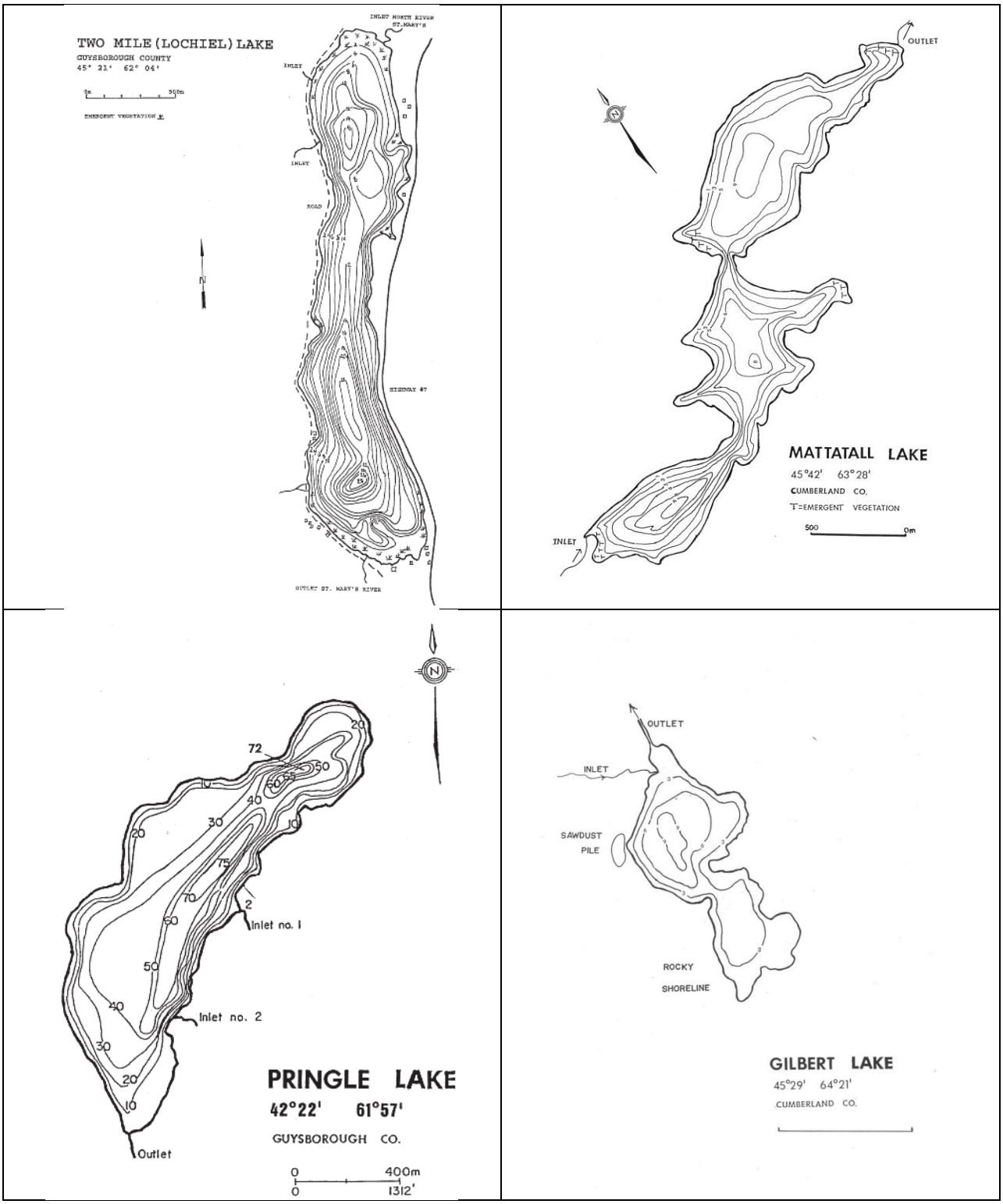

Figure 2. Bathymetric maps for each study lake, from the Nova Scotia Department of Fisheries and Aquaculture. The largest to smallest lake are Mattatall, Lochiel, Pringle and Gilbert. Limnological data can be found in Table 1.

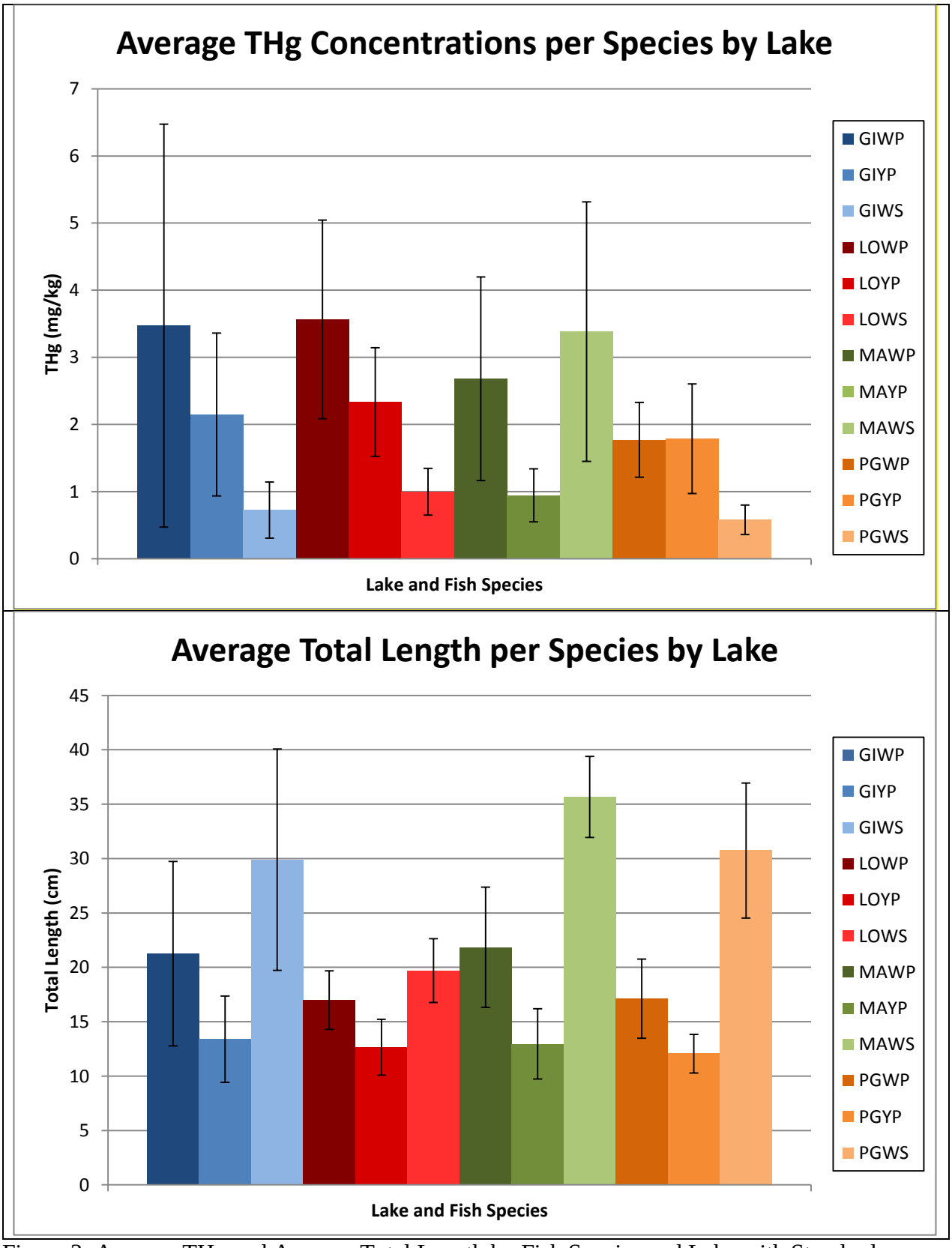

Figure 3: Average THg and Average Total Length by Fish Species and Lake with Standard Deviation.

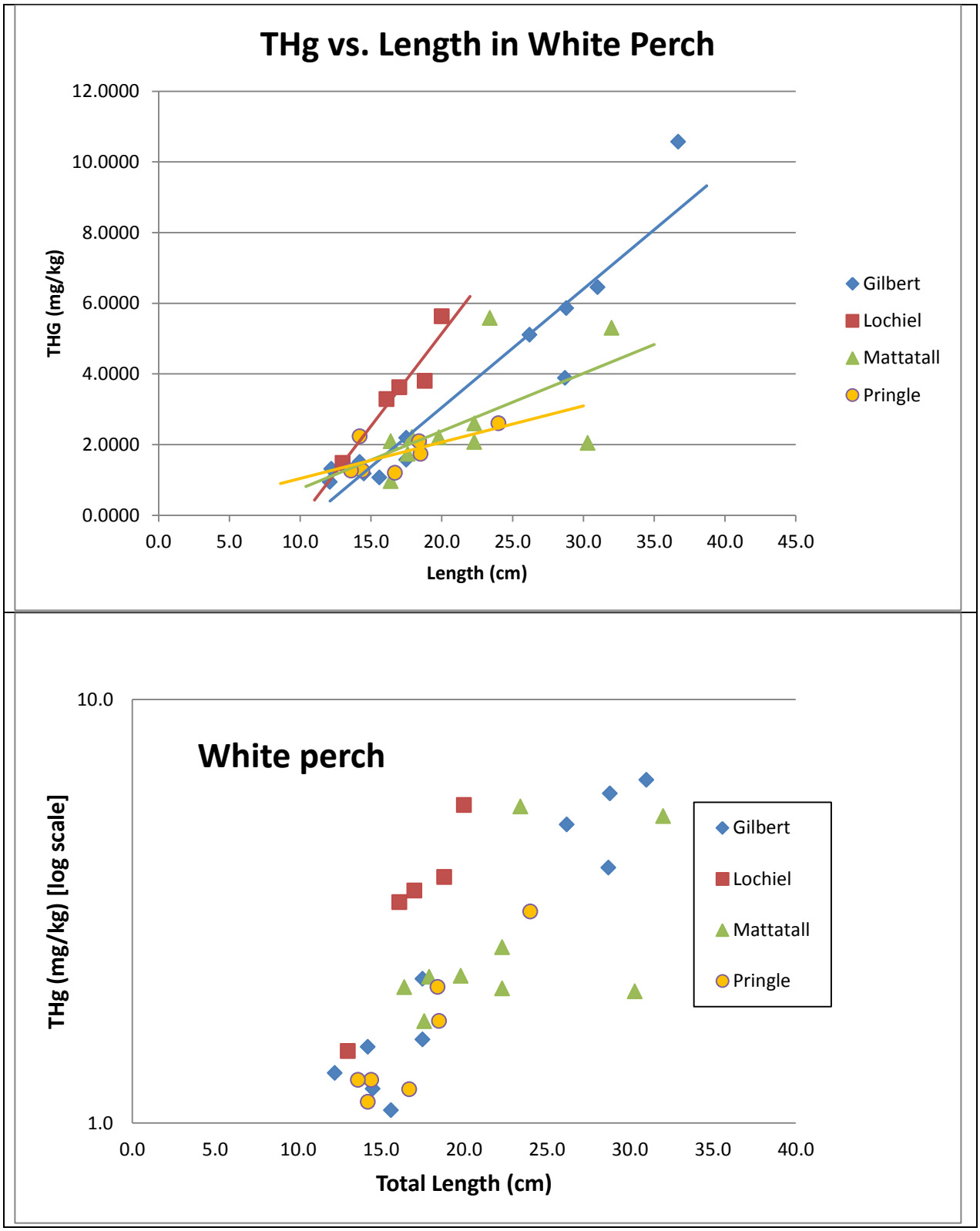

Figure 4: THg vs. Length for White perch. Two plots are presented for this species. The top shows the trendlines (see Table 3 for regression equations). The bottom shows the data on a log-10 scale to better display the distribution.

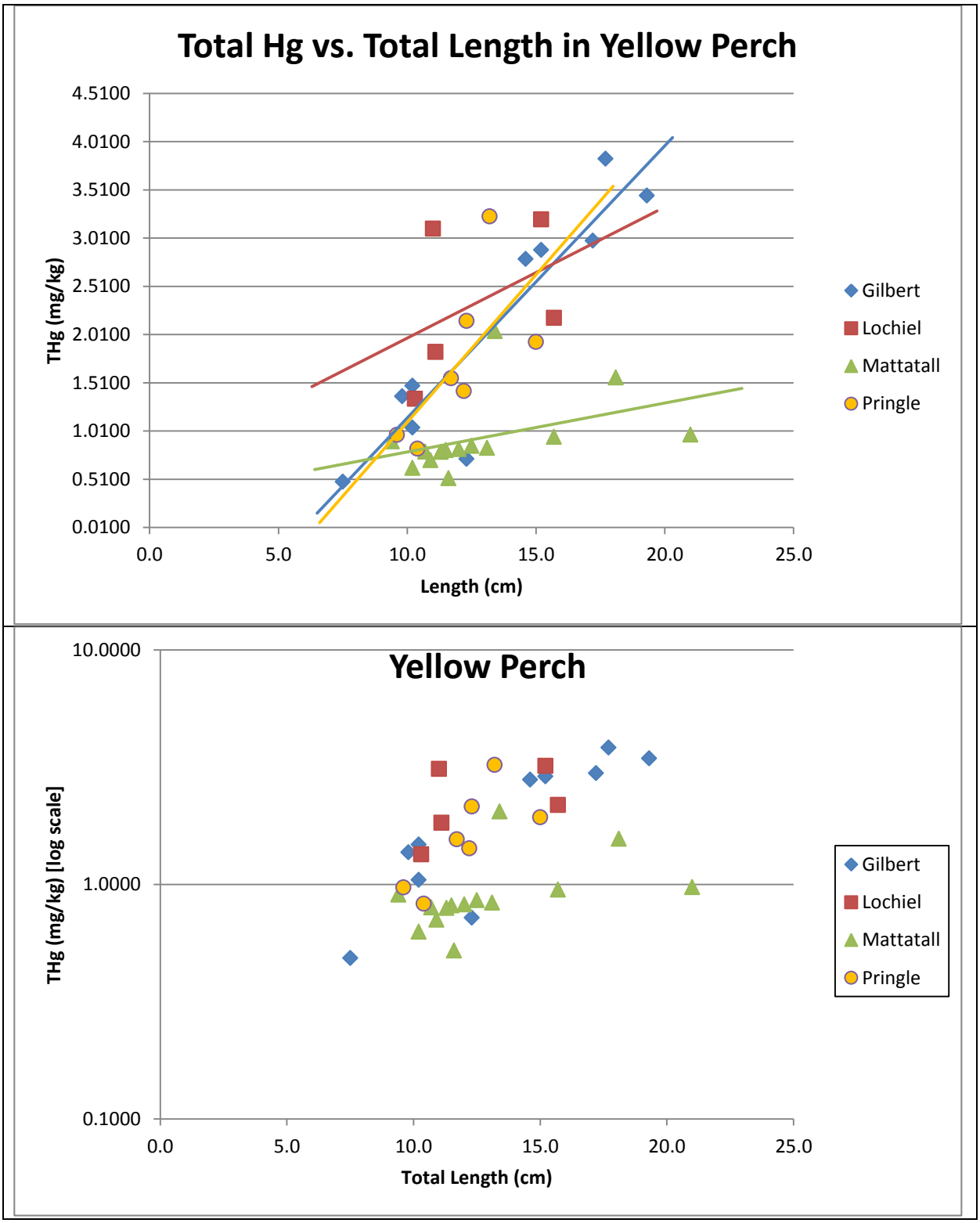

Figure 5: THg vs. Length for Yellow perch. Two plots are presented for this species. The top shows the trendlines (see Table 3 for regression equations). The bottom shows the data on a log-10 scale to better display the distribution.

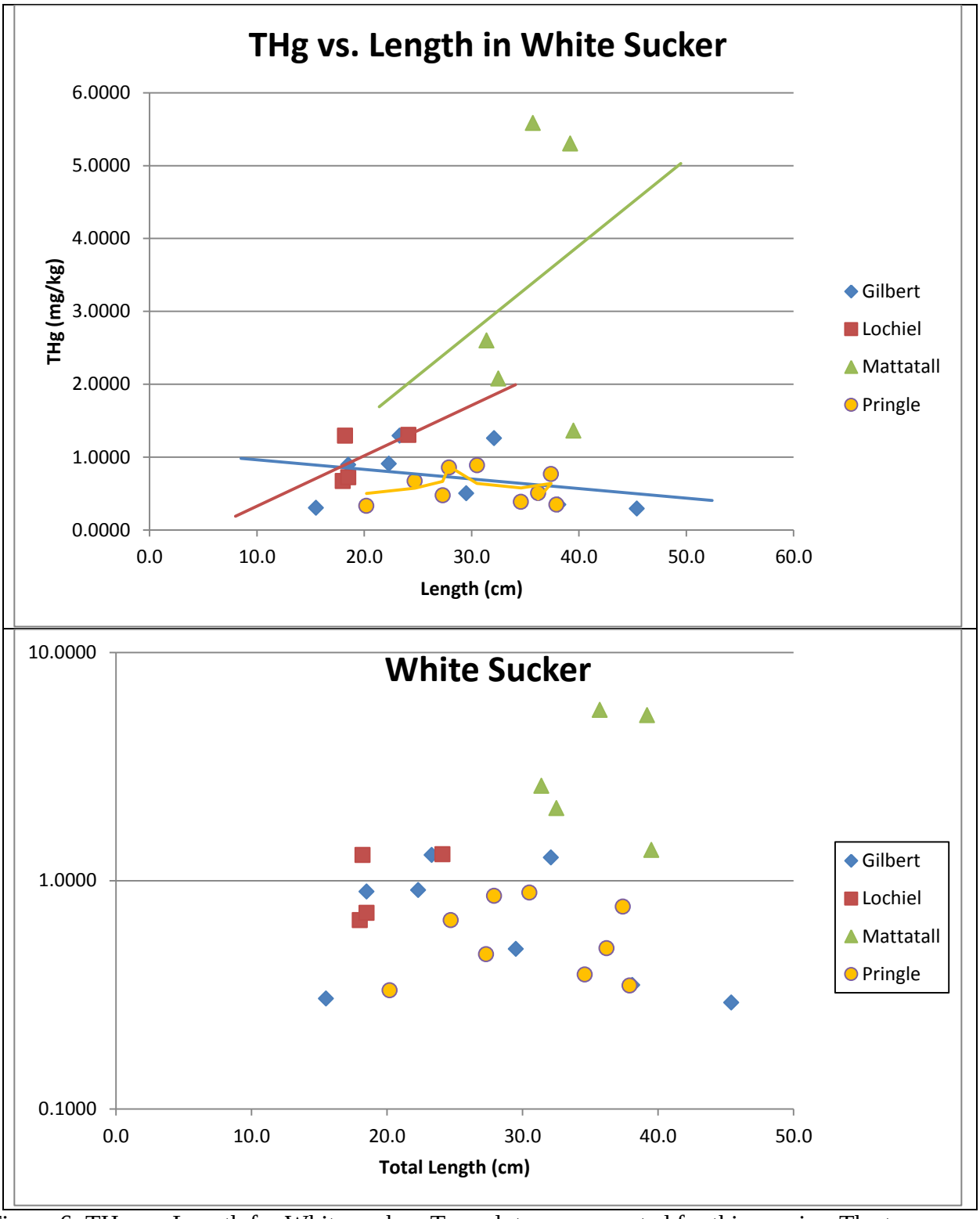

Figure 6: THg vs. Length for White sucker. Two plots are presented for this species. The top shows the trendlines (see Table 3 for regression equations). The bottom shows the data on a log-10 scale to better display the distribution.

Tables

Table 1: Water quality parameters collected by lake using a YSI 6600 multi-parameter water quality SONDE. Surface area values from Alexander et. al., (2006) and Nova Scotia Lake Survey Program, (2014).

Parameter	**Gilbert**	**Lochiel**	**Mattatall**	**Pringle**
pH	7.0	7.4	7.4	7.2
Conductivity (µS/cm)	49.8	50.4	47.2	66.8
Total Organic Carbon (mg/L)	5.4	3.7	4.8	2.7
Chlorophyll (µg/L)	7.3	2.9	2.7	1.5
Alkalinity ($CaCO_3$ mg/L)	5.2	8.4	11.1	6.2
Sulfate (mg/L)	2.7	3.7	2.1	2.8
Secchi Depth (m)	2.005	3.35	2.95	4.4
Max Depth (m)	10.5	26.2	7.8	26.0
Surface Area (ha)	22.7	129.2	106.8	62.7

Table 2: Lake, species, and average THg and total length concentrations per lake by species with standard deviations and N representing the number of fish samples per species, by lake.

Lake	Species	N	Average THg (mg/kg)	SD +/-	Average Total Length (cm)	SD +/-
Gilbert	White Perch	12	3.47	3.00	21.25	8.48
Gilbert	Yellow Perch	10	2.15	1.21	13.40	3.97
Gilbert	White Sucker	8	0.73	0.42	29.89	10.18
Lochiel	White Perch	5	3.56	1.48	16.98	2.69
Lochiel	Yellow Perch	5	2.33	0.81	12.66	2.57
Lochiel	White Sucker	4	1.00	0.35	19.7	2.94
Mattatall	White Perch	10	2.68	1.52	21.84	5.52
Mattatall	Yellow Perch	14	0.94	0.40	12.96	3.24
Mattatall	White Sucker	5	3.38	1.93	35.66	3.72
Pringle	White Perch	7	1.77	0.56	17.11	3.64
Pringle	Yellow Perch	7	1.79	0.82	12.06	1.78
Pringle	White Sucker	9	0.58	0.22	30.74	6.20

Table 3: Linear regression data of THg and total length per species by lake. The significance in trend line data within a species between the lakes is given by the p-value.

Lake	Species	R^2	Slope	Intercept	P
Gilbert	White Perch	0.8989	0.3353	-3.6534	
Lochiel	White Perch	0.9113	0.5204	-5.3332	
Mattatall	White Perch	0.3531	0.1632	-0.8819	
Pringle	White Perch	0.4518	0.1029	0.0108	
All	White Perch				0.33
Gilbert	Yellow Perch	0.8536	0.2882	-1.6766	
Lochiel	Yellow Perch	0.1871	0.1360	0.6127	
Mattatall	Yellow Perch	0.1731	0.0508	0.2861	
Pringle	Yellow Perch	0.4445	0.3060	-1.9605	
All	Yellow Perch				0.003
Gilbert	White Sucker	0.1025	0.0132	1.0955	
Lochiel	White Sucker	0.3398	0.0692	-0.3649	
Mattatall	White Sucker	0.0523	0.1187	-0.8498	
Pringle	White Sucker	0.000002	0.00005	0.5797	
All	White Sucker				0.0005

Appendix

Table 4: Average weight in grams with standard deviations (SD) where N represents the number of fish samples per species by lake

Lake	Species	N	Average Weight (g)	SD +/-
Gilbert	White Perch	12	157.33	175.12
Gilbert	Yellow Perch	10	29.80	23.80
Gilbert	White Sucker	8	329.00	289.47
Lochiel	White Perch	5	62.40	22.95
Lochiel	Yellow Perch	5	20.00	8.60
Lochiel	White Sucker	4	70.00	31.20
Mattatall	White Perch	10	134.00	119.53
Mattatall	Yellow Perch	14	24.43	22.53
Mattatall	White Sucker	5	405.2	76.02
Pringle	White Perch	7	56.57	44.76
Pringle	Yellow Perch	7	18.00	7.30
Pringle	White Sucker	9	279.33	156.39

Table 5: Quality control data measuring average THg in mg/kg with standard deviations (SD) for certified reference materials (TORT-2, DORM-3, and DOLT-4) and in-house reference fish materials (10307, 11142a, PGWS7, and MABB4).

CRM/SRM	N	Average THg (mg/kg)	SD +/-
TORT	7	0.348	0.03024
DORM	22	0.487	0.03291
DOLT	22	2.755	0.09335
10307	5	0.3988	0.01985
11142a	3	2.2309	0.13562
PGWS7	5	0.4602	0.02193
MABB4	6	0.895	0.02067