BIOL* 4110 Final Paper

Mercury and Polychlorinated Biphenyls Effects on Fish in Ontario Lakes

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Introduction

Water pollution has become a major issue in the twenty-first century, both naturally and anthropogenically (Chaudhry *et al.,* 2017). Pollutants in water can come from microplastics and heavy metals, originating from industries and affecting aquatic ecosystems (Chaudhry *et al.,* 2017). The lakes of Ontario, Canada are not exempt from this increase in pollution and the variety of fish species that call them home may be at risk (Gandhi *et al.,* 2014).

One of the contaminants majorly impacting fish in the Ontario lakes is mercury; a natural heavy metal that has increased in abundance as a result of industrial processes, causing biomagnification of mercury levels in fish (Ghandi *et al.,* 2014). The leading anthropogenic source of mercury is coal-fired electricity generation which was once popular in Canada (Ghandi *et al.,* 2014). However, pollution concerns have led to these power plants being shut down, with the last one in Ontario officially closing in 2014 (Harris *et al.,* 2015).

In addition to mercury, polychlorinated biphenyls (PCBs) are another major contaminant affecting fish species in Ontario lakes; PCB levels started to increase in the 1930s (Bhavsar *et al*., 2007). PCBs are found in electric fluids, pesticides, plastics and many more products, which can leach into water sources (Bhavsar *et al.,* 2007). However, PCBs were banned in Canada in the 1970s to help decrease their concentrations as they were harmful to the environment (Bhavsar *et al.,* 2007). Regardless, the PCB half-life is 10-20 years, meaning the contaminant persists in the atmosphere for a long time (Sinkkonen *et al.,* 2000).

Since there are many issues associated with mercury and PCB, it is important to further observe the impacts they have on aquatic ecosystems. For instance, in addition to passive diffusion through the gills, mercury bioaccumulates through food webs causing fish at higher trophic levels to have greater mercury concentrations relative to their prey (Kidd *et al.,* 2012).

Also, fish consume about 90% of the mercury from food, making mercury concentration greatly dependent on their diet (Kidd *et al.,* 2012). Consequently, PCBs also bioaccumulate and are highly persistent in aquatic ecosystems where they dissolve in water and make their way up the food chain (Hornbuckle *et al.,* 2006).

The lifespan of a fish also contributes to their uptake of mercury and PCB; those that have lived longer have more contaminants in their bodies (Murphy *et al.,* 2018). For example, with mercury, fish that have longer lifespans have more time to bioaccumulate mercury, specifically in their fat tissues (Evans *et al.,* 2005; Turyk *et al.,* 2012). PCB concentrations in fish have also been correlated to age, with the older the fish having the higher concentrations and, like mercury, PCBs tend to accumulate in the fats of fish (Hornbuckle *et al.,* 2005; Murphy *et al.,* 2018).

Furthermore, a fish's habitat is important when looking at mercury and PCB contaminant levels. For example, demersal fish species have shown greater concentrations of mercury than pelagic fish species because mercury levels increase as depth increases, impacting the fish at greater depths (Romero-Romero *et al.,* 2022). Mercury and PCBs often accumulate in the sediment of water bodies, affecting demersal species that inhabit the bottom of water bodies (Huo *et al.,* 2017).

With the current research on the contaminants, there are some uncertainties. For example, there is limited research on PCBs in aquatic environments (Weitekamp *et al.,* 2021). It is also unclear how diet affects mercury concentrations in fish (Beldowska *et al.,* 2016). In addition, the abiotic cycling of mercury within aquatic ecosystems is not well known, and research is ongoing (Kidd *et al.,* 2012). Exploring these uncertainties is vital in understanding the effects of trophic level, lifespan, and habitat on contaminant uptake.

Based on our uncertainties, our research question is: "how are the fish in Ontario lakes becoming affected by changing mercury and PCB contaminant levels over time?". We hypothesize that the changes in PCBs and mercury concentrations have occurred in fish historically, due to the 1977 PCB ban, and the 2014 closure of the coal power plants emitting mercury throughout Ontario. We predict that 1) over time, PCB concentrations in fish will have decreased as a result of the ban and 2) over time, the mercury concentrations in fish will have decreased as a result of the closure of coal power plants. In addition, we hypothesize that a fish species' trophic level, lifespan, and habitat will determine the level of mercury and PCB contaminants they accumulate. We predict that 1) species at higher trophic levels will have higher levels of contaminants due to bioaccumulation, 2) species with longer lifespans will have higher levels of contaminants due to these contaminants accumulating in their bodies over time, and 3) demersal species will have higher levels of contaminants due to their proximity to contaminant-laden sediment.

Methods

For our study, we used data from the fish contaminants database provided by the Ontario Ministry of the Environment, Conservation and Parks, and 3 tables from the rfishbase package in R studio: "species", "diet", and "popchar". From the fish contaminants database, we used four datasets (1993-1998, 1999-2001, 2002-2004, 2005-2018) and used rbind to create one dataset from 1993-2018. To carry out our analysis, we used the following R studio packages: tidyverse, dplyr, ggplot2, lubridate, janitor, readxl, rfishbase, performance, margins, pracma, MuMIn, visreg, and gridExtra.

Data was tidied by removing columns and rows that weren't pertinent to our study (ex. non-fish samples, non-PCB or non-mercury contaminants), and converting dates to a consistent format which was then simplified to a column with only the year samples were collected. Mercury was always measured in ug/g wet, but PCB was measured in either ng/g wet or pg/g wet, so we converted picograms to nanograms.

The contaminant dataset and the rfishbase "species" table were merged by fish common names and fishbase's species codes were included for each. Names that didn't match but had an equivalent in fishbase were manually changed (ex. "burbot (ling)" to "burbot"). The "species" table also included habitat (called "DemersPelag" in the table) which could now be merged into the contaminant dataset by species code. The "diet" table included trophic level ("Troph"); the average of entries for adult and juvenile/adult life stages were calculated and merged by species code. Adult and juvenile/adult life stages were chosen because trophic level can change throughout a species' development. The "popchar" table included maximum recorded ages ("tmax"); the maximum entry for each species was merged by species code.

After tidying and merging our data, we ended up with a total of 160547 samples (65831 PCB samples, and 94707 mercury samples) consisting of 28 fish species, from 1759 locations in Ontario, Canada. One dataset for each contaminant was created to simplify modelling.

Statistical Analysis

Data for both contaminants was heavily right-skewed, so data was log-transformed to make distributions more normal. This worked well for mercury data however, PCB data ended up looking bimodal after the transformation. Other transformations were attempted, including square root, log base 10, and inverse, but none gave results that were closer to normal distributions.

We chose to use a linear regression model to test our hypotheses since our analysis explores multiple predictor variables, both numeric and categorical. To more easily compare the effect of these predictor variables on our response variable, contaminant concentration, we scaled our numeric values (year of sample, lifespan, and trophic level). We ran our linear models for each contaminant through MuMIn dredge and found that the best fit model for PCB included all four predictor variables. Mercury, however, had two best fit models (within 4 delta AIC) one that included all four predictor variables and one that excluded only lifespan. Since models within 4 delta AIC are considered indistinguishable and visreg doesn't work well with averaged models, we decided to use the model with all 4 predictor variables for mercury as well.

Results

For our first prediction that contaminant concentrations will have decreased over time (due to the ban of PCB and closure of the mercury coal-fired plant), we found that the mercury and PCB concentrations increased by 1.148 and 5.319 per year, respectively, with the outcomes being statistically significant ($p = 2e-16$; $p= 2e-16$) for both contaminants, respectively (Fig. 1).

For our second prediction that species at higher trophic levels will have higher levels of contaminants due to bioaccumulation, we found that the mercury and PCB concentrations increased by 1.546 and 1.112, respectively, as trophic level increased, with both results being statistically significant ($p = 2e-16$; $p = 2e-16$), respectively (Fig. 2).

For our third prediction that fish species with longer lifespans will have higher levels of contaminants due to the contaminants accumulating in their bodies over time, we found that mercury and PCB concentrations decreased by 0.9960 and 0.8460 for each additional year of lifespan. For mercury concentration it was statistically insignificant ($p = 0.261505$), while the PCB concentration was statistically significant ($p = 2e-16$) (Fig. 3).

Finally, for our fourth prediction that demersal species will have higher levels of contaminants due to their proximity to contaminant-laden sediment, we found that for mercury concentration, only pelagic-oceanic fish had lower contaminant concentrations than demersal fish and was statistically significant ($p = 0.000902$). Benthopelagic and pelagic fish had significantly higher levels of mercury than demersal fish ($p = 2e-16$; $p = 2e-16$). Pelagic-neritic fish had slightly higher mercury concentrations than demersal fish, but the difference was insignificant (Fig. 4). For PCB concentration, we found that benthopelagic, pelagic-neritic, and pelagic-oceanic fish all had higher levels of PCBs than demersal fish, however only pelagic-neritic fish were significantly different ($p = 2e-16$). Pelagic fish had lower levels of PCB than demersal fish and this was also significant ($p = 2.95e-14$) (Fig. 4).

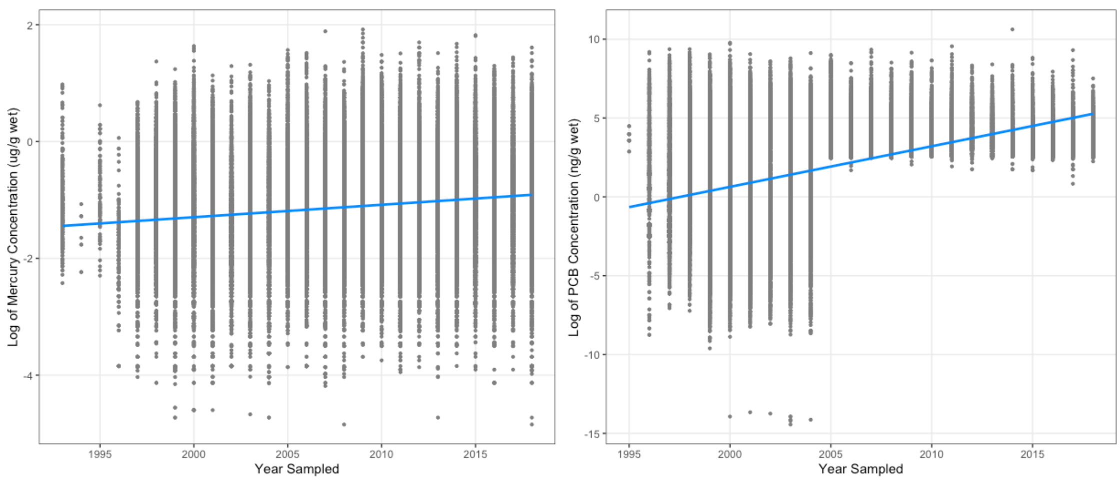

Figure 1. Log-transformed Mercury concentration (ug/g wet) provided on the left and PCB concentration (ng/g wet) shown on the right during the years 1993-2018. 160574 samples were collected from 28 fish species and taken from 1759 Ontario Lakes in Canada. Each dot represents one fish sample. The blue line represents the slope.

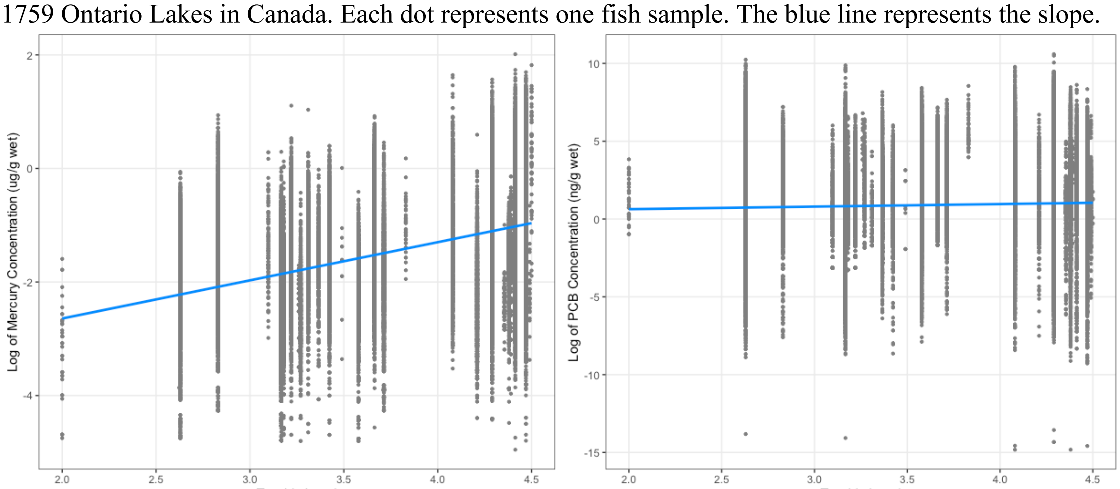

Figure 2. Log-transformed Mercury concentration (ug/g wet) on the left and PCB concentration (ng/g wet) on the right compared to the averaged trophic levels of 28 fish species. 160574 samples were collected during 1993-2018 and taken from 1759 Ontario Lakes in Canada. Each dot represents a fish sample. The blue line represents the slope.

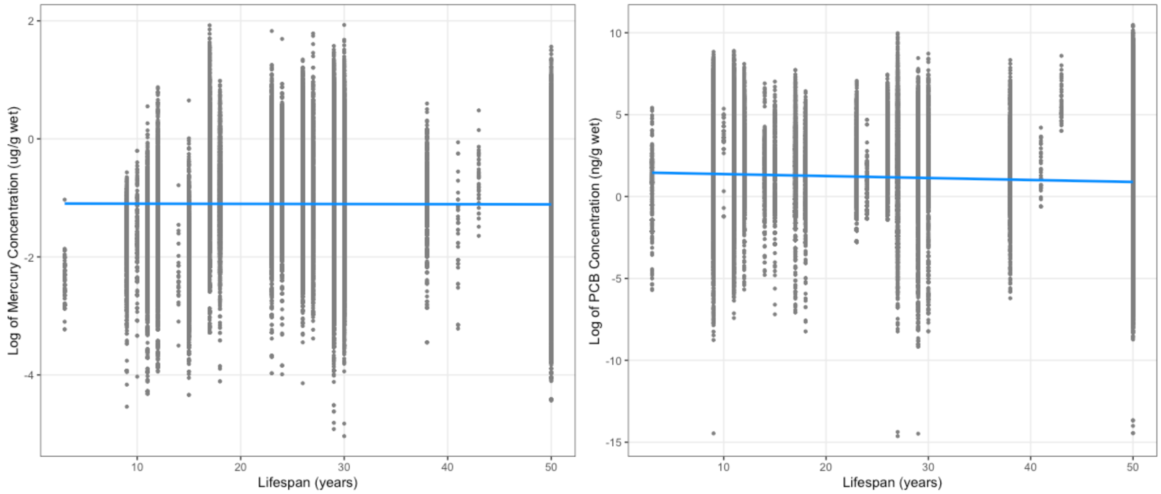

Figure 3. Log-transformed mercury concentration (ug/g wet) on the left and PCB concentration (ng/g wet) on the right compared to the lifespan (years) of fish in 160574 samples. Data was collected from 28 fish species during 1993-2018 and sampled from 1759 Ontario Lakes in Canada. Each dot represents a fish sample. The blue line represents the slope.

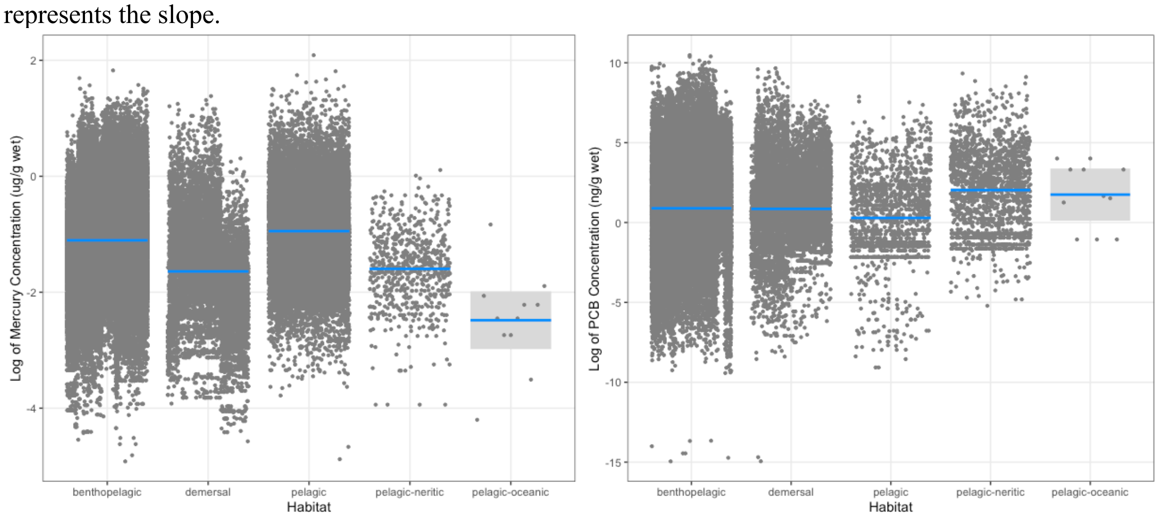

Figure 4. Log-transformed mercury concentration (ug/g wet) on the left and PCB concentration (ng/g wet) on the right compared to habitat type (benthopelagic, demersal, pelagic, pelagic-neritic, pelagic-oceanic) in 160574 samples of 28 fish species during 1993-2018 collected from 1759 Ontario Lakes in Canada. For comparison, the demersal habitat was used as the reference group. Each dot represents a fish sample. The blue lines represent the means.

Discussion

The purpose of this study was to explore how mercury and PCB contaminant levels in Ontario lakes are affecting fish species. The data from our results showed that our prediction that over time, PCB concentrations in fish will have decreased (as a result of the ban), along with the prediction that over time mercury concentrations in fish will have decreased (as a result of the coal-plant shutdowns), was not supported (Fig. 1). Our prediction that species at higher trophic levels will have higher levels of contaminants due to bioaccumulation was supported (Fig 2). However, our prediction that species with longer lifespans will have higher levels of contaminants due to these contaminants accumulating in their bodies over time was not supported (Fig 3). Finally, our prediction that demersal species would have higher levels of contaminants due to their proximity to contaminant-laden sediment, was not supported (Fig 4).

A study done by Bhavsar *et al.* (2007), demonstrated that PCB sediments are becoming a net source, rather than a net sink meaning PCB contaminants are being emitted faster than they are being absorbed, causing the increase in PCB contaminant levels. While there have been closures in coal power plants around Ontario, there are still global emissions contributing to the increase in mercury pollution (Visha *et al.,* 2018). In addition, Bhavsar *et al.* (2007) and Visha *et al.* (2018) found that invasive species are altering the food chain which is causing both PCB and mercury levels to become displaced, increasing their concentrations. In addition to invasive species being a major contributor, a study by Gandhi *et al.* (2015) showed that climate change is the greatest contributor to increasing contaminant levels. Warmer temperatures caused by climate change are increasing the movement of PCB and mercury contaminants due to factors such as sea ice melting, and flooding. These studies are essential in understanding why our hypotheses and predictions were not supported, and why the containment levels in fish are increasing.

Furthermore, a study done by Gandhi *et al.* (2014) and Hornbuckle *et al.* (2006), have both shown that species at higher trophic levels have a greater bioaccumulation level, ingesting more contaminants than species at lower trophic levels. As well, a study done by Visha *et al.*

(2018), showed that in Ontario lakes, higher predatory fish such as walleye, lake trout and chinook salmon, had higher contaminant levels, proving to be consistent with our findings. Although studies have found evidence that contaminants accumulate throughout a fish's life, making long-lived fish more susceptible to higher levels of contaminants due to longer exposure times, our results didn't follow this trend (Gewurtz *et al.,* 2011). A possible explanation for why our prediction was not supported is that each individual fish's age was not recorded so although their lifespan may be long, they may have been sampled at an earlier life stage. Also, Gewurtz *et al.* (2011) mentioned that factors such as dietary patterns, activity, and growth rate can affect the bioaccumulation in fish, suggesting that lifespan alone may not be enough to predict contaminant levels.

Lastly, there have been many studies showing that demersal fish species are more affected by PCB and mercury contaminants that end up in the sediment, however, our results didn't follow this trend (Huo *et al.,* 2017; Romero-Romero *et al.,* 2022). While there was significant variation in contaminant levels between some habitats, especially for mercury, demersal species did not have the highest levels for either contaminant. Unfortunately, there is overlap in these habitat classifications, meaning that while demersal species do spend their lives near the sediment, this does not mean that other species completely avoid this area. Additionally, pelagic-oceanic fish were underrepresented in our dataset, which may have skewed our habitat results.

Throughout our analysis we encountered limitations that could have affected our results. First, our research was limited to only data from Ontario lakes, and excluded data from other provinces, territories, or states. With increased data present to analyze from various locations, patterns in our data could have been more prominent. Also, our total number of fish species studied decreased drastically (from 58 to 28 species) when pulling in fishbase data, as all values were not available for all species. If more fish species were included, then our results could be altered due to more variability in the dataset. It is also important to consider the locations that the fish samples were taken from. Since our data came from both rural and urban areas, then the level of contaminants in fish may vary in each location. For instance, urban lakes could have more pollution due to anthropogenic processes (Qin *et al.,* 2022). Yet, with no control group to compare our contaminant levels to, our results are more limited.

To further analyze our research, it would be valuable to view how the concentration of contaminants changed between various-sized lakes rather than all lake sizes grouped together. In addition, as our datasets contained only 28 fish species, we could look deeper into the contaminants' effects on those specific fish species. Finally, it would be valuable to see how PCB and mercury are being absorbed and changing over time in each life stage of fish, as we only focused on the lifespan of the fish species.

Overall, in the face of increasing PCB and mercury concentrations, it is important to understand the effects that both mercury and PCB are having on fish species in the Ontario lakes over time, specifically with trophic level, lifespan, and habitat. As well as how these outcomes may play out in the future, especially with the impacts of climate change and lake pollution.

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