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Accumulation of Polychlorinated Biphenyls in the Lower Trophic Levels of Keuka Lake

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by

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Abstract

Studies examining the extent of pollutant bioaccumulation in freshwater food webs often only focus on the extent of contamination of top predator fish species. In this study, polychlorinated biphenyl (PCB) concentrations and lipid contents were measured in Keuka Lake bulk zooplankton, zebra mussels (*Dreissena polymorpha*), and freshwater mysid shrimp (*Mysis diluviana*) in order to evaluate bioaccumulation patterns among these lower trophic level species. Average lipid contents of samples were 1.4, 0.5 and 4.2% (wet wt.) for zooplankton, zebra mussels and mysid shrimp, respectively. A total of 41different PCB congeners were quantified with mysid shrimp samples having the highest wet weight sum PCB concentrations (mean = 205.7 ng/g wet wt.) and zebra mussels had the highest lipid weight adjusted sum PCB concentrations (mean = 30,856 ng/g lipid wt.). Zooplankton generally had the lowest PCB concentrations among the biota sampled. The major contributors to PCB contamination were PCB #138 and PCB #153 for all three species. There was a positive correlation found between PCB congener hydrophobicity (log K_{OW}) and their degree of biomagnification in zebra mussels and mysid shrimp. Biomagnification factors averaged 1.2 and 7.2 for mysid shrimp and zebra mussels, respectively. These results showed that PCBs are biomagnifying in lower trophic levels of aquatic food chains, which increases the risks of PCB exposure to upper trophic levels in these food webs.

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Introduction

Polychlorinated biphenyls (PCBs) are globally ubiquitous contaminants found in both aquatic and terrestrial environments (Safe, 1994). The release of these chemicals into the environment began from their manufacture and use in a variety of industries including plastic manufacturing, electronics and their use as a fire retardant (Safe, 1994). Although the production of PCBs was banned in the late 1970's in North America, these chemicals are still released into the environment from older manufactured products and from contaminated soils and aquatic sediments (Safe, 1994). PCBs are of concern in the environment not only because their specific chemical properties which allow them to accumulate in organisms, but they may also pose serious health risks. For example, they have been known to have cancerous properties along with potential reproductive and endocrine disruptor toxicities (Safe, 1994). For humans, much of the risks of exposure to pollutants such as PCBs are associated with the consumption of contaminated fish (Safe, 1994).

Persistent organic pollutants such as PCBs have specific chemical properties that cause them to be very stable and also highly hydrophobic chemicals (Safe, 1994). Due to these properties, PCBs are highly soluble in lipids and are also not easily eliminated by aquatic organisms causing them to bioaccumulate in their fat stores (Mackay, 1982; Fisk et al., 1998). This is a risk to upper trophic levels since PCBs also have the capacity to biomagnify in the food web (Oliver and Niimi., 1988). Depending on the number of chlorine substituents, PCBs can also vary substantially in their hydrophobicity. As a general trend, there is a positive correlation between the number of chlorine substituents found on the compound and hydrophobicity (Hawker and Connell, 1988). The

hydrophobicity of persistent organic pollutants such as PCBs can be measured using the octanol-water partition coefficient (log K_{OW}). Generally, the higher log K_{OW} value, the more hydrophobic the compound. Importantly, the rate at which an organism can eliminate persistent organic pollutants is also dependent on log K_{OW} (Fisk et al., 1998). It is likely that the less hydrophobic PCBs with fewer chlorine substituents are more likely to be excreted from the body and will not accumulate as readily as more hydrophobic ones (Oliver and Niimi, 1988).

Bioaccumulation is the increase in concentration of a chemical in an individual from its environment, including uptake from food and exposure across respiratory and dermal surfaces (Daley et al., 2009). Biomagnification is generally represented as the increase in PCB concentration that occurs between predator and prey with food web biomagnification referring to the general increase in pollutant bioaccumulation from lower to higher trophic levels. The main mechanism of this process occurs through the consumption of contaminated food and the generally limited capacity of aquatic biota to metabolize and excrete these compounds (Monikh et al., 1997). Although pollutant exposure may occur via respiratory routes, for very hydrophobic contaminants such as PCBs, exposure from the water across the gill is very minimal with uptake from food being the most important path of PCB exposure for fish (Russell et al., 1999).

Food web biomagnification is often examined by measuring PCBs in top predator fish such as lake trout (*Salvelinus namaycush*) (Rasmussen et al., 1990). However, biomagnification is not limited to fish and can be investigated at different trophic levels to see if this phenomenon is consistent throughout a food web. The New York Finger Lakes were created by glaciation and have food webs similar to the Great Lakes

(Dadswell, 1974). A species native to these lakes is the freshwater mysid shrimp (*Mysis diluviana*) whose distribution was dictated by the extent of the Pleistocene glaciation (Dadswell, 1974). The mysid shrimp is an omnivore and feeds mainly on zooplankton and lake sediment and can range from 3 mm to 20 mm in size (Adare and Lasenby, 1994). Their presence in the Great Lakes and Finger Lakes gives the food webs in these lakes an interesting food chain dynamic.

The presence of the mysid shrimp in freshwater lakes can add another trophic level in the food web where additional transfer of PCB can occur between mysid predator and zooplankton prey in comparison to lakes where mysids are absent (Rasmussen et al., 1999). A study that supports this idea found that longer food chains will lead to greater accumulation of PCBs in top predators (Rasmussen et al., 1990). The study of Rasmussen et al., (1990) developed a food web classification based on the presence of mysid shrimp and pelagic forage fish such as rainbow smelt (*Osmerus mordax*) and alewife (*Alosa pseudoharengus*). Class 1 food webs were in lakes without these two components and were the simplest food chains. Class 2 food webs contain pelagic forage fish but no mysid shrimp, and Class 3 are the most complex, containing both pelagic forage fish and mysid shrimp (Rasmussen et al., 1990). The mysid shrimp is also high in fat content and could therefore also be responsible for increased bioaccumulation of hydrophobic chemicals in fish that consume them since PCBs accumulate in the fatty tissues of biota (Adare and Lasenby, 1994; Mackay, 1982).

The aim of this study was to investigate and compare lipid content and PCB contamination of Keuka Lake zooplankton, zebra mussels and mysid shrimp. Keuka Lake is one of the New York Finger Lakes and contains 15 species of zooplankton in

addition to mysid shrimp and also the non-native zebra mussel (*Dreissena polymorpha*) and these species can serve as a major source of food and PCBs for fish in the lake (Browne, 1981). It is predicted that mysids will have higher PCB concentrations and lipid content relative to zebra mussels and zooplankton and will also exhibit a greater degree of PCB biomagnification relative to the other two species. We also predict that there will be a positive relationship between mysid shrimp total length and PCB contamination with larger, potentially older individuals accumulating more PCBs relative to smaller younger shrimp. These results will provide important information regarding PCB bioaccumulation patterns in lower trophic levels of freshwater food webs.

Materials and Methods

Sample collection

Samples for lipid content and PCB analyses were collected from Keuka Lake on August 8, 2014, August 9, 2014 and September 27, 2014. Zooplankton samples were collected using mesh nets. The August samples were collected using a horizontal tow with a 0.5m x 2.0m zooplankton net containing 500 μm mesh. Nets were placed at a depth 2m below the surface and towed for 10 minutes. The nets collected biomass for PCB analysis. The September collections were completed by vertical net haul with a 0.5 m diameter zooplankton net containing 64 μm mesh. The vertical hauls were placed at a depth of 33 m. Multiple net hauls were completed to obtain sufficient biomass for analysis.

Mysid shrimp samples were collected at night using a vertical net haul at a depth of 25 m using a 0.5m x 2.0m zooplankton net containing 500 μm mesh. Samples were

collected at night and Global Positioning System (GPS) was used to identify collection sites in order to maintain consistency of sampling locations. Depth of collection was also kept consistent for all mysid shrimp sampling. In order to minimize sediment disturbance and contamination of samples, the net was gradually dropped to the bottom and was slowly hauled to the surface. To avoid crushing the mysid shrimp as they were brought to the surface, the mesh of the net collection bucket was covered with tape. Multiple repetitions (>10) of this vertical haul were required to collect sufficient biomass (>100 individuals). For each sample collection, a duplicate sample was collected and preserved in 80% ethanol to measure individual mysid shrimp lengths and produce a size distribution for the samples.

Once zooplankton and mysid shrimp samples were collected, they were transferred to separate solvent (acetone/hexane) rinsed 100ml glass jars and capped with solvent rinsed aluminum foil. Samples in the field were stored in coolers and kept at approximately 4°C until they were brought to the laboratory where they were kept at -20 °C until analysis.

Zebra mussel samples were collected in a location perpendicular to the zooplankton and mysid shrimp locations at a depth of approximately 2-3 m. Samples were collected by snorkeling and retrieving submerged rocks. Rocks were brought to the surface and intact zebra mussels were manually removed from each rock and transferred to a solvent rinsed glass jar capped with solvent rinsed aluminum foil. Samples were stored on ice and brought to laboratory to be stored at -20°C until analysis.

Laboratory procedure

All mysid shrimp and zebra mussel samples were counted and measured for total length (mm) prior to lipid and PCB extraction. The lipid and PCB extraction technique was based on the procedure described by Daley et al. (2009). A micro-extraction technique was used to determine % lipid and congener specific PCB concentrations. For each group analyzed (zooplankton, zebra mussels and mysid shrimp), approximately 0.5g wet weight of sample was used for each replicate. The 0.5g of sample was homogenized with 15g of activated sodium sulfate using a glass mortar and pestle. A 12 port glass manifold with 20 mL glass syringes packed with glass wool in the bottom surface were prepared with luer lock connectors that were attached to 1 μm glass syringe filters then fitted into the manifold for the solid phase extraction. Test tubes were placed inside the manifold to collect the eluent. The homogenized sample was packed into the glass syringes filled with 15 ml of 1:1 dichloromethane(DCM):hexane. Mortar and pestle were rinsed with 15 ml 1:1 DCM:hexane and added to the syringe. Samples were spiked with 50 ul of a 700 ug/L recovery standard PCB #34. Sample was left to extract for an hour then valves were opened for gravity filtration. Vacuum was often used to induce dripping of the eluent. Columns were set to drip at a rate of 3-5 mL per minute, until columns were dry and total eluent volume reached 35 mL.

Once eluents were collected, they were concentrated using a rotary-evaporator to approximately 1 mL volume then reconstituted to a volume of 10 mL. A 1 mL sample was taken for gravimetric lipid content determination. The sample was concentrated back down to approximately 1ml using rotary-evaporator. Clean-up was performed using glass chromatography columns containing 6 g of Florisil® (magnesium silicate) capped with

approximately 1 g of sodium sulfate and suspended in hexane. Sample extracts were added to the Florisil® followed by a 50 ml hexane rinse of the column with columns allowed to run dry following the hexane rinse. The eluent from the Florisil® adsorption affinity chromatography column was collected and rotary-evaporated back down to less than 1mL. Samples were brought back up to exactly 1 ml using iso-octane and were placed in 2 mL gas chromatography vials, capped and stored in the refrigerator until gas chromatography analysis.

Gas chromatography analysis was completed by the University of Windsor's Great Lakes Institute for Environmental Research. PCB analysis was performed using an electron capture equipped gas chromatograph (GC-ECD) as described in Lazar et al., (1992). A total of 41 congeners were consistently detected in samples including PCBs 31/28, 52, 44, 42, 64, 74, 70, 66/95, 60, 101, 99, 97, 110, 151, 149, 118, 146, 153, 105, 141, 138, 158, 129, 182/187, 183, 185, 174, 171, 200, 172, 180, 170/190, 201, 203, 195, 194, and 206 and represent a log K_{OW} range from 5.67 - 8.09 (Hawker and Connell, 1988). For co-eluting congeners, the primary congener represents the dominant constituent of each peak. Blanks and an external PCB standard (Quebec Ministry of the Environment Congener Standard) were run on the gas chromatograph with every batch of 6 samples.

The reference homogenate was an in-lab standard of Onondaga lake carp homogenate that has been previously analyzed. The data analysis tool of Excel was used to complete statistical comparisons. The recovery of the PCB #34 standard was 99%, indicating that extractions were successful.

Results

The percent lipid content found in each group increased from zebra mussels to zooplankton to mysid shrimp with average values of 0.5%, 1.4% and 4.2, respectively (Figure 1). Zooplankton had the lowest wet weight concentration of total PCBs (44.9 ng/g), then zebra mussels (79.3 ng/g) and mysid shrimp had the greatest (205.7 ng/g) (Figure 2). This changed when PCB concentrations were lipid normalized to adjust for these differences in fat content among the different sample types. Zebra mussels, the least fatty specimen, had the highest lipid weight PCB concentration (30,856 ng/g) then mysid shrimp (5069 ng/g) and zooplankton had the least (4286 ng/g) (Figure 3). An analysis of variance (ANOVA) statistical test was performed between the three groups and demonstrated a significant difference in lipid corrected PCB concentrations between the three types of biota with a p-value of 0.003.

Figure 1. Average lipid content % wet wt. for Keuka Lake zooplankton, zebra mussels and mysid shrimp.

Figure 2: Average wet weight sum PCB concentrations (ng/g wet wt.) for Keuka Lake zooplankton, mysid shrimp and zebra mussels.

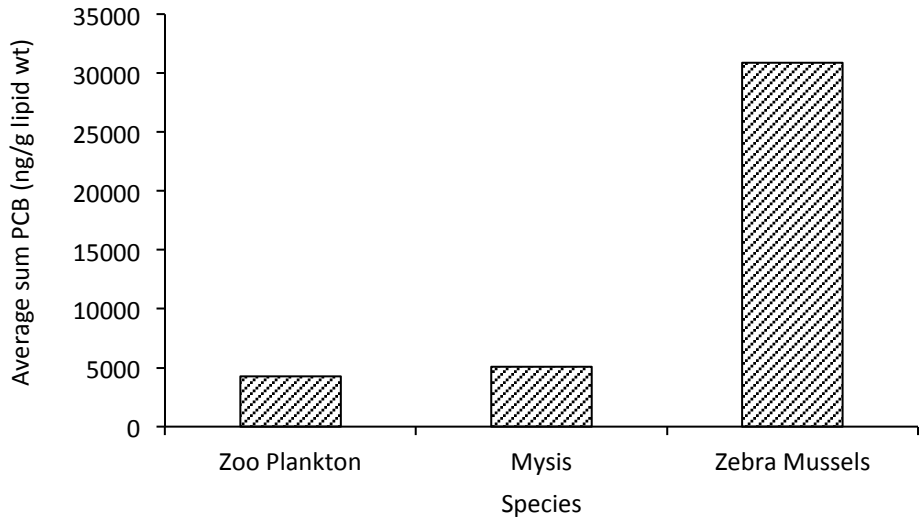

Figure 3. Average lipid corrected sum PCB concentrations (ng/g lipid wt) for Keuka Lake zooplankton, mysid shrimp and zebra mussels.

To investigate potential patterns associated with the degree of PCB chlorination, PCB congeners were assigned to their chlorination groups ranging from tri- to nona-chloro substitution. The log K_{OW} value increases as you increase the number of chlorine

substituents. The general trend for all samples was an increase in percent of sum PCB PCB from tri-chloro to hexa-chloro with hexachlorobiphenyls representing the greatest proportion of sum PCBs and then decreasing proportions from hexa-chloro to nona-choloro substitution (Figure 4). Figure 5 provides the average lipid corrected concentration for each chlorination group for zebra mussels, zooplankton and mysid shrimp. The average lipid corrected sum PCB concentrations showed zebra mussels to have much greater PCB concentrations when compared on a per lipid content basis. The percent contributions of individual PCBs were also compared against their respective log K_{OW} values (Figure 6). The general trend shows the highest contributions were for PCBs with log K_{OW} values from approximately 6.5 – 7.5 for all sample groups.

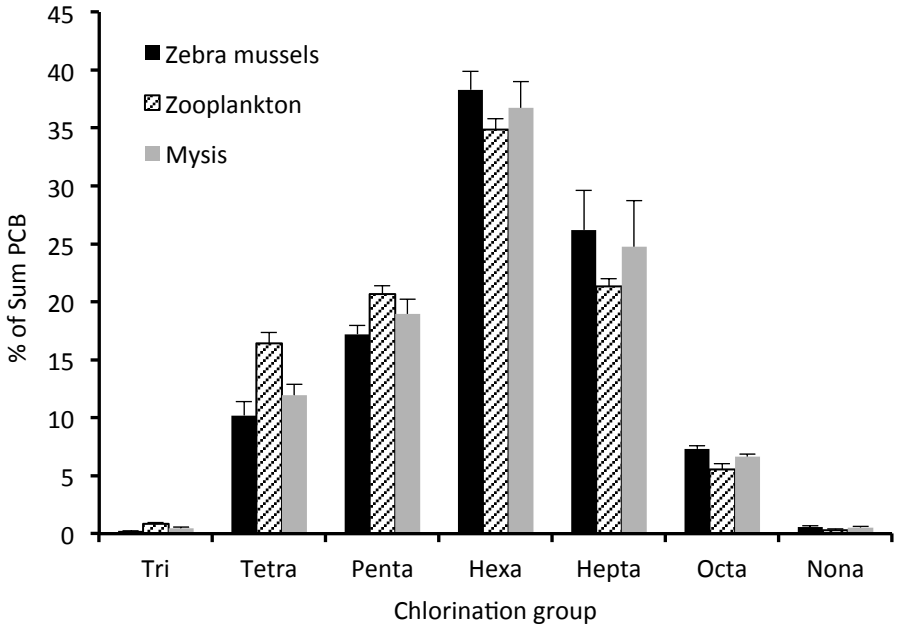

Figure 4. Proportional (%) contributions of PCB chlorination groups to sum PCBs quantified in Keuka Lake zooplankton, zebra mussels and mysid shrimp. Error bars indicate ± 1 standard deviation.

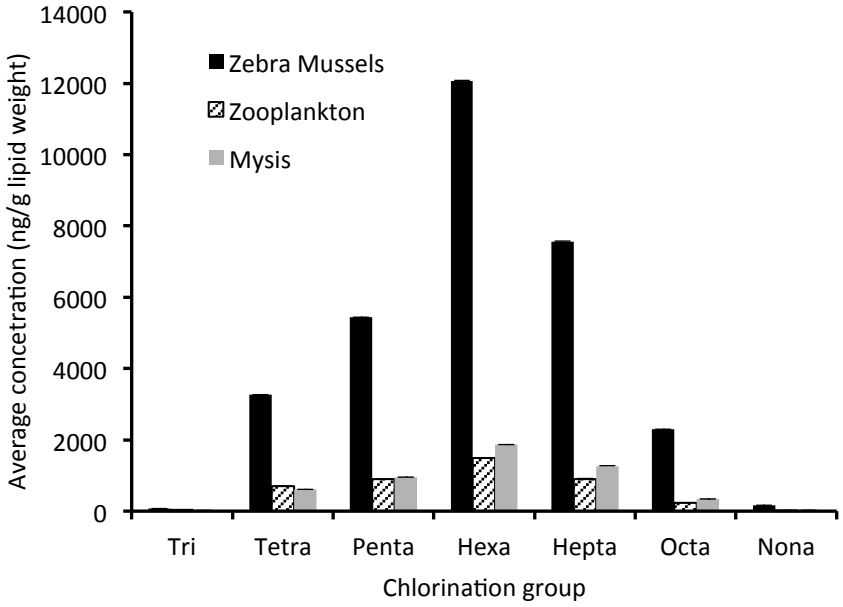

Figure 5. Average lipid corrected concentrations of PCB chlorination groups quantified in Keuka Lake zooplankton, zebra mussels and mysid shrimp.

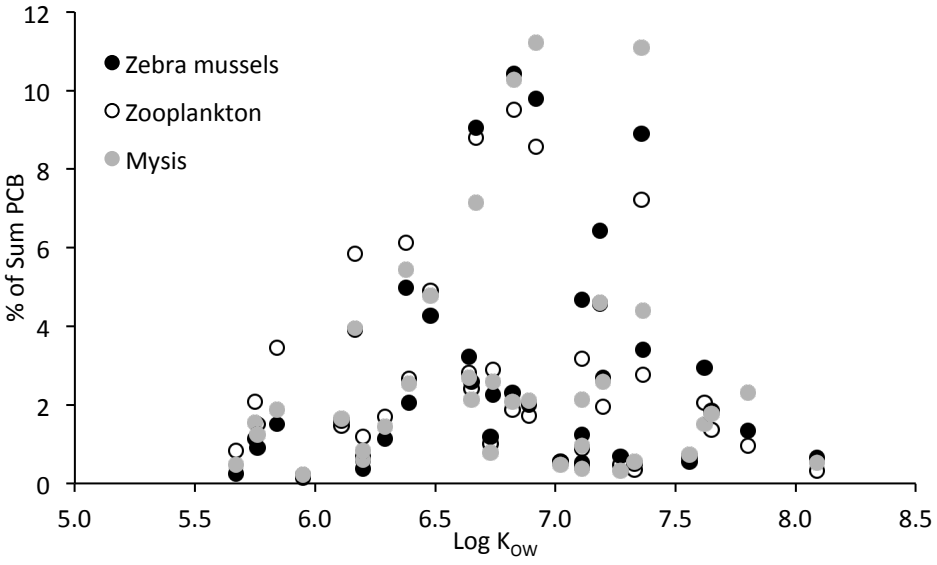

Figure 6. Relationship between percent contribution of individual PCBs (% of sum PCB) versus PCB congener hydrophobicity (log K_{OW}) in zebra mussels, zooplankton and *Mysis*.

In order to estimate the extent of PCB biomagnification by zebra mussels and mysid shrimp, lipid corrected PCB concentrations measured for these species were compared to those determined in zooplankton. This comparison provides an estimate of PCB congener biomagnification factors (BMF) for these species. If the biomagnification factor is greater than 1, this demonstrates that zebra mussels and mysid shrimp have biomagnified the PCB concentration relative to that measured in zooplankton. A plot of the relationship between individual PCB congener BMF values and their respective log K_{OW} values for zebra mussels and mysid shrimp is provided in Figure 7. The relationships between PCB congener BMF and log K_{OW} were positive for both zebra mussel ($R^2 = 0.712$) and mysid shrimp ($R^2 = 0.442$) samples with a steeper slope observed for zebra mussel samples.

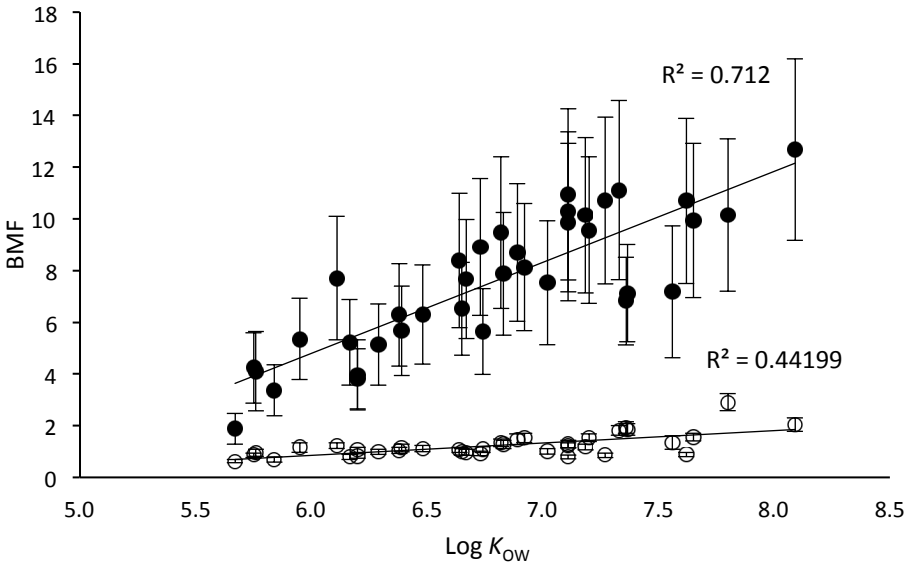

Figure 7. Relationship between PCB congener biomagnification factors for zebra mussels:zooplankton (●) and mysid shrimp:zooplankton (○) and congener hydrophobicity (Log K_{OW}).

A student's t-test was performed to test for significant differences in the magnitude of BMF values determined for zebra mussels and mysid shrimp. The BMF of zebra mussels was significantly higher with a p-value of less than 0.001.The average BMF value for zebra mussels was 7.199 and mysid shrimp was 1.183 (Figure 8).

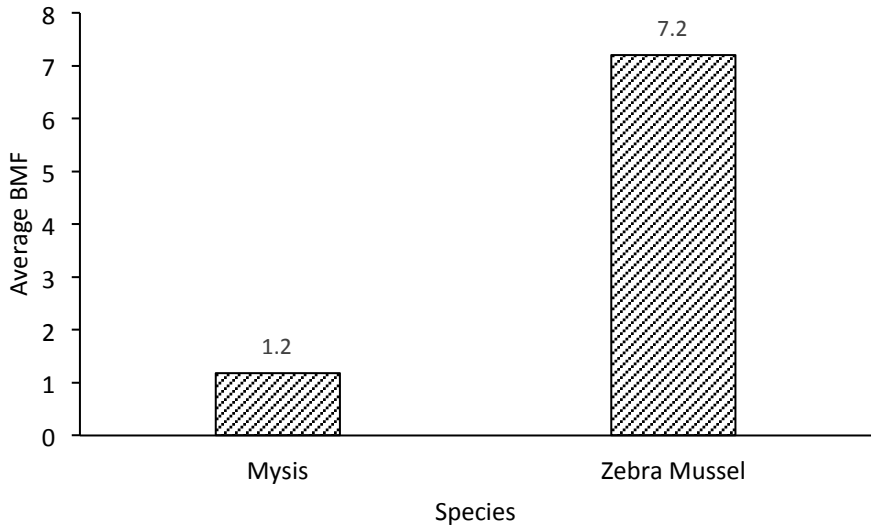

Figure 8. Average PCB congener biomagnification factors (BMF) determined between Keuka Lake mysid shrimp: zooplankton and also zebra mussels: zooplankton.

The average proportional contribution (%) of individual PCB congeners to the total PCB concentrations quantified in zooplankton are provided in figure 9. For zooplankton, PCBs 66/95, 101, 149, 153, 138 and 180 each contributed to ≥ 5 % of the total PCB concentration with PCB 138 having the highest individual contribution at approximately 9.5% of sum PCBs. Combined, these six congeners contributed to an average of approximately 46.0 % of the sum PCBs measured in zooplankton.

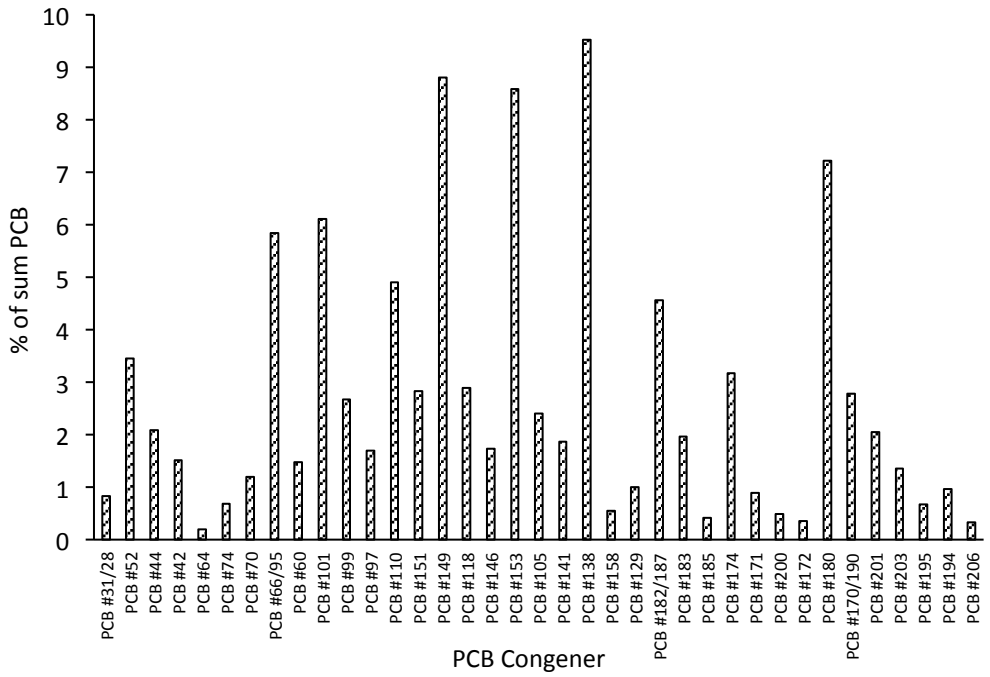

Figure 9. Proportional contributions (%) of individual PCB congeners to sum PCBs quantified in Keuka Lake zooplankton.

For zebra mussels and mysid shrimp, PCB 153 and PCB 138 were the predominant PCBs detected in samples (Figure 10). The PCB congeners 149, 153, 138 and 180 constituted approximately 37.7% of the sum PCBs quantified in zebra mussels with PCBs 66/95, 101, 110, 182/187 and 174 each contributing ≥ 4% to sum PCBs in these samples. Mysid shrimp PCB profiles were dominated by PCBs 66/95, 101, 110, 149, 153, 138, 187, 174, 180 and 170/190 with these peaks contributing to an average total of 61.5% of the sum PCBs quantified in mysid shrimp. For zebra mussels and mysid shrimp PCBs 138 and 180 represented the predominant congeners contributing to sum PCBs. Eight PCB congeners accounted for the majority of the total PCB concentration found in all three groups. The most common PCBs were congeners 66/95, 101, 110, 149, 153, 138, 182/187, 180. 153 and PCB 138. These were found in the greatest

concentration for all groups. Mysid shrimp also contained a higher concentration of PCB # 170/190.

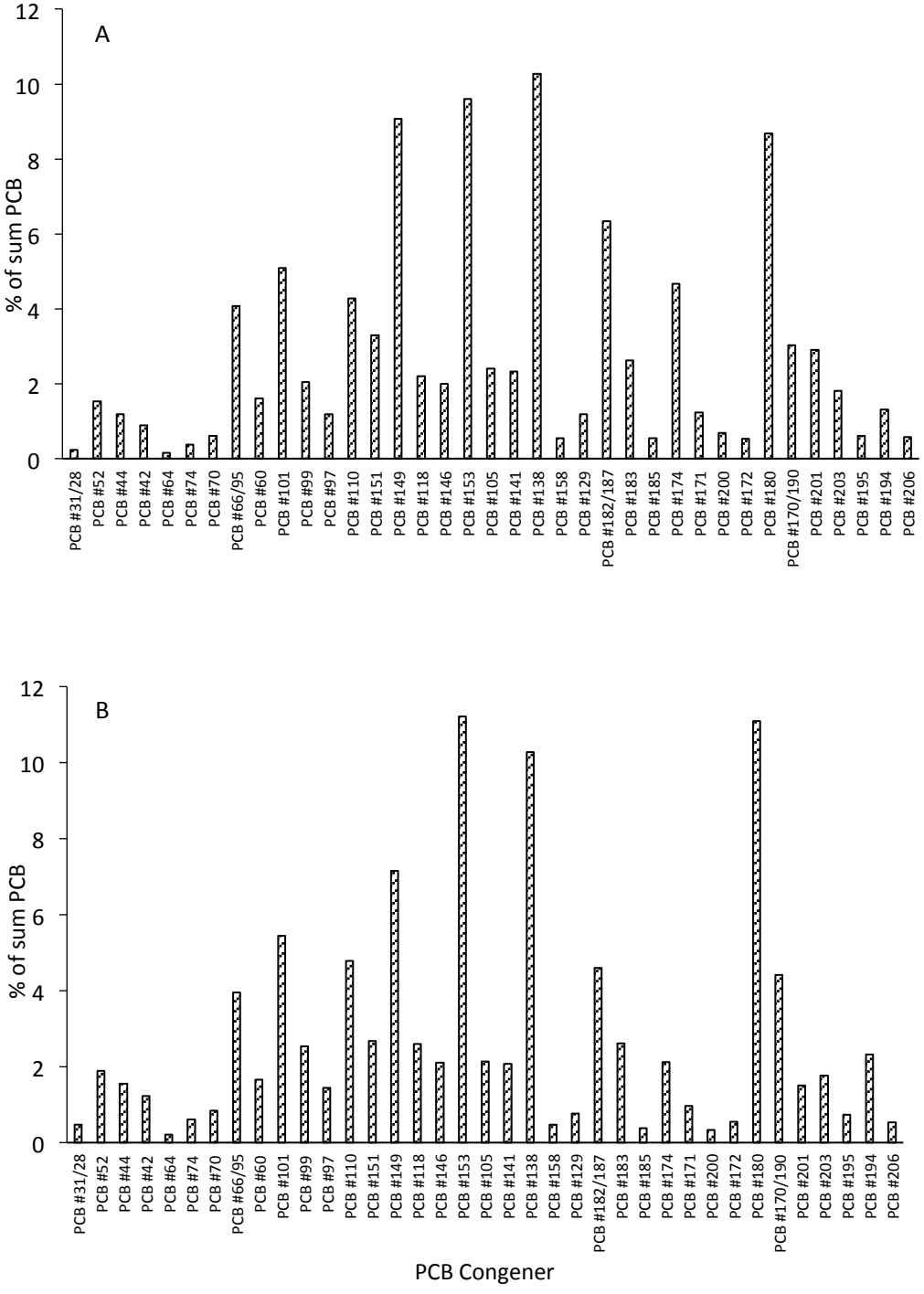

Figure 10. Proportional contributions (%) of individual PCB congeners to sum PCBs quantified in Keuka Lake (A) zebra mussels and (B) mysid shrimp.

Sum PCB concentrations quantified in mysid shrimp were positively correlated with the average total length of individual shrimp present in each sample (Figure 11; R^2 = 0.871). Linear regression analysis indicated that this relationship was statistically significant (p = 0.027).

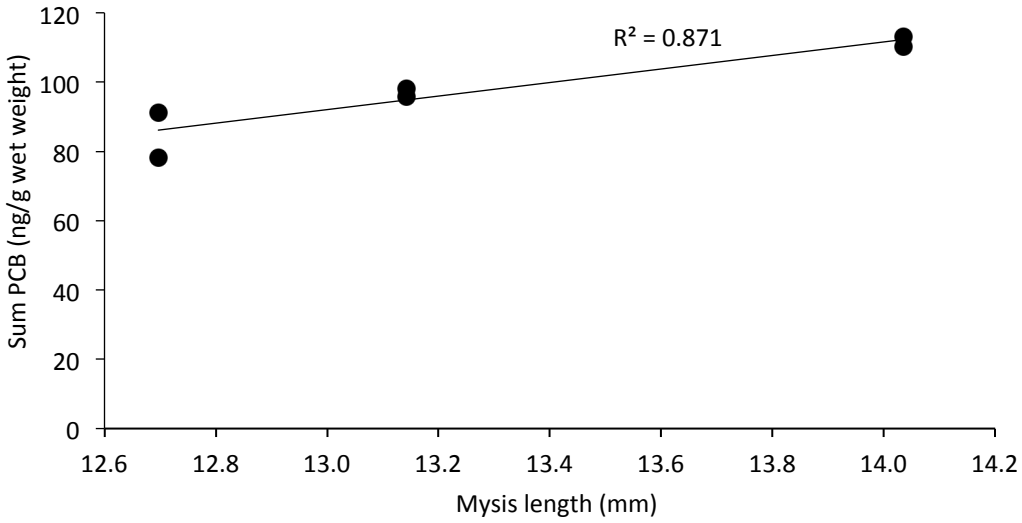

Figure 11. Relationship between wet weight sum PCB concentrations and total length for Keuka Lake mysid shrimp.

Discussion

Differences in lipid levels and PCB accumulation of each group

It was found that mysid shrimp had the highest average lipid content among the three species with zebra mussels having the lowest average lipid content. These lipid values can change depending on the season due to different ecological reasons. For example, zebra mussels collected post-spawning in the late summer may be lower in fat content and may not have had sufficient time to regain their lipid stores (Bruner et al., 1994). The high fat levels of mysid shrimp in this experiment can be justified by the

findings of Adare and Lasenby, (1994). They assessed the lipid content of mysid shrimp at different times throughout the year and found that mysid shrimp contain the highest lipid content from July to late August (Adare and Lasenby, 1994). Mysid shrimp may exhibit greater fat since they were also collected in late summer when it is likely they would be collecting fat for the winter, a phenomenon which is observed in many aquatic organisms (Brunner et al., 1994).

Wet weight sum PCB concentrations were highest for mysid shrimp samples which is associated with their higher lipid contents and ability to bioaccumulate chemicals relative to zebra mussels and zooplankton which had lower lipid contents. This agrees well with the hypothesis that that ability of an animal to accumulate PCBs in their tissues when considering the whole organism from a wet weight basis (Mackay, 1982). However, when compared only on a lipid weight basis, zebra mussels were found to have nearly 6 times higher PCB concentrations in their lipid tissues relative to mysid shrimp and significantly higher also in comparison to zooplankton samples. This difference suggests that the mysid shrimp still have much more capacity to accumulate PCBs in their fat stores relative to the lower fat content zebra mussels and zooplankton (Mackay, 1982). These differences may also be explained by physiological properties such as differences in feeding and age. Zebra mussels can live up to five years and are therefore exposed to PCBs over a long time period allowing them to maximize the amount of PCBs that accumulate in their limited fat content (Bruner et al., 1994). Zebra mussels also feed by constantly filtering particles from the water and because of this are likely exposed almost continuously to PCBs from such feeding (Bruner et al., 1994). In comparison, the mysid shrimp life-cycle can last up to a maximum of approximately 2-3

years and with their much higher fat content it will take longer for them to accumulate as much PCB in their fatty tissues. It is not known how old the shrimp were for this study (Adare and Lasenby, 1994). Mysids also feed on a range of items including lake sediments, zooplankton and phytoplankton which may have very different PCB concentrations relative to the particles consumed by zebra mussels (Adare and Lasenby, 1994). There was also a positive correlation between mysid shrimp body length and the extent of PCB accumulation. Mysid shrimp grow larger in size as they age and also increase in fat content (Adare and Lasenby, 1994). This significant positive relationship between mysid length and sum PCB concentrations indicates that mysids continue to bioaccumulate PCBs as they grow in size in Keuka Lake. This is important for fish predators that may consume mysid shrimp as larger shrimp are more likely to contribute to higher PCB concentrations in predator diets and lead to greater food chain biomagnification as described by Rasmussen et al. (1990).

Lipid tissues of organisms represent the primary compartment for the bioaccumulation of hydrophobic chemicals such as PCBs (Mackay, 1982). Bioaccumulation will occur when the rate of elimination of contaminants is less than the rate of uptake of contaminants (Brunner et al., 1994). As demonstrated in this study, PCBs bioaccumulated in zooplankton, zebra mussels and mysid shrimp relative to their increasing fat contents. Independent of lipid content, we observed that PCB concentration increased as we moved up the food chain from primary (zooplankton) consumers to secondary (mysid shrimp and zebra mussels) consumers. We also observed the biomagnification of PCBs between zebra mussels and zooplankton and also mysid shrimp and zooplankton. Assimilation of contaminants such as PCBs from the water into

the food chain starts with phytoplankton (Gobas, 1993). In a study investigating the bioaccumulation of PCB 153 in different phytoplankton species, Mazak et al., (1997) found that zooplankton feeding on certain species of phytoplankton will accumulate PCBs. Zooplankton are primary consumers and exist in a lower trophic level than zebra mussel and mysid shrimp, so we determined the level of chemical accumulation from one trophic level to the next. The average biomagnification factor from zooplankton to mysid shrimp was slightly greater than 1. This shows that mysid shrimp are accumulating greater amounts of PCBs than zooplankton, likely from their food source. Zebra mussels had an average BMF of 7.2. Since most aquatic organisms obtain organic contaminants from their diets rather than the water, the difference between these is most likely attributed to varying feeding behaviors (Evans et al., 1982). Although both are secondary consumers, mysid shrimp tend to feed only at night and reside in the sediment during the day (Evans et al., 1982). As stated before, this differs from the constant filtering behavior of zebra mussels.

Influence of compound hydrophobicity on biomagnification

The octanol:water partition coefficient is used to determine the hydrophobicity of a chemical (Hawker and Connell, 1988). The PCBs measured in the samples ranged in Log K_{OW} from 5.67-8.09 (Hawker and Connell, 1988). The most common PCB congeners ranged from tetra-chloro substituted to hepta-chloro substituted PCBs. The PCB congeners with the greatest concentration were PCB 138 and PCB 153. Oliver and Niimi (1988) provide a comparison of PCBs in Lake Ontario species including zooplankton and mysid shrimp. Their study results support our finding that these two congeners often occur in highest concentration in biological samples (Oliver and Niimi,

1988). Oliver and Niimi (1988) also suggested that it would be valuable to study the health effects of these particular PCB congeners to develop guidelines for fish consumption (Oliver and Niimi, 1988). The group of congeners found in greatest concentration was hexa-chloro substituted biphenyls. This is supported by the study of Mcfarland and Clarke, (1989) which demonstrated that a high proportion of environmental PCB contamination comes from this group. The low concentrations of lower chlorination groups may be due to the ability of organisms to break down and excrete these compounds more readily than the more hydrophobic ones (Fisk et al., 1998). The low abundance of the higher chlorination groups may also be due to their scarcity in the environment as these congeners were present in lower proportions in industrial PCB mixtures (Safe, 1994). The tri-chloro and tetra-chlorobiphenyl congener groups tend to be found in greater concentration in the lower trophic levels (Oliver and Niimi, 1988). Zooplankton samples in this study had a greater percent sum PCB of the tri-chloro and tetra-chlorobiphenyl than the zebra mussel and mysid shrimp. This finding was supported by Oliver and Niimi, (1988) who also elaborated that higher trophic levels contained higher amounts of greater chlorine substituted biphenyls. We would expect to find this trend to continue if greater trophic levels were studied. The biomagnification factor of PCBs also increased with greater hydrophobicity of the compound for zebra mussels and mysid shrimp. This trend is widely supported and shown in a study on yellow perch eggs. As log K_{OW} increased, there was an increase in fugacity, or accumulation (Daley et al., 2009).

Conclusion

Detectable concentrations of individual PCB congeners were quantified in each of Keuka Lake zooplankton, zebra mussels and mysid shrimp. This study also demonstrated that these pollutants can bioaccumuate and biomagnify even within the lower trophic levels of an aquatic food web. This is of great concern to top predators of the aquatic food web as they may accumulate unhealthy amounts of contaminants from their food sources. Some waterfowl may exploit invasive zebra mussels as a food source. A study done on waterfowl in the Great Lakes showed that proportions of PCB congeners found in waterfowl were consistent with the PCBs found in zebra mussels (Mazak et al., 1997). Lower reproductive success rates may be linked to the accumulation of these contaminants (de Kock and Bowmer, 1993). Ducks that consumed contaminated zebra mussels were found to have 60% less reproductive success due to abandoned nests, fewer eggs laid and greater chick mortality than ducks fed less contaminated zebra mussels (de Kock and Bowmer, 1993). The Keuka Lake food web is very similar to those present in the Great Lakes where PCB bioaccumulation and biomagnification continues to occur (Gobas, 1993). The results of this study indicate that PCB biomagnification in the lower trophic levels may be an important mechanism contributing to this problem. This is important to human health and the consumption of contaminated fish that are part of such food chains and represent the primary path of human exposure to pollutants such as PCBs.

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