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MERCURY, POLYCHLORINATED BIPHENYLS, SELENIUM, AND FATTY ACIDS IN TRIBAL FISH HARVESTS OF THE UPPER GREAT LAKES

Matthew J. Dellinger¹, Jared T. Olson¹, Bruce J. Holub², and Michael P. Ripley³

¹Institute for Health and Equity: Medical College of Wisconsin, Milwaukee, WI

²University of Guelph, Dept. of Human Health and Nutritional Sciences, Guelph, ON, Canada

³Chippewa Ottawa Resource Authority, Sault Ste Marie, MI, USA

Abstract

The Chippewa Ottawa Resource Authority monitors fish contaminants in Anishinaabe (Great Lake Native American) tribal fisheries. This paper updates previously reported trends in two Persistent Bioaccumulative Toxic (PBT) substances which are the primary contributors to consumption advisory limits for these fish: Methylmercury (MeHg) and Polychlorinated Biphenyls (PCBs). Also, we report for the first time, an analysis of nutritional benefit bioindicators and metrics in these same Upper-Great Lakes fish harvests: Selenium (Se) and Omega-3 Fatty Acids (PUFA-3s). A novel risk/benefit quantification originally presented by Ginsberg et al^(1, 2) is reported here to characterize the tradeoffs between fatty acid benefits and toxic MeHg health outcomes. We also report a Se benefit metric to characterize the possible protective value against MeHg neurotoxicity based on Ralston et al.^(3, 4) Congruent with Anishinaabe cultural motivations to consume fish from their ancestral fisheries, nutritional content was high in locally-caught fish and, in some respects, superior to farmed/store-bought fish. These Great Lakes fish still contained levels of PBTs that require careful education and guidance for consumers. However, the contaminant trends suggest that these fish need not be abandoned as important (both culturally and nutritionally) food sources for the Anishinaabe who harvested them.

Keywords

Mercury; Native Americans; Polychlorinated Biphenyls; Omega-3 Fatty Acids; Selenium

1. INTRODUCTION

The Chippewa Ottawa Resource Authority (CORA) in Sault Ste. Marie, Michigan, formerly through the Inter-Tribal Fisheries and Assessment Program (ITFAP), has been monitoring contaminant concentrations in the fillet portions of lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*) from the 1836 treaty-ceded waters of lakes Superior, Huron, and Michigan since 1991 (Figure 1). CORA represents the fisheries interests of five Ojibwa and Ottawa tribes (collectively called Anishinaabe) whose ancestors ceded lands through the 1836 Treaty of Washington⁽⁵⁾ but retained the rights to hunt and fish on those lands and waters. The contaminant monitoring program was initiated because the

CORA-regulated commercial fishery annually harvests about 2 million kg of lake whitefish and 0.5 million kg of lake trout from the three upper Great Lakes, and many Native American families derive income from the fishery.⁽⁶⁾ The Anishinaabe share a tradition of fish consumption and many locally caught fish serve as important cultural and nutritional resources.

Funding from the National Institutes of Health was secured in 2016 to investigate Mercury (Hg), fatty acids (including omega-3 and omega-6 polyunsaturated fatty acids (PUFA-3/6)), and selenium (Se) as part of a collaborative project titled: “An Anishinaabe Fish Consumption Advisory to Promote Environmental Health Literacy.”⁽⁷⁾ The purpose of this paper is to present, for the first time, contaminant and nutritional data on ten species of fish collected by CORA which were either purchased near Sault Ste. Marie Michigan or caught in the treaty-ceded waters. Two species, lake trout and whitefish, are routinely monitored by CORA while the other eight fish species are new additions to the sampling of fish, both wild caught and store-bought, available in the Great Lakes region.

The presence of Persistent Bioaccumulative Toxics (PBTs) in Great Lakes fish has created a need for fish consumption advisories and monitoring. These advisories may negatively impact fish consumption habits in unintended ways. Due to the cultural and nutritional importance of fish, CORA is collaborating with researchers from Medical College of Wisconsin, to improve advice by considering factors that may countervail risks from PBT exposure. Both selenium and PUFA-3 have been proposed as mitigating factors to PBT-related health risks in fish.^(8, 4, 9, 10) For example, it is well-documented that consumption of PUFA-3s from fish (eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)) reduces inflammation and lowers the risk of chronic diseases such as heart disease, cancer, obesity, type 2 diabetes, and arthritis.^(11–15, 1, 16–19) PBT exposures from fish are associated with many of the same risks that PUFA-3s counteract: cancer, diabetes, heart disease, metabolic disorders, and childhood developmental deficits.^(20–22, 1, 23–29, 11, 30)

Ginsberg et al.^(1, 2) have presented a method for comparing the benefits of PUFA-3 relative to the risks from MeHg in fish. The estimates consider adult cardiovascular disease risk and infant neurodevelopment risk. Like the methods that federal agencies use to derive reference doses for toxic agents, the Ginsberg et al. method uses published dose-response data to estimate predicted changes in risks to identical health endpoints (i.e. increased risk of heart disease mortality associated with MeHg compared to the decreased risk from the associated PUFA-3s). Although the method is not meant as a commentary on the biological mechanisms of MeHg toxicity, it is a useful indicator of health tradeoffs for consuming fish which are the almost exclusive exposure route for both MeHg and PUFA-3. We recently reported, using PUFA-3 data from non-CORA monitoring, that these estimates suggest considerable risk reductions to cardiovascular and neural developmental endpoints from consuming lake trout and whitefish in the 1836 treaty-ceded waters.⁽³¹⁾ Here, we compare updated contaminant data to PUFA-3 data in matched fish samples to derive a more accurate assessment of the risk/benefit estimates developed by Ginsberg et al.^(1, 2)

In addition to the benefits associated with PUFA-3s, selenium has also long been considered a beneficial nutrient because of its suspected role as a mitigating factor for methylmercury

toxicity.⁽³²⁾ For example, Ralston et al⁽³⁾ demonstrated that symptoms of Hg toxicity in rats is dependent on the relative intake of selenium and Hg, suggesting that selenoenzymes may be the molecular target of methylmercury. Ralston^(3, 4, 9) has proposed that weighted molar ratios of mercury and selenium be used to determine a selenium health benefit value (HBV_{Se}) for seafood. The HBV_{Se} accounts for the relative molar ratio of Se:Hg, as well as the absolute amount of each present, thus indicating the relative amount of dietary Se provided by the fish.. We have considered this model as well and applied it to ten fish species sampled in the treaty-ceded waters of upper Michigan.

Since the Anishinaabe share a culture of fish subsistence they are culturally motivated to consume locally-caught fish. When surveyed, Anishinaabe participants reported to eat 420g/week of fish, but when measured they consumed 78.4g/week of fish.⁽¹²⁾ By comparison, the EPA and United States Department of Agriculture (USDA) both recommend a safe and healthy fish consumption rate of 240g/week,^(33, 11) thus illustrating the unintended nature of the response to the EPA report. The Anishinaabe tend to overestimate fish consumption, suggesting a perceived importance of the food, congruent with the culture. However, the actual rate of consumption is considerably lower (below advisory recommendations and below levels known to be therapeutic for several health endpoints). Thus, the perceived risk from consuming fish normally associated with subsistence may be higher than intended. It is, therefore important to evaluate these species as holistically as possible (i.e. considering benefits as well as risks) so that tribal organizations can best advise their communities. Given the high prevalence of chronic diseases in these Native American populations, ^(20, 34–38) along with the need to safeguard infant neurodevelopment, these investigations are relevant for safeguarding population health and reducing health disparities that burden Native American communities.

2. METHODS

2.1. Fish Collection, Sample Preparation and Analysis

Fish sampling methods are identical to previous CORA monitoring.^(16, 31, 39) Methods for fish collection and analysis are also reported in Dellinger et al.⁽³⁹⁾ and Moths et al.⁽¹⁶⁾ The sampling design is based on EPA-approved methods^(12, 39, 16, 40) that were originally designed to compare to the Michigan Fish Contaminant Monitoring Program protocols.⁽⁴¹⁾ In summer 2016 CORA/ITFAP coordinated their monitoring efforts in collaboration with an NIEHS R21. Normally, twelve samples per species, per source (Lake Superior, Lake Michigan, and Lake Huron,) are sampled on a yearly rotation between lakes. The NIEHS R21 grant corresponded with Lake Superior sampling for lake trout and whitefish. Six traditionally caught species, including invasive (smelt), and four supermarket fish species (n=80) from tribal fishery (CORA) areas (Eastern Lake Superior) were selected for sampling to investigate the options available to Anishinaabe fish consumers. These species were targeted by CORA scientists with the input of local health professionals from the Inter-Tribal Council of Michigan to fill important data gaps in their recommendations of fish that are known to be commonly consumed by the Anishinaabe. Walleye were sampled from Lake Munuscong of the St. Marys River, a tributary of Lake Huron.

2.1.1 Fish Collection—The following six fish species from tribal fishery (CORA) areas were sampled: whitefish (*Coregonus clupeaformis*) (n=12), lake trout (*Salvelinus namaycush*) (n=12), walleye (*Sander vitreus*) (n=7), yellow perch (*Perca flavescens*) (n=7), herring (*Coregonus artedii*) (n=7), and smelt (*Osmerus mordax*) (n=7). Four species of fish not caught in subsistence areas, but were available for purchase, were selected by commercial names (n=7 each): farmed Atlantic salmon, light canned tuna, cod, and tilapia. Fish were weighed, measured, aged, and filleted before preservation by freezing at -20°C until sample processing. Standardized selection criteria were observed for accepted samples of lake trout and whitefish. Each year three fish were accepted per species for each of the following four target length ranges: 17 – 19in (431.8 – 482.6mm), 19.1 – 21in (485.1 – 533.4mm), 21.1 – 23in (546.1 – 584.2mm) and 23.1in – 25in (586.7mm – 635mm). Both lake trout and whitefish were collected from the same lake in three-year rotations, with collections occurring in Lake Superior in 1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013, and 2016; Lake Huron in 1993, 1996, 1999, 2002, 2005, 2008 and 2011; and Lake Michigan in 1994, 1997, 2000, 2003, 2006, 2009 and 2013. Total length in mm, whole weight (kg), and either scales or otoliths were collected from each fish. After biological sampling, each fish was wrapped in aluminum foil, labeled and frozen (-20°C) prior to analysis. Fish age was confirmed with scale or otolith examination. Prior to 1999, all fillets were prepared skin-on to more closely match non-tribal regulatory protocols. However, after 1998 fillets were prepared skin-off to match consumption advice from tribal health professionals.

2.1.2 Laboratory Analyses—The time between capture and lipid extraction was 2 weeks. The lipid data reported herein were analyzed at the DHA/EPA Omega-3 Institute, University of Guelph Ontario. Those methods included high performance capillary gas-liquid chromatographic analyses grade solvents and lipid standards obtained from Nu-Check Prep Inc.⁽¹⁶⁾ Sample processing for the years 1994–2006 was carried out by the Great Lakes Laboratory for Fisheries and Aquatic Sciences⁽³⁹⁾. Contaminant analyses from 2007–2016, including metals, was conducted at Axys Analytical, Ltd. of Sydney, British Columbia, Canada. Ten-gram tissue samples were mixed with anhydrous sodium sulfate and soxhlet extracted for 7 hours. Samples were then concentrated by rotary evaporation for lipid determination. Samples were then dissolved in petroleum ether and extracted four times with acetonitrile saturated with petroleum ether. Residues were then transferred to a glass chromatographic column containing 20 grams of Florisil. The column was then eluted with 200mL of 6% diethyl ether/94% petroleum ether (fraction A1) and then with 200mL of 15% diethyl ether/85% petroleum ether (fraction B1). Fraction B1 was then appropriately prepared for electron capture gas chromatography. Fraction A1 was then transferred to a Silicic column for additional cleanup. Following three additional extraction repetitions, samples were ready for contaminant quantification.

Sample processing for the years 1994–2006 was carried out by the Great Lakes Laboratory for Fisheries and Aquatic Sciences as described previously (60). For organochlorines and PCBs, homogenates of whole fish were thawed and a 5-gram portion was then transferred to a large (750mL) mortar to which anhydrous sodium sulfate was added. After thorough grinding, this mixture was transferred to a large chromatography column (22mm 199 internal diameter x 500mm length). Samples were then eluted with 300mL methylene

chloride at 200 10mL/min. Samples were then concentrated by rotary and nitrogen evaporation. Following gel filtration chromatography, sample extracts were pre-filtered with a 25mm, 0.5µm PTFE sterile filter unit during loading onto an Analytical Biochemistry Laboratories model 1002A gel permeation chromatography (GPC) unit. Samples were loaded into 5mL loops and the flow rate was set to 5mL/min. The column was packed with 60 grams of Bio Beads S-X3, 200–400 mesh (Bio-Rad Laboratories, Richmond, CA) in a 25mm x 600mm glass column. The elution solvent was 300mL of DCM:Hexane (1:1). Compounds of interest were eluted in the second 150mL fraction. Both 3% water deactivated and dry silica gel columns were prepared by packing glass

Contaminant values from the most recent sampling years are reported here and compared to previous trends and noted for consistency. Mean values of PBTs and PUFAs were used per sample-year of all samples for risk-benefit comparisons and comparisons to previous trend data. This provides an overview of how risks and benefits may change on average for various consumption scenarios. Very limited, and in most cases no, historical data from CORA sampling were available for comparison to the 2016 sampling of herring, perch, walleye, smelt, salmon, tuna, cod, and tilapia. For additional information on previous trend analysis and sampling see Dellinger et al (2012)⁽³⁹⁾

2.2. Calculation of Cardiovascular and Neurodevelopmental Risk/Benefit Metric

Ginsberg and Toal⁽¹⁾ selected studies from the literature^(23, 42, 25, 26, 8) to support an integrated risk/benefit analysis for adult cardiovascular and *in utero* neuro developmental end points on a species-specific basis. These studies describe dose-response relationships between MeHg (but not other contaminants such as PCBs), PUFA-3s, and common health endpoints for adults and fetuses. Mozzafarian and Rimm⁽⁸⁾ observed a 14.6% decreased relative risk to Coronary Heart Disease (CHD) per 100 mg/day of PUFA-3, whereas a 23% increased relative risk for CHD was observed per 1 ppm hair Hg by others.^(23, 42) The method therefore subtracts risk of adult CHD from MeHg (23% higher risk/1 ppm hair Hg) from the benefit (14.6% lower risk/100 mg PUFA-3). For fetal development (more sensitive) the method subtracts risk (3.5 VRM points/1 ppm maternal hair Hg) from the benefit (3.04 VRM points/100 mg maternal PUFA-3). This is based on observations of 6-month mother-infant pairs by Oken et al.⁽⁴³⁾ in which 2.0-point VRM increase per 100 mg/day of PUFA-3 was observed contrasted with a 7.5-point VRM decrease per 1 ppm hair Hg. Ginsberg et al.⁽²⁾ recently updated the model for infant neural development, which estimates changes in Visual Recall Memory (VRM points) in children who were exposed *-in utero* to material MeHg. These equations are as follows:

$$\begin{aligned} \text{Net risk/benefit for adult CHD} &= [(PUFA-3 \text{ mg/meal}) \times (\text{no. meals/week}) \times (1 \text{ week/7 days}) \times (14.6 \% \text{ lower risk/100 mg PUFA-3})] - [(hair \text{ Hg change/fish meal}) \times (\text{no. meals/week})] - (0.51 \text{ ppm hair Hg}) \times (23 \% \text{ higher risk/1 ppm hair Hg}) \\ \text{Net risk/benefit for infant VRM} &= [(PUFA-3 \text{ mg/meal}) \times (\text{no. meals/week}) \times (1 \text{ week/7 days}) \times (3.04 \text{ VRM points/100 mg PUFA-3})] - [(hair \text{ Hg change per fish meal}) \times (\text{no. meals/week}) \times (3.5 \text{ VRM points/1 ppm hair Hg})] \end{aligned}$$

2.3. Calculation of Selenium Health Benefit Value

The HBV_{Se} was calculated using Ralston's updated model.⁽⁴⁾ The method calculates the molar ratio of Se:Hg. The equation yields positive values when the amount of Se present in

the fish exceeds Hg (MeHg). This would indicate that health risks otherwise associated with MeHg exposures are negated because dietary Se available in excess of amounts sequestered by Hg remain bioavailable. Negative values indicate MeHg concentrations exceed Se; thus, maternal consumption of that food does not offer protection from its MeHg content but could instead disrupt Se transport to the fetus. The equation is as follows (units are in $\mu\text{mol/kg}$): $\text{HBV}_{\text{Se}} = ([\text{Se}-\text{Hg}]/\text{Se}) \times (\text{Se} + \text{Hg})$.

3. RESULTS

3.1. PBTs Burdens and General Observations

As observed elsewhere,⁽³⁹⁾ trout and whitefish from Lake Superior are less contaminated with PCBs than those from Huron and Michigan. In 2014 we reported a decreasing trend of PCB burdens in lake trout and whitefish collected by CORA from 1992–2011.⁽³⁹⁾ This remains the case, especially for Lake Superior, for both species (Figure 2). Mean total PCB from 2016 Lake Superior whitefish was 0.006 ppm compared to 0.013 from 1992–2011. The mean total PCB from 2016 Lake Superior lake trout was 0.04 ppm compared to 0.053 ppm from 1992–2011.⁽³⁹⁾ Hg burdens for these species fit with the previously reported increasing trend and were comparable to our previously reported Hg burdens (Figure 3).⁽³⁹⁾ In our most recent assessment (Lake Superior 2016, Table 1) the mean Hg concentration was 0.059 ppm for whitefish and 0.122 ppm for lake trout. Both findings are consistent with the previously observed Lake Superior trends in which mean Hg from 1992–2011 was 0.05 ppm in whitefish and 0.137 ppm in lake trout.⁽³⁹⁾

Table I displays mean total Hg and PCB for all years and lakes (i.e. Lake Huron and Lake Michigan) in which only lake trout and whitefish were sampled. These data also matched a continuation of the previously observed trends. Figures 2 and 3 include whitefish and lake trout data from the past two decades, 1996–2016, (i.e. including Lake Superior 2013 and Lake Michigan 2012).

3.2. Risk/Benefit Calculations Comparing PUFA-3 to Hg

Table II displays the data used to generate the PUFA-3/MeHg nutritional benefit metrics and results. All the fish tested, except for walleye, would impart benefits to reduce cardiovascular risk and promote neurodevelopment when assessed using the Ginsberg et al. (2009, 2016) methodology. This method assumes a benefit from all PUFA-3 not just EPA +DHA. Farm raised tilapia contained about a quarter of the total PUFA-3 found in walleye and imparted only marginal benefit because of the low levels of mercury found in tilapia. The fish that appears to impart the most benefit on average relative to its Hg content is lake trout, followed by farmed salmon (Table II). In general, the Ginsberg et al.^(1, 2) methodology applied to this Great Lakes dataset supports the notion that, when considered holistically, fish meals impart health benefits despite PBT burdens.

3.3. Se, Hg, and Se Health Benefit Values

Table III displays the data used to calculate beneficial value of Se relative to Hg and the resulting health benefit value by species. All HBV values were positive, suggesting that Hg toxicity may be counteracted by the selenoenzyme supporting activity of the selenium

content. Both walleye and tuna returned positive health benefit values despite having elevated Hg levels relative to the other fish. Counterintuitively, the lowest molar ratios of selenium to Hg and thus the lowest levels of health benefit were found in the fish that also had the lowest levels of Hg: farmed salmon, tilapia, and wild cod. This is due to low selenium values. All wild caught fish consistently contained sufficient selenium to achieve positive molar ratios but some of the individual farm raised fish did not. Four of the seven farmed salmon and one of the seven tilapias were below the level of detection for selenium.

4. DISCUSSION

4.1. Exploring Risk and Benefit Estimates of Fish in the Anishinaabe Fisheries

4.1.1 Contaminant Trends—These monitoring results are meant to represent fish regularly harvested and consumed by the Anishinaabe. Confirmation that ongoing monitoring of PBT concentrations match what was previously reported instills confidence that the updated CORA database will be useful for generating consumption advice and education for the local fishing populations. This is the first report of estimated PUFA-3 and selenium benefits in the longstanding CORA/ITFAP monitoring program. This is also the first time PBT and nutritional benefit data have been included in the same monitoring efforts for ten fish locally consumed by the Anishinaabe who rely on the 1836 treaty-ceded fisheries. It has been observed elsewhere that PCBs are decreasing in Great Lakes fish,^(44–47) in Anishinaabe tribal fish harvests,⁽³⁹⁾ in the Anishinaabe people,⁽²⁸⁾ and in the general population.⁽⁴⁸⁾ Though not intended as a formal analysis of contaminant trends, the current (2016 Lake Superior) PBT results conformed to our previous observation that PCBs in lake trout and whitefish are declining. In the Great Lakes, the tissue burdens of some traditionally important (to the Anishinaabe) species of fish are high enough to merit careful continued guidance. The guidance should encourage consumption of fish without exceeding PBT recommendations that CORA and others state and tribal advisories have adopted. Advisories should also consider the size, source, and species of fish in preparing their recommendations.

4.1.2 PUFA-3 Benefits—Novel methods that are still evolving in the literature to allow risk/benefit estimations using selenium^(3, 4, 9) and PUFA-3^(1, 2) compared to Hg. We previously applied the Ginsberg et al^(1, 2) model to Hg levels in CORA fish but relied on outside data for mean PUFA-3.^(31, 49) We had reported that the model reveals considerable benefits to both adults and infants when considering Hg relative to PUFA-3 from consuming Great Lakes whitefish and lake trout. The current analysis confirms for the first time that these, and at least two other traditionally wild-caught fish (herring and perch), could impart PUFA-3 benefits even when adjusted for Hg, but not PCB, contamination. Ginsberg et al. are currently working on a model to include PCBs in the risk/benefit model.⁽⁵⁰⁾ The benefit estimates in Table II use an assumed meal of 6oz. Most species sampled here can be consumed at least once per week (6oz/week) without exceeding the Agency for Toxic Disease Registry (ATSDR) minimal risk levels on both MeHg (0.3µg/kg/day) and PCBs (0.02µg/kg/day) to for an average 81kg adult. Lake Michigan trout could be consumed twice a month using these assumptions. For lake trout and whitefish, the limiting factor is still

PCB contamination (using ATSDR standards). Childbearing women and children may want to observe more conservative intakes.

For the most part, non-traditional fish also imparted PUFA-3 benefits, especially farmed salmon which are high in lipids. The farmed salmon, however, contain large amounts of PUFA-3 but even more PUFA-6 (Table II). Reduced PUFA-3 and increased PUFA-6 in farmed fish has been observed elsewhere,⁽⁵¹⁾ especially for tilapia.⁽¹⁷⁾ This is unsurprising since terrestrial feeds are devoid of EPA and DHA (the PUFA-3s for which the most evidence of benefit exists) which are primarily propagated through aquatic food chains.⁽⁵¹⁾ PUFA-6s are considered inflammatory as well as antagonistic to the *de novo* production of EPA and DHA when their intake is low (i.e. low fish/seafood consumption). A higher ratio of PUFA-3/6 in overall diet has been suggested as beneficial.^(52–54) PUFA-3/6 ratios may serve as a helpful indicator when comparing fish to one another. However, PUFA-3s from both fish/seafood and plant sources may reduce CHD risk with little apparent influence from background PUFA-6 intake. Since PUFA-6s may compete with plant-based PUFA-3 metabolism (into EPA/DHA), increasing plant-based PUFA-3s (relative to PUFA-6) may reduce CHD risk when seafood-based PUFA-3 (EPA+DHA) intake is low.⁽⁵⁵⁾ Given the interference of PUFA-6 with *de novo* EPA/DHA enrichment within the body from plant-based PUFA-3s, the elevated presence of total PUFA-3 relative to PUFA-6 in all wild-caught fish is a noteworthy advantage considering the cultural interest in these fish.

4.1.3 Selenium Benefits—Ralston's health benefit value for Se outlines an intriguing premise that Se-enriched diets not only prevent MeHg toxicity, but can also rapidly reverse some severe symptoms of excessive exposure to Hg from dietary sources.^(9, 56) Hg has strong binding affinities for Se, MeHg exposure therefore sequesters Se, directly impairing Se-dependent enzymes (selenoenzymes) activities and their synthesis. This causes irreversible inhibition of selenoenzymes. Selenoenzymes are necessary to ameliorate oxidative damage throughout the body, particularly in the brain and neuroendocrine tissues. This could explain why studies of maternal populations exposed to foods that contain Hg in molar excess of Se, such as shark or pilot whale meats,⁽⁵⁷⁾ have observed adverse child outcomes whereas studies of populations exposed to MeHg by eating Se-rich ocean fish^(58, 59) observe improved neurodevelopmental outcomes instead of harm.^(4, 59) An alternative explanation is the elevated PCB in pilot whales relative to fish from other studies. Ralston⁽⁹⁾ points out that since the Se contents of freshwater fish are dependent on local soil Se status, fish with high MeHg from regions with poor Se availability may be cause for concern. The present data from Lake Superior sampling demonstrate that Se is adequately available in locally caught, freshwater fish, to meet Ralston's^(4, 9) criteria for a health benefit value of selenium relative to MeHg.

Just as the farmed fish sampled by CORA were higher in PUFA-6, these fish also tended to lack Se. On average, the HBV_{Se} for farmed salmon and tilapia were positive. However, these two species were the only farmed fish in the sample analyzed by CORA/ITFAP and the only fish to return non-detects on Se. Further study is warranted to investigate the dietary health value of farmed fish relative to wild fisheries. Wild caught diets are often assumed to impart more benefits than those more reliant on mass-produced foods. Approaches that assess both dietary nutrients and contaminants simultaneously may provide evidence to support this

claim. It would also be useful to investigate the differences in health outcomes of populations who consume mostly wild fish and those who consume only farmed. This is of great interest to organizations who wish to support the subsistence cultures of their communities, as is the case with CORA and the Anishinaabe.

4.2. Closing Thoughts: Fish Consumption as Natural Resource Stewardship

This sampling was part of a larger effort to communicate important advice and environmental data to the populations who are served by CORA. Monitoring efforts must strive to provide the clearest picture possible on environmental conditions for the public. A clear picture includes the positive aspects of environmental monitoring and stewardship in addition to the vigilance required to reduce PBT emissions. Over 14 years of collaborations with CORA and other tribal consortia throughout the Great Lakes region have repeatedly demonstrated that Native American populations feel demoralized when the benefits of fish consumption are omitted from advisories which are instead focused solely on contaminants. Data like those reported here should be added to fish consumption advisories to support the mission of improving the environmental health of the Great Lakes region and the health of Great Lakes populations.

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Social Media Summary

This paper presents fish tissue burdens of: Methylmercury and Polychlorinated Biphenyls and estimates health benefits from selenium and omega-3 fatty acids. These Upper Great Lakes fish present health benefits balanced against risks.

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Figure 1.
The Treaty-ceded territories associated with the U.S. Upper Great Lakes Anishinaabe tribes. Tribal commercial fishing is monitored by The Chippewa Ottawa Resource Authority (CORA) and Great Lakes Indian Fish and Wildlife Commission (GLIFWC).

Figure 2. Raw data for total PCB concentrations (ppm) across time (years 1996–2016) for whitefish and lake trout from Lake Huron, Lake Michigan and Lake Superior (n=12 for each species, per year, per lake). The trendline represents the linear least squares regression of all data points

Figure 3.

Raw data for total Hg concentrations (ppm) across time (years 1996–2016) for whitefish and lake trout from Lake Huron, Lake Michigan and Lake Superior (n=12 for each species, per year, per lake). The trend line represents the linear least squares regression of all data points.

Table 1

Mean and Standard Deviation (SD) total Hg and PCBs found in fish tissues

Species	Source	Date Sampled	N	Mercury (SD) ppm	PCBs (SD) ppm
Walleye	Lake Huron *	2016	7	0.436 (0.194)	0.067 (0.098)
Smelt	Lake Superior	2016	7	0.065 (0.009)	0.011 (0.001)
Herring	Lake Huron	2016	7	0.068 (0.014)	0.026 (0.006)
Perch	Lake Huron	2016	7	0.069 (0.040)	0.003 (0.002)
Whitefish	Lake Superior	2016	12	0.059 (0.014)	0.006 (0.002)
Whitefish	Lake Huron	2014	12	0.084 (0.036)	0.034 (0.015)
Whitefish	Lake Michigan	2015	12	0.127 (0.031)	0.031 (0.013)
Lake Trout	Lake Superior	2016	12	0.122 (0.041)	0.040 (0.016)
Lake Trout	Lake Huron	2014	12	0.118 (0.026)	0.079 (0.029)
Lake Trout	Lake Michigan	2015	12	0.133 (0.042)	0.138 (0.064)
Tuna	Store	2016	7	0.234 (0.033)	0.0004 (0.0001)
Salmon	Store	2016	7	0.005 (0.001)	0.002 (0.0005)
Cod	Store	2016	7	0.033 (0.028)	0.0001 (0.0001)
Tilapia	Store	2016	7	0.003 (0.000)	0.0001 (0.00003)

* St. Marys River

Table II

Data and risk estimates for ten fish collected in 2016 from the 1836 treaty-ceded waters and local markets. PUFA-3 is reported in mg/100g for comparison to other literature, risk estimates are based on 6oz per meal for comparison with Ginsberg et al (2009, 2015). Negative number indicate decreased CHD risk.

Species	XHg(ppm)	PUFA-3 (mg/100g)	PUFA-6 (mg/100g)	PUFA-3 (mg/6oz)	CHD risk	VRM net
Walleye	0.436	244.1	118.8	415.2	20%	-4.27
Smelt	0.065	624.2	250.3	1061.8	-22%	3.71
Herring	0.068	783.3	385.0	1332.4	-28%	4.84
Perch	0.069	221.7	66.6	377.1	-8%	0.68
Whitefish	0.059	724.5	269.3	1232.4	-26%	4.53
Lake Trout	0.122	2395.3	1095.4	4074.4	-85%	15.99
Tuna	0.234	578.5	115.1	984.0	-11%	1.01
Salmon	0.005	1902.7	2122.5	3236.5	-68%	13.99
Cod	0.033	307.1	26.1	522.4	-11%	1.81
Tilapia	0.003	61.4	221.7	104.4	-2%	0.41

Table III
Mean and standard deviation total Hg, Se, and Health Benefit Values (HBV_{Se}) based on Ralston et al. (2016)

Species	Hg (ppm)	Se (ppm)	$\mu\text{mol (Hg/kg)}$	$\pm$ SD	$\mu\text{mol (Se/kg)}$	$\pm$ SD	HBV _{Se}	$\pm$ SD
Walleye	0.436	0.496	2.174	0.900	6.287	1.066	5.536	0.306
Smelt	0.065	0.510	0.324	0.044	6.459	0.606	6.443	0.603
Herring	0.068	0.645	0.339	0.154	8.169	1.837	8.155	1.824
Perch	0.069	0.635	0.344	0.184	8.047	2.009	8.033	1.992
Whitefish	0.059	0.581	0.294	0.066	7.358	2.316	7.346	2.314
Lake Trout	0.122	0.579	0.608	0.191	7.329	0.983	7.278	0.946
Tuna	0.234	0.624	1.167	0.154	7.908	0.370	7.736	0.306
Salmon	0.005	0.242	0.025	0.003	3.059	4.600	3.059	4.600
Cod	0.033	0.347	0.165	0.130	4.391	1.076	4.385	1.061
Tilapia	0.003	0.279	0.015	0.002	3.539	2.024	3.539	2.024