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Fatty Acids in Ten Species of Fish Commonly Consumed by the Anishinaabe of the Upper Great Lakes

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Abstract

The Chippewa Ottawa Resource Authority (CORA) in Sault Ste. Marie, Michigan, has been monitoring contaminant concentrations in the fillet portions of fish from the 1836 treaty-ceded waters of lakes Superior, Huron, and Michigan since 1991. The goal is to provide up to date consumption advice for their CORA member tribes. For the first time since the program started, CORA has included fatty acid analysis in 2016 monitoring of fish in Lake Superior. Ten species were targeted by CORA based on 25 years of experience and regular discussions with Anishinaabe fish consumers. This paper reports these results and presents some preliminary discussion of the consequences for consumption advice for the CORA member tribes who inhabit the Great Lakes region. Six of the species were sampled from Lake Huron and Lake Superior and four were sampled from supermarkets. Wild caught fish are an important link to the culture of Great Lakes Native American tribes and important sources of food and omega-3 polyunsaturated fatty acids (PUFA N-3). While some PUFA N-3 data from the Great Lakes is available, this dataset provides an important supplement and is specific to the 1836-treaty ceded waters of CORA. This paper confirms the presence of PUFA N-3s in Great Lakes fish traditionally harvested by the CORA tribes.

Keywords

Great Lakes sport fish; PUFA-N3; fatty acids; tribal harvests; Native Americans

Introduction

The Chippewa Ottawa Resource Authority (CORA), previously through the Inter-Tribal Fisheries and Assessment Program (ITFAP), in Sault Ste. Marie, Michigan, has been monitoring contaminant concentrations in the fillet portions of lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*) from the 1836 treaty-ceded

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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) around Michigan ceded through the 1836 Treaty of Washington. The contaminant monitoring program was initiated to assist with the development of consumption recommendations for certain fish species (targeted by the tribes due to regional, cultural, and commercial significance). The CORA fish consumption advisories are thus created for and by the Anishinaabe tribes. In addition to the cultural importance of fish subsistence, 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 (Taylor and Ferreri, 2000).

Consumption of many wild caught ocean fish may also provide considerable benefits from consumption of polyunsaturated fatty acids (PUFA). It is important for organizations such as CORA, however, to highlight the value of the local fish caught and consumed by the populations they serve. Our extensive work with these groups through focus groups and outreach have demonstrated the need for cultural contextualization of the entire risk assessment process, including monitoring (Dellinger et al., 2017). Many tribal members will ignore advice that is perceived as negative towards their cultural practices. The CORA monitoring program therefore works to characterize the positive aspects of the culturally-important local species. This focus (including the beneficial PUFA N-3 content of the fish monitoring program) is meant to promote trust, interest, and enthusiasm within the Anishinaabe tribes who receive the eventual advice. The data reported here support the efforts to provide nutritional benefit data collected by and for Anishinaabe tribal fish consumers.

Funding from the National Institutes of Environmental Health Science (NIEHS) was secured in 2016 to investigate PUFA N-3 during otherwise routine harvests and CORA contaminant monitoring. The primary purpose of this paper is to present, for the first time, polyunsaturated fatty acid (PUFA) data that will be used to develop recommendations on ten species of fish collected by CORA which are purchased near Sault Ste. Marie Michigan or caught in the treaty-ceded waters. We also discuss the implications of using these results in recommendations which are in development with ongoing collaborations with CORA (Dellinger et al., 2017). Although other datasets indicate the presence of omega-3 (PUFA N-3) polyunsaturated fatty acids in many fish from the Great Lakes region (Williams et al., 2014, Pantazopoulos et al., 2013, Wang et al., 1990) it is important to confirm that the CORA recommendations can be built using their own data for their populations.

The presence of Persistent Bioaccumulative Toxics (PBTs) in Great Lakes fish has created a need for fish consumption advisories. Polychlorinated biphenyls (PCBs) and methylmercury (MeHg) are most prevalently featured in fish consumption advisories. These advisories may negatively impact fish consumption habits in unintended ways. It is well documented that abandonment of traditional foods is a nutritional health risk for indigenous North Americans (Sheehy et al., 2015, Sharma, 2010, Ho et al., 2008, Schell, 2012, Johnson et al., 2009, Johns et al., 2013, Whiting and Mackenzie, 1998). Therefore, concerns regarding the loss of nutrition have been added to the concerns of incurring health risks from eating PBT contaminated food. For example, the most recent estimate of measured Anishinaabe fish

consumption is 2 ounces per week, about one third of the daily fish intake recommended by many federal agencies (U.S.EPA, 2004, USDA, 2005, USDA, 2015) despite their heritage as a fishing culture (Quaife, 1947, Dellinger, 2004, Dellinger et al., 2012). We previously reported that benefits from PUFA N-3 from these fish could be substantial (Dellinger and Ripley, 2016). This conclusion was drawn from published PUFA data (Williams et al., 2014) that was not part of CORA sampling. CORA has documented PUFA N-3 content in seven Lake Superior siscowet lake trout (*Salvelinus namaycush siscowet*) (Moths et al., 2013). Aside from this, PUFA N-3 content in the tribal fish harvests monitored by CORA could only be inferred from non-tribal, published data.

Methods

Fish Collection and Fatty Acid Analysis

CORA has monitored contaminants in two important subsistence species, lake trout and whitefish, for over 20 years (Moths et al., 2013, Dellinger and Ripley, 2016, Dellinger et al., 2014). CORA added eight species of locally caught or purchased fish to their 2016 monitoring work. 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. Methods for fish collection and analysis are also reported elsewhere (Dellinger et al., 2014, Moths et al., 2013). The sampling design is based on CORA methods approved by the Environmental Protection Agency (Dellinger, 2004, Dellinger et al., 2014, Moths et al., 2013, ITFAP, 2008) that were originally designed to compare to the Michigan Fish Contaminant Monitoring Program protocols (MDEQ, 1995). Normally, twelve samples per species, per source (Lake Superior, Lake Michigan, and Lake Huron,) are sampled on a yearly rotation between lakes. Here we report Lake Superior and Lake Huron sampling (summer 2016). Six traditionally caught and four supermarket fish species from tribal fishery (CORA) areas were selected for sampling to investigate the options available to Anishinaabe fish consumers.

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 available for purchase locally, were selected by commercial names (n=7): farmed Atlantic salmon (fillets), tuna (canned light), cod (fillets), and tilapia (fillets). Lake Superior fish were weighed, measured, aged, and filleted (if not already done) before preservation by freezing at -20°C until sample processing. The time between capture and lipid extraction was 2 weeks.

The lipid data on fatty acid including omega-3 fatty acid compositions as EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) were analyzed at the DHA/EPA Omega-3 Institute, University of Guelph, Ontario. The methods included high-performance capillary gas-liquid chromatographic (GLC) analyses of the fatty acid methyl ester derivatives as prepared from the fish lipid extracts using standard fatty acid mixtures for identification. The methodology is similar to that reported previously (Moths et al., 2013).

Total lipid extraction of measured weights of the ground representative fish samples was performed via homogenization in a Waring blender in the presence of a chloroform/methanol solvent and known amounts of tridecanoin (internal standard from Nu Chek Prep, Elysian, MN, USA) for subsequent quantitation of the fatty acids present therein following GLC analyses. The Bligh and Dyer method (Bligh and Dyer, 1959), as developed for extracting lipids from fish, was used. It has been established to be more efficient than other methods for extracting both polar and non-polar lipids. This method provides a minimum lipid extraction efficiency of at least 90% (Xiao et al., 2012).

A known aliquot of the total lipid extract (lower chloroform phase) was taken for transmethylation of the fatty acids present therein (Morrison and Smith, 1964). The fatty acid methyl esters were prepared using boron trichloride in methanol and heating the methylation tubes in a boiling water bath. The resulting fatty acid methyl esters were analyzed on a Varian 3400 gas-liquid chromatograph (Palo Alto, CA) with a 60 meter DB-23 capillary column (0.32 mm internal diameter) using a standard mixture (qualitative and quantitative) with the known fatty acid components including EPA (20:5 n-3) and DHA (22:6 n-3) for verifications (authentic standard mixtures from Nu Chek Prep, Elysian, MN, USA). Based on the fixed compositions (known percentages) of 24 different commonly-occurring fatty acids in standard mixtures obtained from Nu Chek Prep (Elysian, MN), the GLC recoveries for the various fatty acids were 102.3 % (+/- SD 2.3 %) (+/- SE 0.5 %) and were 102.8 % and 105.5 % for EPA (20:5 n-3) and DHA (22:6 n-3), respectively. GLC analyses revealed the recovery for the various long-chain fatty acid standards relative to the shorter chain (palmitic acid, 16:0) to be 99-105 %. The variance (SD) based on replicate analyses for the major fatty acids is well below 2% and below 5% for the minor fatty acids.

Results and Discussion

FA in Anishinaabe Harvests and Store-Bought Fish

Summary data for the fish samples are displayed in Table 1. Fish weight varied somewhat with walleye varying the most (27% coefficient of variation, CV). Length, often used to fine-tune consumption advice, varied less ranging from 5% CV in perch to 12% CV in lake trout. Total Fatty Acid (FA) content (mg/100g wet weight) varied considerably within fish species. Perch was the leanest fish and the fattiest was farmed salmon. A summary of fatty acid concentrations in fish are displayed in Table 2. Amounts of PUFA N-3 and PUFA N-6 in fish species varied considerably with cod varying the least and whitefish varying the most. Farmed salmon varied the most in PUFA N-6 content. Lake trout was also quite variable in both PUFA N-3 and PUFA N-6 content. This was largely driven by two outliers. One trout was exceptionally lean (530.1 mg/g PUFA N-3 and 281.6 mg/g PUFA N-6) and another very fatty (4,331.7 mg/g PUFA N-3 and 1,996.9 mg/g PUFA N-6).

Overall, the highest mean PUFA N-3 levels were found in locally caught Lake Trout followed by farmed salmon (mean: 2,395.3 mg/100g and 1,902.7 mg/100g respectively). Lake trout sampled by CORA contained nearly double the PUFA N-3 levels found in mixed trout species in the Canadian Nutrient File (CNF, which incorporates data from the United States Department of Agriculture (USDA))(Canada, 2017). Mean total PUFA-3s found in CORA-sampled lake trout were also greater than those found in other studies from Lake

Superior (Williams et al., 2014, Pantazopoulos et al., 2013) and the CORA-sampled whitefish were mid-range between those sampled from recent similar studies (Williams et al., 2014, Pantazopoulos et al., 2013). PUFA-3 content may vary depending on the season sampled, differences in diet, or differences in the waterbody types that were sampled (Williams et al., 2014). The leanest of the Great Lakes fish from CORA sampling was yellow perch (221.7 mg/100g fish). The lowest concentrations of PUFA N-3 found in this study was in Tilapia (61.4 mg/100g fish) which was nearly a quarter of what the CNF reports. Total PUFA N-3 data from the CNF for smelt, herring, perch (mixed species), whitefish, and farmed Atlantic salmon sample were all within one standard deviation of the data reported here for the same fish. Tuna from this sample was roughly two standard deviations and cod five standard deviations greater in total PUFA-3 than what the CNF reports.

Figure 2 displays the proportions of all fatty acids for each species of fish. Other studies have implicated tilapia as containing unfavorable fatty acid profiles (Weaver et al., 2008). In addition to containing relatively low PUFA-3 and high PUFA-6 tilapia from this sampling was also highest in saturated fatty acids (Figure 2). Considerable differences were observed for ratios of PUFA N-3 and PUFA N-6 (Table 2). Leaner fish tended to have higher PUFA N-3/6 ratios. The highest PUFA N-3/6 ratio observed was 11.81 in cod followed by Tuna (5.01). The highest PUFA N-3/6 ratio among the Great Lakes fish was in perch (3.46). All local wild fish had high PUFA N-3/6 ratios (2.2 and greater) whereas farmed fish, salmon and tilapia, both had poor ratios (0.93 and 0.28 respectively). This deviated somewhat from the CNF database in which farmed Atlantic salmon has as ratio of 2.50. Williams et al. (2014) observed that, despite differences in absolute concentrations of PUFAs, fish species analyzed as part of their study had mean PUFA-3/6 ratios that were similar to mean ratios reported in previously published research. This was also true of the current study in which PUFA-3/6 ratios from CORA-sampled Lake Superior lake trout and whitefish were close to those previously reported (2.1 - 2.2 in Pantazopoulos et al. 2013, Williams et al. 2014).

The highest PUFA N-3/6 ratio was found in cod, though it contained modest PUFA N-3, which is consistent with other reports (USDA, 2005, Weaver et al., 2008). All Great Lakes-harvested fish as well as tuna had favorable PUFA N-3/6 ratios whereas farm-raised fish did not. This may underscore the importance of consuming wild fish as a mitigating factor for metabolic health risks, especially cardiovascular disease which is the number-one killer of adult Anishinaabe (GLITEC, 2011). Notably, farmed salmon contain large amounts of PUFA N-3 but even more PUFA N-6. Reduced PUFA N-3 and increased PUFA N-6 in farmed fish has been observed elsewhere (Sprague et al., 2016), especially for tilapia (Weaver et al., 2008). This is unsurprising since terrestrial feeds are devoid of EPA and DHA which are primarily propagated through aquatic food chains (Sprague et al., 2016). Elevated dietary ratios of PUFA-3/6 is considered a health benefit (Simopoulos, 2006, Simopoulos, 2008). These data all align with the local cultural norm that fish is a healthy and important food source and will serve as welcome information when designing health-positive messaging for the CORA service area.

Comparison to Guidelines and Previous Monitoring

National and international guidelines have converged on consistent recommendations for the general population to consume at least 250 mg/day of EPA+DHA or at least 2 servings/week of oily fish (Mozaffarian and Wu, 2011). Eight ounces (227g) is often used as an assumed average meal size for adults (Anderson et al., 1993). Figure 3 displays the total EPA+DHA per eight ounces of fish in relation to the amount of that fish that would meet the 250mg/day recommendation. Of the fish traditionally consumed by the Anishinaabe, only walleye and perch would require more than two eight ounce meals per week to meet this standard. Similarly, cod and tilapia would require more than two meals per week to achieve 250mg/day. An average 8oz meal of lake trout and farmed salmon meet the recommendation at one meal per week, while an average 8oz meal of smelt, herring, whitefish, and canned tuna fall between the two categories.

We recently reported PCB and MeHg trends from whitefish and lake trout sampled by CORA. From 2012-2014 CORA observed means of 0.018ppm PCBs and 0.055ppm MeHg in Lake Superior whitefish and means of 0.078ppm PCBs and 0.194ppm MeHg in fillets of lake trout (Dellinger et al., 2017). To stay within safe ranges estimated by Agency for Toxic Substances and Disease Registry (ATSDR) chronic, oral minimal risk levels for MeHg (0.3µg/kg/day) and PCB (0.02µg/kg/day) an average 81.9 kg adult can consume six ounces of lake trout/week and twenty-two ounces/week of whitefish (PCBs being the limiting factor of the two). These amounts correspond to roughly one 6-ounce meal of Lake Superior lake trout/week and three, 8-ounce meals of whitefish per week. If compared to Figure 3, this suggests that many adult Great Lakes fish consumers can at least achieve 250mg/day of EPA +DHA without exceeding ATSDR guidelines for Hg and PCBs. These are rough estimates, cooking can alter both FA and PCB content, and different organizations (such as the Environmental Protection Agency) use slightly different reference doses than the ATSDR MRLs. Children and child-bearing women would follow more restrictive guidelines and/or supplement with store bought fish such as cod. A more in-depth risk and benefit analysis of the 2016 Lake Superior fish is in preparation as a next step to assist in developing CORA's recommendations.

Conclusion

Chronic diseases relating to metabolic health are the primary cause of death for the Anishinaabe (GLITEC, 2011, WDHS, 2005). Compared to non-native people, the Anishinaabe experience significantly higher mortality and morbidity as a result of chronic diseases, including; cancer, diabetes, obesity, and heart disease (GLITEC, 2011, WDHS, 2005). PUFA N-3s have been linked to decreased cardiovascular mortality (Mozaffarian and Rimm, 2006, Mozaffarian and Wu, 2011) as well as decreased symptoms of depression and anxiety (Haghighi et al., 2015, Colin et al., 2003, Beydoun et al., 2015, Martins, 2009). The proportion Anishinaabe who experience depression is 42% and the rate of suicide is significantly higher than the other races of the region (GLITEC, 2011). FA data on Anishinaabe harvests are therefore crucial for developing consumption advice that promotes positive health outcomes. The data presented here suggest that many of the fish consumed

under traditional and local harvests should offer substantial dietary PUFA-3 at moderate intakes.

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Figure 1. The Treaty-ceded territories associated with the Anishinaabe tribes. Tribal subsistence is monitored by the Chippewa Ottawa Resource Authority/Inter-tribal Fisheries and Assessment Program (CORA/ITFAP) and Great Lakes Indian Fish and Wildlife Commission (GLIFWC).

Figure 2.
Proportion (percent) of mean fatty acid types in each species of fish.

Figure 3.

Milligrams of DHA+EPA per eight ounces of fish. Whisker bars represent the minimum and the maximum while the box is the 25th and 75th percentile within the median denoted by the contained line. Horizontal lines indicate whether one or two 8 oz (227 g) meals of the species per week would provide recommended daily requirement for DHA+EPA.

Summary information and fatty acid content of Great Lakes fish and locally available supermarket Fish. Source includes the waterbody caught by CORA or the source indicated on the packaging.

Table 1

	Fish Species	Source	N	Weight, kg (Mean $\pm$ SD)	Length, mm (Mean $\pm$ SD)	mg FA /100 g fish (Mean $\pm$ SD)
Great Lakes	Walleye	Lake Huron	7	1.26 $\pm$ 0.34	507.3 $\pm$ 50.0	820 $\pm$ 240
	Rainbow Smelt	Lake Superior	7	0.023 $\pm$.002	NA	1,920 $\pm$ 260
	Lake Herring	Lake Huron	7	0.553 $\pm$ 0.10	388.0 $\pm$ 22.9	2,890 $\pm$ 800
	Yellow Perch	Lake Huron	7	0.113 $\pm$ 0.02	212.7 $\pm$ 11.2	510 $\pm$ 40
	Whitefish	Lake Superior	12	1.41 $\pm$.34	532.2 $\pm$ 47.9	2,480 $\pm$ 1020
	Lake Trout	Lake Superior	12	2.01 $\pm$ 0.41	542.1 $\pm$ 63.0	8,860 $\pm$ 3560
Grocery	Tuna, Canned	Thailand	7	NA	NA	1,520 $\pm$ 240
	Salmon, Farmed	Chile	7	NA	NA	11,920 $\pm$ 4,880
	Cod, Wild	China	7	NA	NA	540 $\pm$ 60
	Tilapia, Farmed	China	7	NA	NA	830 $\pm$ 200

Table 2

Milligrams per 100 grams of fish sample, wet weight, saturated Fatty Acids (SFA), mono unsaturated Fatty Acids (MUFA), and PUFA N-3/6 for fish sampled by CORA summer 2016. Total PUFA-3 includes omega-3 including DPA (22:5 n-3), LNA (18:3 n-3), (18:4 n-3), (20:3 n-3), (20:4 n-3), as well as EPA plus DHA. PUFA-6 includes 20:4 n-6 (arachidonic acid) plus linoleic acid (18:2 n-6) as well as (18:3 n-6), (22:2 n-6), (22:5 n-6), (20:2 n-6), and (20:3 n-6).

	Species	N	Total SFA	Total MUFA	EPA Mean (SD)	DHA Mean (SD)	PUFA N-3 Mean (SD)	PUFA N-6 Mean (SD)	PUFA 3/6 ratio
Great Lakes	Walleye	7	228 (51.5)	245.9 (119.6)	48.5 (15.0)	174.3 (56.5)	244.1 (84.0)	118.8 (43.7)	2.11
	Rainbow Smelt	7	510.2 (74.4)	584.2 (110.7)	178.7 (23.5)	323.0 (36.8)	624.2 (79.4)	250.3 (42.5)	2.51
	Lake Herring	7	867.99 (218.0)	945.3 (372.8)	280.6 (78.2)	320.3 (36.2)	783.3 (133.7)	385.0 (120.3)	2.11
	Yellow Perch	7	172.1 (14.4)	74.6 (8.5)	49.2 (9.8)	166.9 (18.5)	221.7 (25.6)	66.6 (12.0)	3.46
	Whitefish	12	689.1 (254.0)	845.1 (442.0)	214.2 (112.1)	375.8 (95.6)	724.5 (290.4)	269.3 (97.8)	2.72
Grocery	Lake Trout	12	2171.8 (999.9)	3085.3 (1235.0)	567.9 (203.7)	1081.6 (351.4)	2395.3 (890.0)	1095.4 (426.2)	2.20
	Tuna, Canned	7	501.0 (82.7)	371.2 (61.7)	98.5 (18.4)	454.5 (79.5)	578 (102.7)	115.1 (16.9)	5.01
	Salmon, Farmed	7	2308.8 (919.7)	6266.2 (2661.3)	405.2 (155.2)	713.6 (199.2)	1902.7 (668.7)	2122.5 (899.4)	0.93
	Cod, Wild	7	143.7 (16.6)	81.1 (11.1)	96.3 (12.2)	207.1 (21.7)	307.1 (24.7)	26.1 (2.05)	11.81
	Tilapia, Farmed	7	298.1 (62.1)	281.7 (88.7)	2.2 (0.4)	44.6 (6.3)	61.4 (7.3)	221.7 (43.7)	0.28