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Risk-benefit of consuming Lake Erie fish

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ABSTRACT

Background: Consumption of fish is promoted as a healthy way to obtain essential fatty acids (EFA) in the diet, yet the risk of ingesting harmful contaminants remains a concern. A recent study concluded that the risk-benefit of consuming fish from the North American Laurentian Great Lakes, which sustain important commercial and recreational fisheries, is currently unclear. We report the fatty acid (FA) content in skin-off fillets of fifteen fish species from Lake Erie and assess whether recommended dietary requirements for two EFA (EPA and DHA) can be met by safely consuming Lake Erie fishes, as an example of a risk-benefit analysis.

Methods: A total of 146 samples were analyzed for FA and contaminant content. A simulated fish consumption advisory (maximum recommended number of meals per month, up to 32) was calculated for each sample, and used to calculate the maximum amount of EPA+DHA that would be consumed if the consumption advisory was followed.

Results: All fifteen species had nutritionally desirable PUFA:SAFA (>0.4) and n−3:n−6 (>1). Large, fatty species had the highest EPA+DHA content, but had the most restrictive consumption advisories due to high PCB concentrations. To minimize contaminant exposure while maximizing EPA+DHA intake, consumers should consider small lake whitefish and lake trout, small panfish species, and/or walleye. However, very few species had an EPA+DHA content sufficient to safely meet the highest dietary guidelines while following advisories.

Conclusions: Consumption of certain Lake Erie fish, an important recreational and commercial fishery, within the limits of our simulated fish consumption advisories, can be a good supplemental source of beneficial n-3 long chain PUFA.

1. Introduction

The North American Laurentian Great Lakes have been affected over the past several decades by numerous stressors, including but not limited to, toxic substances such as polychlorinated biphenyls (PCBs), dioxins, mercury and pesticides (Bhavsar et al., 2010, 2008, 2007). These stressors have directly and indirectly impacted biota of the Great Lakes and have had negative implications for important commercial and recreational fisheries valued at a total of $>\$4$ billion annually (Great Lakes Information Network, 2012). In particular, the accumulation of contaminants in fish has resulted in the issuance of restrictive fish consumption advisories (Illinois Department of Natural Resources, 2013; Ohio Environmental Protection Agency, 2012; Ontario Ministry of the Environment, 2013).

Abbreviations: ALA, α-linolenic acid (18:3n−3); DHA, docosahexaenoic acid (22:6n−3); EFA, essential fatty acid(s); EPA, eicosapentaenoic acid (20:5n−3); FA, fatty acid(s); FAME, fatty acid methyl ester(s); FAO, Food and Agricultural Organization; LC-PUFA, long chain (i.e., ≥20 carbons) polyunsaturated fatty acid(s); LIN, linoleic acid (18:2n−6); MUFA, monounsaturated fatty acid(s); OMOE, Ontario Ministry of the Environment; OMNR, Ontario Ministry of Natural Resources; PCBs, polychlorinated biphenyls; PUFA, polyunsaturated fatty acid(s); SAFA, saturated fatty acid(s); WHO, World Health Organization

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While contaminant concentrations in Great Lake fishes pose a potential health risk to those who consume them (Ontario Ministry of the Environment, 2013), fish in general is promoted by nutrition and health experts as a healthy part of the human diet (Bourre and Paquotte, 2008; Health Canada, 2011). Fish and other seafood products are known to contain high quality proteins, essential nutrients such as vitamins D and B12, as well as iodine and selenium (Larsen et al., 2011). In addition, fish contain high levels of "essential" n-3 and n-6 long chain polyunsaturated fatty acids (LC-PUFA) which cannot be synthesized by the human body in amounts adequate for optimal health (Arts et al., 2001; Gerster, 1998). Essential fatty acids (EFA) have important roles in the healthy functioning of the human body and have been shown to have beneficial effects in relation to cardiovascular disease, diabetes, inflammatory diseases, and neurological health (Lands, 2009; Yashodhara et al., 2009). Consequently, nutritional guidelines in many countries stress the importance of including fish in the diet as a source of EFA (Kris-Etherton et al., 2009).

Thus, advice concerning the consumption of fish can be contradictory, depending on whether consumption advice is generated by contaminant levels (e.g., health risks) or nutrients such as EFA (e.g., health benefits). Ideally, both the risks and benefits of consuming fish should be considered and balanced, such that consumers achieve maximum EFA intake with minimal intake of potentially harmful contaminants. Several studies have addressed this by providing dietary advice after considering the nutritional benefits against the possible risks of fish consumption (Levenson and Axelrad, 2006; Mozaffarian and Rimm, 2006; Mozaffarian, 2009) while other studies have taken more quantitative approaches (Dewailly et al., 2007; Domingo et al., 2007; Ginsberg and Toal, 2009; Smith and Sahyoun, 2005; Stern and Korn, 2011).

Fatty acid research on Great Lakes sport fishes (i.e., species that are regularly caught and consumed by anglers) in relation to human dietary requirements has thus far been relatively scarce. While earlier studies reported FA content for selected species and locations in the Great Lakes (Chan et al., 1999; Wang et al., 1990), Turyk et al. (2012) recently concluded that the lack of data concerning n−3 EFA in Great Lakes sport fish populations is a hindrance to risk-benefit analyses. More recent studies have presented additional FA content for lake trout and/or lake whitefish in the Great Lakes (Moths et al., 2013; Pantazopoulos et al., 2013); however, a comprehensive view of FA content for a variety of other fish species present in the Great Lakes is still lacking. Further, although the risks of consuming Great Lakes sport fish are well-documented (Illinois Department of Natural Resources, 2013; Michigan Department of Community Health, 2013a; Ontario Ministry of the Environment, 2013), to our knowledge there have been no quantitative risk-benefit analyses on consumption of Great Lakes fishes in the published literature. As ~4.2 million adults in the U.S. Great Lakes region consumed at least one Great Lakes fish meal over the course of a year, and consumption of sport fish by children is related to that of their parents (Imm et al., 2007, 2005), FA data are needed to provide consumption advice that not only considers the potential risks of consuming Great Lakes fishes, but also the benefits.

In this study, we report the FA content and composition of 15 fish species from Lake Erie, with particular focus on EPA and DHA (n-3 LC-PUFA). We then assess the relative benefits of consuming Lake Erie fishes in terms of EPA+DHA intake, with the relative risk due to environmental contaminants. This is assessed by determining whether EPA+DHA dietary guidelines can be met by consuming Lake Erie fish, while adhering to consumption advisories due to contaminants. This analysis is particularly relevant given the importance of Lake Erie to commercial, recreational and possibly subsistence fishing interests in the U.S. and Canada. For example, the freshwater commercial fishery in Lake Erie is the largest in the Great Lakes and Canada (valued at $194 million in 2011; (Ontario Ministry of the Environment, 2012)), and is the most popular Great Lake amongst U.S. anglers for recreational fishing (U.S. Fish & Wildlife Service 2011).

2. Materials & methods

2.1. Sample collection and laboratory analysis

The Sport Fish Contaminant Monitoring Program of the Ontario Ministry of the Environment (OMOE) has analyzed skinless, boneless fish muscle tissue from over 2000 locations within Ontario for a suite of contaminants since the 1970s. To conduct a risk-benefit analysis of fish consumption, 146 samples of 15 fish species from Lake Erie were selected from the Program's tissue bank for additional fatty acid analysis. In order to capture spatial, seasonal and gender variability, samples of both male and female fish were selected, having been collected between April and October (i.e., the most popular period for fishing) of 2010, from one or more regions within Lake Erie, including the western basin (LE1), central basin (LE2), Rondeau Bay (LE2a), Long Point Bay (LE3), and the eastern basin (LE4) (Table S1).

All samples were analyzed for FA content, as well as contaminants of concern in the Great Lakes, including mercury, total PCBs, mirex, photomirex, toxaphene, and total chlordane. Within the Canadian waters of Lake Erie, fish consumption restrictions are due to elevated levels of PCBs and/or mercury (Bhavsar et al., 2011; Ontario Ministry of the Environment, 2013). New York, Ohio, Pennsylvania and Michigan state agencies have also issued restrictive fish consumption advisories for the American waters of Lake Erie due to elevated levels of PCBs (State of the Great Lakes, 2009). In this analysis, concentrations of mirex, photomirex, toxaphene and total chlordane for all fish samples were too low to result in consumption advisories, and were thus not considered further. For black crappie, bluegill and pumpkinseed, the 2010 samples used for FA analysis had only been tested for mercury concentrations, as this is generally the most restrictive contaminant for these species in Lake Erie (OMOE unpublished data). However, to confirm that mercury was the consumption-limiting contaminant for these species, PCB concentrations in samples collected from the same location within Lake Erie in 2009 were examined (OMOE unpublished data). In all cases, PCB concentrations were too low to generate consumption advisories more restrictive than the restrictions due to mercury concentration, and so the 2009 samples were not included in the analysis.

After collection, fish were measured for total length and weight, sexed, and then filleted (skin removed) and stored at −20 °C until chemical analysis at the OMOE laboratory in Toronto, ON, and FA analysis at the Environment Canada laboratory in Burlington, ON. Samples were analyzed for contaminants using accredited OMOE methods (Gewurtz et al., 2011; Ontario Ministry of the Environment, 2007, 2006)). Methodology for FA extraction is described in full in the Supplementary material.

2.2. Fatty acid profiles and risk-benefit calculation

Four individual FA out of the 47 that were identified in the laboratory analysis are highlighted due to their nutritional importance: linoleic acid (LIN, 18:2n−6), α-linolenic acid (ALA, 18:3n−3), eicosapentaenoic acid (EPA, 20:5n−3) and docosahexaenoic acid (DHA, 22:6n−3). Summary measures of quantified FA were calculated including; n-3, n−6, total monounsaturated FA (MUFA), total saturated FA (SAFA) and total polyunsaturated FA (PUFA). FA content was examined as wet weight (ww; mg/100 g), dry weight (dw; mg/100 g), proportion of total quantified FA (%)

and proportion of total lipids (%). For each species, mean values of each FA measurement were calculated, and variation due to sex, sampling season and sampling location was explored. Linear regression was used to explore relationships between fish length and FA content.

Simulated consumption advisories – the maximum number of 227 g (8 oz) fish meals that can be safely consumed per month based on contaminant concentrations – were calculated for each individual fish sample using the standard OMOE method (Bhavsar et al., 2011; Ontario Ministry of the Environment, 2013). Individual fish were assigned two simulated consumption advisories, reflecting recommended consumption for the general population and the sensitive population (i.e., women of child-bearing age and children under the age of 15). The fish consumption advisory benchmarks used in this study are the same as those used in the *Guide to Eating Ontario Sport Fish* (Ontario Ministry of the Environment, 2013), which provides advice for individual fish species from >2200 Ontario water bodies including the Canadian waters of Lake Erie, relative to the length of the fish. These benchmarks are similar to U.S. state agencies that also issue fish consumption advisories for the Great Lakes (See Supplemental Material, Table S2). The OMOE currently issues consumption advisories of 8, 4, 2, 1 or 0 meals/month, according to contaminant concentrations. The 8 meals/month category is a catch-all for all instances where concentrations are below the first consumption advisory benchmark (based on survey results that Ontario anglers typically do not eat beyond 8 meals/month of Ontario-caught fish (Awad, 2006); other agencies may use different categories, e.g. 16 meals/month (Michigan Department of Community Health, 2013b)). Thus, in some cases, concentrations are low enough such that consumers could safely consume ≥ 8 meals/month. For example, the advisory benchmark for the sensitive population to reduce advised meals from 8 to 4 meals/month is 0.26 μg total mercury/g. As such, all fish with a mercury concentration <0.26 μg/g are assigned a consumption advisory of 8 meals/month – regardless if the actual concentration was 0.24 μg/g or 0.07 μg/g. However, a consumer could safely eat 28 meals/month if the fish in question had a concentration of 0.07 μg/g. In order to maximize the human dietary EFA intake for those species with very low contaminant concentrations, simulated consumption advisories considering up to a maximum of 32 meals/month were used in this study (See Supplemental Material, Table S3). Consumption advisories for each individual fish sample were calculated for both mercury and PCBs separately, and then an overall simulated advisory was derived based on the most restrictive consumption advisory for that sample. Due to current limitations of science on the toxicity of a mixture of chemicals with varying concentrations and modes of actions, to our knowledge, fish consumption advisories issued for the Great Lakes by authorized agencies are based on the most restrictive contaminant.

Various health organizations worldwide have issued guidelines regarding EFA intake, and primarily issue recommendations in terms of daily or monthly intake of EPA+DHA. This study considered recommended EPA+DHA values issued by six agencies worldwide, as reported by Kris-Etherton et al., (2009) (See Supplemental Material, Table S4). All recommended intake values were converted to mg (EPA+DHA)/month (where, for simplicity, 1 month=30 d). EPA and DHA content for each individual fish sample was summed (EPA+DHA) and expressed as mg/100 g ww, which was then converted to mg/227 g ww.

The amount of EPA+DHA per 227 g fish meal was multiplied by the calculated maximum consumption advisory (i.e., number of fish meals that could be "safely" consumed per month) based on the contaminant thresholds, resulting in the EPA+DHA intake per month in mg. This calculation assumes that people consume the maximum recommended number of meals each month. Thus, this reflects the benefit (i.e., EPA+DHA intake) a consumer would receive by consuming a particular Lake Erie fish, after limiting intake to exposure to harmful contaminants (i.e., risk). Coho salmon were not included in the risk-benefit analysis due to low sample size ($n=2$).

Fish consumption advice based on contaminants is often provided in relation to the size of the fish, as contaminant concentrations tend to increase with fish size (Gewurtz et al., 2011). However, the relationship between fish size and FA content is less established. When assessing the relative risks and benefits of consuming fish, an understanding of the relationship between EPA+DHA content and fish size may be useful. For example, published consumption advice for a 70 cm lake trout from the eastern basin of Lake Erie is 1 meal/month, while a 20 cm lake trout from the same population is 8 meals/month (Ontario Ministry of the Environment, 2013). Thus, consumption of a smaller lake trout, when possible, would reduce the risk of exposure to contaminants. If EPA+DHA content also increases with fish size, then eating a smaller lake trout would not only reduce contaminant intake, but would also reduce EPA+DHA intake. However, if EPA+DHA content is relatively constant regardless of fish size, then consuming a small lake trout would reduce contaminant intake while maintaining EPA+DHA intake. Thus, in this scenario, consumption of smaller fish reduces the risk without reducing the EFA benefits. To explore this relationship, the relationship between fish length and maximum monthly EPA+DHA intake (i.e., EPA+DHA intake adjusted for consumption advisories) was examined.

3. Results

3.1. Fatty acid content

This summary is limited to four nutritionally-important FA – LIN, ALA, EPA and DHA as well as the following summary indices; n-3, n-6, SAFA, MUFA, PUFA, n-3:n-6 and PUFA:SAFA (Table 1). For all species considered, %PUFA in total FA ranges from 18–60%, with black crappie, bluegill, largemouth bass, northern pike, pumpkinseed and yellow perch comprised of $\geq 50\%$ PUFA (Fig. 1a). All species have a favorable PUFA:SAFA (>0.7, Fig. 1a) compared to recommended nutritional guidelines of 0.4–0.5 (World Health Organization, Food and Agriculture Organization, 2003). Within PUFA, Coho salmon, lake trout, northern pike, walleye, lake whitefish and rainbow trout have the highest proportion of n-3 FA (Fig. 1b). For all species, more than 40% of PUFA is comprised of EPA+DHA (Fig. 1b). FA values (as a proportion of FA or lipids) from this study were also compared to other values for freshwater fish in the literature (See Supplemental Material, Fig. S1). Either lack of reporting or differences in fish sizes in the earlier studies precluded from presenting a comparison of wet weight FA content. Overall, FA values reported (as % of total lipids) in this study were lower than those for fish from Lake Superior (Wang et al., 1990) and the St. Lawrence River (Chan et al., 1999), but similar to values reported (as % of total FA) for Lake Erie (Pantazopoulos et al., 2013). However, lake trout and lake whitefish from this study have proportionally more EPA+DHA and n-3 compared to values reported for Lake Erie (Pantazopoulos et al., 2013) (Fig. S1).

Mean FA content for each species is presented as mg/100 g ww (Table 1). Dry weight measurements, % of total FA and % of total lipids are presented in the Supplemental Material (Tables S5–S7). Mean EPA+DHA content ranged from 106–142 mg/100 g ww for black crappie, bluegill, pumpkinseed, and yellow perch (Table 1). Mean EPA+DHA content varied considerably (111–440 mg/100 g ww) for large, lean species such as largemouth bass, smallmouth bass, northern pike, walleye, white bass, and white perch (Table 1).

Table 1
Mean fatty acid content (mg/100 g ww) ± standard deviation in Lake Erie fish species.

Species	LIN	ALA	EPA	DHA	EPA+DHA	n-3	n-6	n-3:n-6	SAFA	MUFA	PUFA	PUFA:SAFA	FA	Lipid
Black crappie	16 ± 4	7 ± 2	15 ± 4	111 ± 4	126 ± 5	161 ± 11	89 ± 7	1.8 ± 0.2	156 ± 17	98 ± 24	252 ± 12	1.6 ± 0.2	505 ± 48	888 ± 89
Bluegill	29 ± 11	12 ± 5	17 ± 3	89 ± 12	106 ± 13	139 ± 20	87 ± 10	1.6 ± 0.2	138 ± 17	58 ± 10	231 ± 29	1.7 ± 0.1	427 ± 52	746 ± 75
Channel catfish	89 ± 56	92 ± 58	161 ± 75	162 ± 65	398 ± 214	660 ± 377	275 ± 161	2.5 ± 0.3	1159 ± 764	2121 ± 1624	950 ± 544	0.9 ± 0.1	4230 ± 2905	5543 ± 3128
Coho salmon	10 ± 4	0	275 ± 92	669 ± 201	944 ± 293	1459 ± 478	392 ± 170	3.8 ± 0.4	1570 ± 677	2188 ± 1074	1851 ± 648	1.2 ± 0.1	5608 ± 2399	6675 ± 2597
Lake trout	8 ± 4	0.4 ± 1	256 ± 145	639 ± 292	896 ± 435	1323 ± 703	381 ± 226	3.6 ± 0.4	1213 ± 668	2084 ± 1396	1706 ± 924	1.4 ± 0.1	5003 ± 2976	6145 ± 3341
Lake whitefish	122 ± 93	51 ± 45	373 ± 217	341 ± 119	714 ± 330	961 ± 432	323 ± 136	3.1 ± 0.8	1828 ± 861	4679 ± 2602	1302 ± 563	0.7 ± 0.1	7809 ± 4009	9502 ± 4761
Largemouth bass	9 ± 9	4 ± 0	13 ± 9	98 ± 31	111 ± 36	153 ± 47	71 ± 25	2.2 ± 0.5	128 ± 37	78 ± 29	225 ± 70	1.8 ± 0.3	431 ± 127	755 ± 145
Northern pike	5 ± 6	3 ± 5	21 ± 7	113 ± 32	134 ± 38	160 ± 47	50 ± 14	3.2 ± 0.5	93 ± 17	42 ± 9	211 ± 60	2.2 ± 0.3	350 ± 83	658 ± 130
Pumpkinseed	21 ± 5	5 ± 0.5	27 ± 4	115 ± 24	142 ± 26	176 ± 28	119 ± 8	1.5 ± 0.3	145 ± 6	75 ± 10	299 ± 21	2.1 ± 0.2	519 ± 19	985 ± 66
Rainbow trout	210 ± 106	189 ± 103	357 ± 177	613 ± 267	967 ± 440	1395 ± 625	435 ± 218	3.4 ± 0.6	1875 ± 1025	2618 ± 1671	1928 ± 900	1.1 ± 0.2	6422 ± 3483	8587 ± 4392
Smallmouth bass	20 ± 32	12 ± 22	36 ± 25	172 ± 78	208 ± 102	313 ± 166	123 ± 77	2.7 ± 0.4	246 ± 126	437 ± 365	438 ± 243	1.7 ± 0.2	1121 ± 728	1584 ± 855
Walleye	52 ± 119	49 ± 114	141 ± 185	250 ± 171	391 ± 351	532 ± 518	190 ± 236	3.1 ± 0.4	406 ± 401	734 ± 982	725 ± 756	1.8 ± 0.2	1864 ± 2135	2627 ± 2786
White bass	47 ± 43	55 ± 54	169 ± 124	264 ± 204	434 ± 322	607 ± 487	225 ± 188	2.8 ± 0.3	688 ± 581	949 ± 1016	862 ± 678	1.3 ± 0.2	2499 ± 2267	3268 ± 2632
White perch	6 ± 3	0.4 ± 0.5	215 ± 80	225 ± 100	440 ± 164	685 ± 278	322 ± 133	2.1 ± 0.3	932 ± 375	1614 ± 715	1008 ± 406	1.1 ± 0.2	3554 ± 1474	4117 ± 1696
Yellow perch	9 ± 5	4 ± 3	22 ± 4	109 ± 20	131 ± 24	148 ± 67	81 ± 16	1.9 ± 0.6	131 ± 27	64 ± 26	230 ± 32	1.8 ± 0.1	425 ± 84	725 ± 100

Mean EPA+DHA content, at 398–970 mg/100 g ww, was considerably higher in fattier species such as channel catfish, lake trout, lake whitefish and rainbow trout (Table 1). A comparison of mean EPA+DHA values of these Lake Erie species to EPA+DHA content of some examples of commercially-sourced fish and shellfish (United States Department of Agriculture, 2013) shows that lean Lake Erie species have levels comparable to yellowfin tuna, shrimp, Pacific cod, halibut, lobster and scallops (Fig. 2). Commercially-sourced Atlantic salmon and Atlantic mackerel had EPA+DHA levels much greater than any of the Lake Erie species (e.g, 2299 and 1966 mg/100 g, respectively) (Fig. 2). Commercially-sourced Coho salmon had similar EPA+DHA levels to Lake Erie Coho salmon (1085 and 944 mg/100 g, respectively) (Fig. 2).

Sample sizes in this study were insufficient to quantitatively assess the effects of sex, season and location on FA content in Lake Erie fishes but a qualitative assessment of the data revealed no obvious patterns. Wet weight FA content significantly increased with fish size in some cases: EPA, DHA, n-3, MUFA and PUFA for lake trout and lake whitefish, n-6 and ΣSAFA for lake trout; DHA and n-6 for black crappie; and PUFA for pumpkinseed. In contrast, there were significant, negative relationships between fish length and EPA+DHA, n-3 and PUFA in northern pike. We recommend that these preliminary observations regarding the relationships between FA content and fish size be confirmed using larger samples sizes, while controlling for potentially confounding factors (e.g., sampling location, sampling season, and sex).

3.2. Contaminant levels

Fish consumption restrictions for Lake Erie fish are generally due to high levels of PCBs, and in some species, mercury (Bhavsar et al., 2011; Ontario Ministry of the Environment, 2013). Simulated consumption advisories calculated for this study are consistent with this pattern (See Supplemental Material, Table S8). PCB concentrations resulted in the most restrictive advisories compared to other contaminants for channel catfish, lake trout, lake whitefish, rainbow trout and white bass, while mercury concentrations generated the most restrictive advisories for black crappie, bluegill, largemouth bass, northern pike, and pumpkinseed. Consumption restrictions for smallmouth bass, walleye, white perch and yellow perch were generated by both mercury and PCBs, and thus the most restrictive contaminant varied by individual fish samples within each species.

Published consumption advisories are separated by location within Lake Erie, as contaminant concentrations vary by location (Ontario Ministry of the Environment, 2013). Within-species differences in contaminant concentrations across locations were also apparent in this study, and generally, simulated consumption advisories were consistent with location-specific advisories issued by OMOE (Ontario Ministry of the Environment, 2013).

3.3. Risk-benefit analysis

The amount of EPA+DHA obtained through fish consumption within simulated advisory limits varied widely by species, due to combined effects of variations in both EPA+DHA levels and consumption restrictions (Fig. 3). A few general patterns emerged, however, particularly when species were grouped as small panfish (black crappie, bluegill, pumpkinseed and yellow perch), larger fatty fish (channel catfish, lake trout, lake whitefish and rainbow trout), and lean fish (largemouth bass, northern pike, smallmouth bass, walleye, white bass, and white perch).

The majority of simulated consumption advisories for small panfish species within the analyzed size ranges are 32 meals/month for the general population and ranged from 6–32 meals/month for the sensitive population (Table S8). EPA+DHA levels

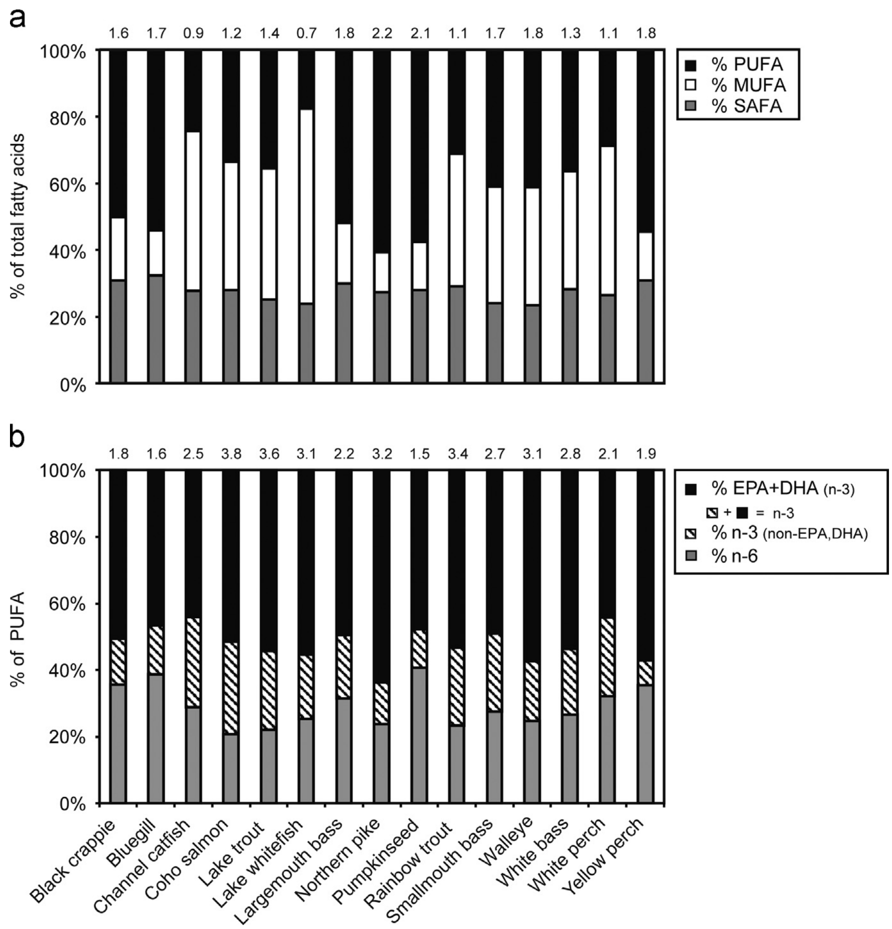

Fig. 1. Mean values for various fatty acids. Mean values for (a) PUFA, MUFA and SAFA, as proportion of total FA, with PUFA:SAFA listed along the top and (b) n−6, EPA+DHA and non-(EPA+DHA) n−3 FA, as proportion of PUFA for each species, with n-3:n−6 listed along the top. In panel (b), bars for EPA+DHA and non-(EPA+DHA) n-3 FA together equal the proportion of total n−3 FA out of PUFA.

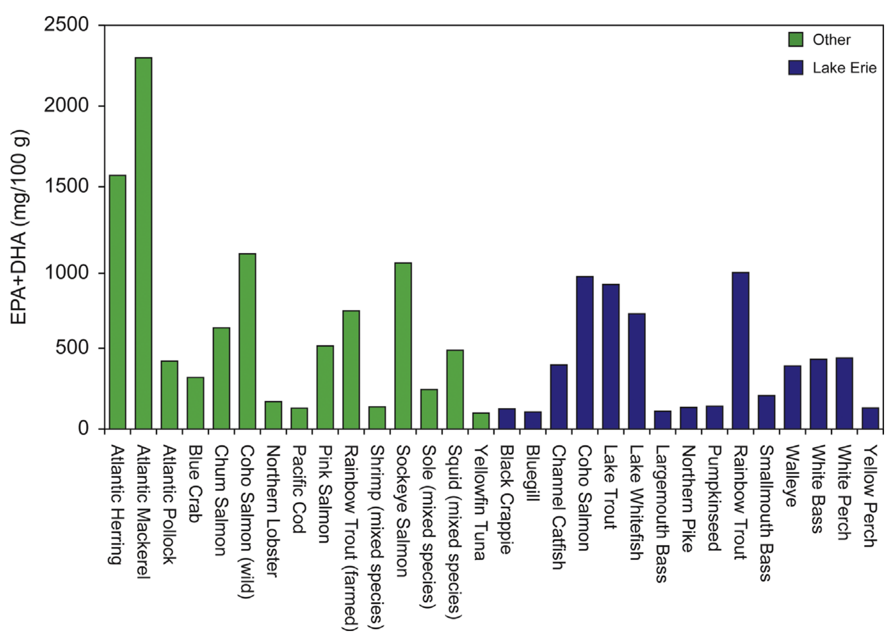

Fig. 2. Comparison of EPA+DHA (mg/100 g) in Lake Erie fish species to commonly consumed marine and freshwater seafood (United States Department of Agriculture, 2013).

were similar (within 25%) for all four species (Table 1). For each species, consumption of the maximum number of fish meals allotted each month would result in EPA+DHA intake that meets the two lowest recommended guidelines (1600 and 4000 mg/month) considered in this study, but not the 13,500, 15,000 or 20,010 mg/month guidelines (Fig. 3).

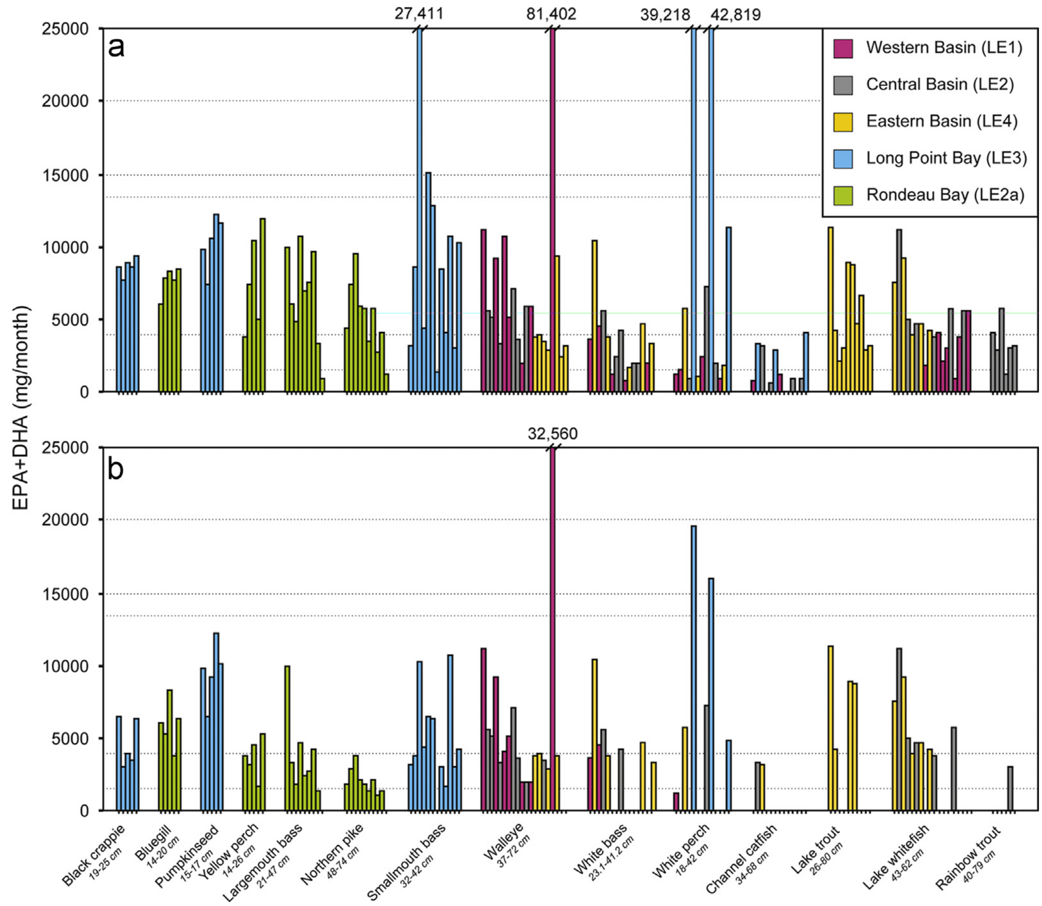

Fig. 3. Maximum monthly EPA+DHA intake (mg/month) if the maximum safe meals of an individual fish are consumed. Within each species, samples are arranged in order of smallest to largest, with size ranges of each species below each label. Bars are shaded to reflect the location within Lake Erie from which the sample was collected. Species are arranged in groups of panfish (black crappie, bluegill, pumpkinseed and yellow perch), lean fish (largemouth bass, northern pike, smallmouth bass, walleye, white bass, white perch,) and fatty fish (channel catfish, lake trout, lake whitefish, rainbow trout). Separate plots are presented for the (a) general and (b) sensitive populations (i.e., women of childbearing age and children under the age of 15), and horizontal lines indicate the selected recommended monthly intake of EPA+DHA (mg) by various agencies (1600, 4000, 13,500, 15,000, and 20,010 mg/month).

All large fatty species have high levels of EPA+DHA compared to other species analyzed in this study (Table 1). However, elevated contaminant levels resulted in more restrictive consumption advisories for these species, particularly for larger individuals. Channel catfish had particularly restrictive advisories and lower EPA+DHA content compared to lake trout, lake whitefish and rainbow trout, making this species the least appropriate choice for a consumer intending to minimize risk while maximizing EFA intake (Table 1, Fig. 3). For the general population, lake whitefish, lake trout and rainbow trout appear to be reliable sources of EPA+DHA, despite restrictive advisories (Fig. 3). Monthly consumption of lake whitefish, lake trout and rainbow trout within the calculated advisory limits would allow a consumer to meet the two lowest dietary recommendations of 1600 and 4000 mg EPA+DHA per month. However, for the sensitive population, many fish of these species have “do not eat” advisories (i.e., 0 meals/month), making them an unsuitable source of EPA+DHA (Fig. 3).

Lean fish varied in EPA+DHA content, even when considering similar size ranges. For example, largemouth bass was substantially lower in EPA+DHA compared to smallmouth bass, white bass, and white perch (Table 1). Of these species, smallmouth bass had the least restrictive consumption advisories, which allows consumption of a greater amount of EPA+DHA per month compared to largemouth bass, white perch and white bass (Fig. 3). However, we only analyzed smallmouth bass individuals from Long Point Bay (LE3) where current published advisories for the general population for this species are less restrictive compared to other areas in Lake Erie (e.g., western basin) (Ontario Ministry of the Environment, 2013). Thus, consumption of smallmouth bass from other Lake Erie locations may not be as favorable. Walleye has higher EPA+DHA content compared to northern pike, but has more restrictive consumption advisories. This resulted in comparable maximum EPA+DHA monthly intake for the two species (Fig. 3).

Maximum EPA+DHA monthly intake appeared to gradually decrease with fish length for walleye, lake trout, lake whitefish and rainbow trout, due to more restrictive consumption advisories for larger fish (Fig. 3, S2). For lake trout and lake whitefish, this pattern was apparent despite a significant increasing trend in EPA+DHA content (mg/100 g ww) with fish length (linear regression, $p < 0.05$), suggesting that even though consumption of a larger fish will result in a greater intake of EPA+DHA compared to a smaller fish, the consumption advisories on large lake trout and lake whitefish are so restrictive that a consumer would receive more benefit (in terms of maximum EPA+DHA monthly intake) by consuming smaller individuals within their advisory limits.

4. Discussion

All 15 of the Lake Erie fishes included in this study have FA profiles favorable for human consumption, with PUFA:SAFA > 0.4 (World Health Organization, Food and Agriculture Organization,

2003) and n−3:n−6 >1.0 (Simopoulos, 2008, 2002). Based on EPA+DHA content alone, particularly healthy fish choices would be rainbow trout, Coho salmon, lake trout and lake whitefish, which are fatty and have mean EPA+DHA contents of >700 mg/100 g. A 100 g serving of any of these four species would correspond to the middle of the range of recommended daily intakes for EPA+DHA (i.e., 500 mg/day; Table S4). However, the assessment presented here only addresses the benefits of consuming Lake Erie fish. PCBs are generally the most restrictive contaminant in regards to formulating fish consumption advisories for Lake Erie, most notably for fatty species, and advisories can be very restrictive, depending on the species, size and the location from which fish were caught (Ontario Ministry of the Environment, 2013). In this study, 62% of the collective 47 samples of lake whitefish, channel catfish, lake trout and rainbow trout have simulated advisories of 0 meals/month for the sensitive population, due to high PCB concentrations (Table S8). Other species which are lower in lipid content tend to have lower PCB concentrations, and in many cases, restrictive advisories are due to elevated mercury levels. However, fish mercury concentrations in Lake Erie are generally low, and do not often result in severe restrictions (Bhavsar et al., 2011). Of the species for which mercury was the most restrictive contaminant, only the largest individuals (6% of 34 samples) of northern pike and largemouth bass resulted in a 0 meals per month advisory, for the sensitive population only (Table S8).

Fatty acid and contaminant assessments for Lake Erie fish may present a contradictory message to the fish-eating public. High EPA+DHA levels indicate that species such as rainbow trout, lake trout and lake whitefish are the most favorable for maximum intake of these beneficial FA. However, the consumption advice for these species, particularly for the sensitive population, is extremely restrictive – in some cases informing that these species should not be consumed at all due to high concentrations of contaminants. It is clear that, in order to provide the best advice to the public, any assessment of the benefits of consuming fish must be first put into the context of acceptable consumption limits for those species. In this study, individual fish samples were analyzed for both contaminant concentrations as well as FA content. Thus, for each individual fish sample, both the risk (i.e., contaminant concentration in relation to guideline values for consumption) and the benefit (i.e., content of EFA such as EPA and DHA in relation to recommended daily intake values) can be assessed, and then summarized for each species.

Based on this analysis, consumers of Lake Erie fish looking to minimize exposure to contaminants while maximizing intake of beneficial FA should focus consumption on: small individuals of lake whitefish and lake trout; individuals of any size of black crappie, bluegill, pumpkinseed, walleye and yellow perch; and/or smallmouth bass and white perch from Long Point Bay. Species with greater risk and less benefit include channel catfish and rainbow trout, where very restrictive consumption advisories limit the amount of EPA+DHA intake.

Focusing on smaller individuals of contaminated species, that are high in EPA+DHA content, will still allow the consumer to ingest levels of EFA comparable to species lower in both EPA+DHA and contaminants, as long as consumption advisories are followed for the species and location in question. In fact, this may be preferable to some consumers, given the wide range across species in the number of fish meals that must be consumed in order to ingest the same amount of EPA+DHA. For example, a person of the sensitive population would have to consume 32 meals of a 17 cm pumpkinseed from Long Point Bay in order to ingest roughly the same amount of EPA+DHA as would be consumed through 16 meals of a 26 cm lake trout from the eastern basin, or 10 meals of a 37 cm walleye from the western basin. Thus, some consumers may prefer to eat a fewer number of fish meals of a generally more restricted species such as lake trout, instead of eating a large number of fish meals of a less restricted species in order to ingest the same amount of EPA+DHA.

There have been a number of attempts in the literature to conduct risk-benefit analyses in regards to fish consumption, with varying success and/or practical application. Domingo et al. (2007) noted that in order for a risk-benefit analysis to be useful, multiple contaminants must be considered, as such is the reality of contaminant pollution in many water bodies. Thus far, this has been generally lacking in risk-benefit analyses. In this study, the OMOE's Sport Fish Contaminant Monitoring Program covers a wide range of environmental contaminants, enabling development of consumption advisories based on the most restrictive contaminant. Further, in order to give clear, quantitative advice to the fish-consuming public, it is useful to base a risk-benefit analysis on specific species and/or water bodies, given that both EFA content and contaminant concentrations can vary widely within species or across locations. As such, we recommend that additional risk-benefit analyses be conducted, for each of the remaining Great Lakes, as well as for inland lakes. In North America, fish consumption advisories for inland lakes are primarily the result of elevated mercury concentrations, not PCBs as in the Great Lakes (Ontario Ministry of the Environment, 2013; Stahl et al., 2009). Thus, consumption advice considering both EFA content and contaminant concentrations for a species, particularly for fatty species, is likely to be very different for a lake trout caught from Lake Erie to one caught from an inland lake, on the basis of different contaminant concentrations alone. What is unclear at this point, however, is how much EFA content varies within a species across different water bodies.

It is important to note several aspects of environmental contaminants and fish consumption that are not addressed in this study. First, there is some evidence for negative confounding effects of mercury and PUFA on brain development (Choi et al., 2014), which may have implications where consumption advisories are due to mercury. This risk-benefit analysis also only addresses one aspect of the benefits of fish consumption – namely, dietary intake of EFA. Recent literature suggests that there may be additional benefits of consuming fish, as this food source also contains high quality proteins, which contain all essential amino acids, as well as many important nutrients found in higher concentrations in fish compared to other food sources (Larsen et al., 2011). There also may be additional health benefits via the substitution effect, whereby consumers who consume more fish eat fewer amounts of less desirable foods, such as red meat (Larsen et al., 2011).

While a large body of the literature has shown that n-3 fatty acids are an integral component of the healthy human diet, several recent studies have indicated that excess n-3 fatty acid intake may be harmful (see (Bushkin-Bedient and Carpenter, 2010)). For example, the American Heart Association cautions against consumption of more than 3 g/day (90,000 mg/month) of n-3 FA (American Heart Association, 2013). In contrast, the European Food Safety Authority reported that long-term intake of EPA+DHA of 5 g/day (150,000 mg/month) has not been associated with any adverse effects (European Food Safety Authority, 2012). No species included in this study had maximum EPA+DHA monthly values >90,000 mg, indicating that there is no real risk of excess intake if the simulated advisories are followed.

5. Conclusions

We demonstrate that the consumption of Lake Erie fish, within the simulated limits of fish consumption due to contaminant levels, can be a reliable source of EFA. Healthy choices include small individuals of lake whitefish and lake trout as well as leaner species such as black crappie, bluegill, pumpkinseed, yellow perch and walleye. Smallmouth bass and white perch can also be considered healthy choices if caught from the Long Point Bay area of Lake Erie. These species would allow consumers to meet the first two recommended levels of monthly EPA+DHA intake; however, very few species have sufficiently high EPA+DHA content and low consumption restrictions for a consumer to meet the upper three dietary guidelines (Table S4).

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SB/DC/KD/AF/MA/MN designed the study, SB/KD/AF/MA analyzed the samples, MN/FN analyzed the data, MN/SB/FN/MA interpreted the results, MN/SB prepared the first draft of the manuscript, all authors provided critical intellectual input to the manuscript and have given final approval for publication.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2014.05.025.

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