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Biomonitoring of populations in Western New York at risk for exposure to Great Lakes contaminants

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Abstract

The New York State Department of Health conducted the Healthy Fishing Communities Program in collaboration with the Agency for Toxic Substances and Disease Registry to assess human exposure to contaminants common to Lake Ontario, Lake Erie and surrounding rivers and waterways among populations in western New York State who eat locally caught fish. The

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2019.108690.

program enrolled licensed anglers and Burmese refugees and immigrants, living near four designated Great Lakes Areas of Concern: Buffalo River, Niagara River, Eighteenmile Creek, and the Rochester Embayment. These target populations were sampled and enrolled independently into the program between February and October of 2013. A core set of contaminants were measured in blood and urine of 409 licensed anglers and 206 Burmese refugees and immigrants which included lead, cadmium, mercury, PCBs, PBDEs, organochlorine pesticides (hexachlorobenzene, mirex, DDT, DDE, and chlordane and its metabolites oxychlordane and trans-Nonachlor), and PFOS and PFOA.

Biomonitoring results showed that both groups had higher geometric means for blood lead, total blood mercury, and serum PFOS compared to the 2013–2014 NHANES reference levels. The Burmese refugee group also showed higher geometric means for creatinine-adjusted urine mercury and lipid-adjusted serum DDE compared to national levels. Licensed angler participants reported eating a median of 16 locally caught fish meals in the past year. Burmese participants consumed local fish throughout the year, and most frequently in the summer (median 39 fish meals or 3 times a week).

The study results provide valuable information on populations at high risk of exposure to contaminants in the Great Lakes Basin of western New York. The results provide the foundation for developing and implementing public health actions to reduce potential exposures to Great Lakes pollutants.

Keywords

Great lakes; Human biomonitoring; Licensed anglers; Refugees and immigrants; Fish consumption

1. Introduction

The watersheds of Lakes Ontario, Erie, and the Niagara and St. Lawrence Rivers are complex ecosystems vital to the history and economy of New York State (NYS). Spread over 40% of the state, they provide drinking water and access to recreational activities to over 4 million people. Although international treaties and local remedial actions have been active in protecting the Great Lakes, the area continues to face effects of historical pollution from municipal and industrial sources (New York State Department of Environmental Conservation [NYSDEC], 2014).

Over 20 years ago, the Great Lakes Areas of Concern (AOCs) were designated as areas most impacted by chemical agents in the U.S.-Canada Great Lakes Water Quality Agreement to help focus water quality improvement efforts (United States Environment Protection Agency [US EPA], 2011). Five AOCs remain in NYS today (i.e., Buffalo River, Niagara River, Eighteenmile Creek, Rochester Embayment, and the St. Lawrence River at Massena). Communities that live close to the AOCs, and those who eat local fish and game are at risk of exposure to chemicals of concern (Johnson et al., 1998; United States Environment Protection Agency [US EPA] and Environment Canada, 2012). For instance, although commercial manufacturing and use of polychlorinated biphenyls (PCBs) in the U.S. ceased in the 1970s, their slow rate of degradation and bioaccumulation in lipids has allowed their persistence in the environment and wildlife (Li et al., 2009; Paliwoda et al., 2016). Similarly, dichlorodiphenyltrichloroethane (DDT), an insecticide and pesticide banned in the 1970s, continues to be detected in the Great Lakes environment (Venier and Hites, 2014), as does mirex, an organochlorine insecticide that has not been legal for use since the late 1970s (Centers for Disease Control and Prevention [CDC], 2009a). More recently, the commercial production of polybrominated diphenyl ethers (PBDEs) has been phased out but they continue to be pervasive in the environment (Venier et al., 2015). Other synthetic chemicals like per- and polyfluoroalkyl substances (PFAS) were introduced in the 1950s and widely used in manufacturing of numerous commonly used consumer products. PFAS, such as perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), although no longer produced in the U.S., continue to persist in the environment and bioaccumulate in the human body (Sagiv et al., 2015).

The NYS Department of Environmental Conservation (NYSDEC) fish sampling data indicate that pollutants such as PCBs are prevalent in NYS AOCs, and mirex and dioxins are found in most NYS AOCs (Preddice et al., 2011). Toxic metals such as lead (Pb) and cadmium (Cd) continue to be found in Great Lakes sediment and daily precipitation samples (Mitchell et al., 2019; Sherman et al., 2015), and concerns regarding mercury (Hg) levels in fish from Lake Erie and Lake Ontario remain (Environment Canada and United States Environmental Protection Agency [US EPA], 2014; McGoldrick and Murphy, 2016). Other studies have reported contamination of fish in Lake Ontario and Lake Erie from PCBs, DDT, dichlorodiphenyldichloroethylene (DDE), toxaphene, chlordane, PBDEs, and PFAS (Gandhi et al., 2017; Hickey et al., 2006; McGoldrick and Murphy, 2016). Significant positive associations between consumption of Great Lakes fish in western NYS and body burden levels of mirex and orthoPCBs, and to a lesser extent DDE, have been reported (Bloom et al., 2005). Based on ongoing concerns about exposure to contaminants in the Great Lakes region, the NYS Department of Health (NYSDOH) continues to provide fish consumption advisories specific to these waters (New York State Department of Health [NYSDOH], 2014).

From 2010 through 2015, the NYSDOH conducted the Healthy Fishing Communities Program in collaboration with the Agency for Toxic Substances and Disease Registry (Agency for Toxic Substances and Disease Registry [ATSDR], 2010). The program aimed to assess exposure to Great Lakes contaminants of concern by measuring body burdens among targeted sub-populations in western NYS at high-exposure risk and utilize data collected to develop and implement public health actions to reduce exposures. In this paper, we present an over-view of our programmatic efforts, and focus on the descriptive data on characteristics of the study populations, and biomonitoring results. Upcoming manuscripts will provide an in-depth assessment by chemical groupings of exposure sources, particularly consumption of locally caught fish.

2. Materials and methods

The program formed an advisory committee, which included stakeholders from community/refugee resettlement groups, environmental groups, academia, and state and local health departments. This committee provided advice and support through all phases of project planning, implementation, and outreach and education.

2.1. AOC focus areas

The program focused on four AOCs in western NYS: Buffalo River, Niagara River, Eighteenmile Creek, and the Rochester Embayment. We focused on Lake Erie and Lake Ontario waters as well because of their connectedness to the AOCs under study and their inclusion in the NYS western region fish advisory (Fig. 1).

2.2. Study populations

The program targeted two subpopulations at increased risk of exposure to persistent contaminants common to the Great Lakes: (1) licensed anglers who lived close to the focus AOCs and ate locally caught fish; and (2) Burmese refugees, immigrants, and their descendants who lived in the City of Buffalo and ate locally caught fish. The two groups were sampled, recruited, and enrolled independently between February and October 2013.

2.2.1. Licensed angler subpopulation—The sampling frame and recruitment processes have been described in detail elsewhere (Wattigney et al., 2019). The catchment areas were defined as the ZIP codes within a 10-mile buffer of the AOCs, and thus licensed anglers were recruited from Erie, Niagara, and Monroe counties in NYS (Fig. 1). Adult licensed anglers who reported living at the address on the fishing license for at least one year and had consumed at least one fish caught from the AOCs or surrounding waters within the past year were eligible to participate. A total of 409 eligible licensed anglers were recruited to participate in the program.

2.2.2. Burmese subpopulation—The city of Buffalo, the second most populous city in NYS and the largest in western NYS, is a popular and "preferred" location for refugee resettlement in the nation (City of Buffalo, 2016; Fike et al., 2015). To sample and recruit the Burmese subpopulation, we used respondent-driven sampling (RDS). Burmese refugee or immigrant adults who had lived in the City of Buffalo for at least one year and had eaten at least 12 fish meals in the past year from the waterbodies of focus were eligible to participate. The RDS sampling methodology and recruitment processes are described in detail elsewhere (Liu et al., 2018; Wattigney et al., 2019). The final sample size was 206.

2.3. Data and biological specimen collection

2.3.1. Licensed angler subpopulation—Data collection procedures for licensed angler participants included obtaining informed consent, height and weight measurements, biological specimen collection (non-fasting blood and 'spot' urine), and a detailed questionnaire administered by a trained interviewer. Questionnaire domains included demographics, residential history, employment history, lifestyle factors, and items related to catch location and species-specific consumption of fish, collected with the assistance of visual aids. All biological specimen collection procedures followed the NYSDOH *Bloodborne Pathogens Program's Exposure Control Plan* standard practices in accordance with the U.S. Occupational Safety and Health Administration (OSHA) standard 29 CFR 1910.1030 (U.S. Department of Labor Occupational Safety and Health Administration

[OSHA]). Specimen processing, handling, and transport procedures followed the respective standard operating procedures specified by the Wadsworth Center, NYSDOH's public health and research laboratory.

Prior to specimen collection, certified phlebotomists screened participants to ensure that they were medically eligible to give blood via venipuncture of the cubital vein. Pre-screened vacutainers supplied by the Wadsworth Center were used to collect blood specimens. For trace metals analysis, 3 mL of whole blood was collected from each participant in purple-top (EDTA) vacutainers. For the purposes of harvesting 5–10 mL of serum for the analysis of PFOA, PFOS, PBDEs, PCBs, and organic pesticides, another specimen was collected in red-top (no preservative) glass vacutainer tubes. Serum harvesting procedures included centrifuging this whole blood sample within a 45 min to 1 h 15 min window after collection to obtain a serum layer. Urine specimens were collected into pre-screened cups and 10 mL transferred into polypropylene tubes containing a preservative designed to stabilize Hg^{2+} and prevent it from outgassing as Hg^0 (Parsons et al., 2005).

2.3.2. Burmese subpopulation—Data collection procedures for the Burmese refugee participants, including biospecimen collection, were conducted similar to the licensed angler participants. Study documents were administered in the participant's native language with the help of a trained interpreter. Because the Burmese refugees consume fish year-round, questions related to total consumption of fish caught in local waters in the past year differed slightly than those asked of licensed angler participants; i.e. Burmese participants were asked how often locally caught fish were consumed in the summer (June–August), fall (September, October), winter (November–March), and spring (April, May). Additional background data collected from the Burmese participants included country of birth, ethnicity/tribe identity, years of schooling, history of living in refugee camps, and length of residence in the U.S.; socio-economic data collected included receipt of Supplemental Nutrition Assistance Program (SNAP) benefits and Women, Infants, and Children (WIC) services; exposure data collected included methods of procuring and storing fish caught from the local waters, preparation and consumption of fish paste, use of the traditional Burmese cosmetic paste or powder (i.e. Thanakar), consumption of betel nut (a mild stimulant), and consumption of additional types of wild animals.

2.4. Laboratory analysis

Analytes measured included: blood metals (total Hg, Pb, Cd), total Hg in urine, and serum PFOS, PFOA, PBDE congeners, PCB congeners, and organochlorine pesticides. Limits of detection (LOD) for each analyte and detection rates in each participant group are presented in Table S1. Blood lipids (cholesterol and triglycerides) and creatinine in urine were also measured.

All specimens were analyzed at the NYSDOH Wadsworth Center, an accredited clinical laboratory facility under CLIA '88 which has supported previous biomonitoring studies in NYS (McKelvey et al., 2011). The trace metals Pb, Cd, and total Hg were measured in whole blood by inductively coupled plasma mass spectrometry (ICP-MS) using a method that is traceable to international standards and validated for biomonitoring studies (Murphy et al., 2009; Palmer et al., 2006). The ICP-MS instrument was calibrated for each of the metals using a matrix-matched (blood) protocol, with calibration standards traceable to the National Institute of Standards and Technology (NIST, Gaithersburg, MD). Matrix-matching requires addition of a reference base blood material to each calibration standard, since blood specimens are simply diluted with a reagent for analysis by ICP-MS. The method LODs were calculated based on IUPAC recommendations in a blood matrix. Internal quality control (IQC) materials (four levels) covering the range of human exposures were included at the beginning, end, and throughout each analytical run. Typical repeatability was 2.0% for Cd; 2.6% for Pb; and 4.0% for Hg. Method accuracy was assessed by analyzing NIST Standard Reference Material (SRM) 955c – Toxic Metals in Caprine Blood. Method performance was monitored through successful participation in six external quality assessment schemes for trace elements that included these three metals in whole blood. The analysis was repeated for any elevated value: > 4 μg/L for Cd, > 5 μg/dL for Pb, and > 10 μg/L for Hg. In addition, 2.5% of all blood specimens were randomly selected for re-analysis. All values exceeding lab-specified thresholds were confirmed with a repeat analysis on another aliquot.

Total Hg in urine was measured using a well-validated biomonitoring method based on ICP-MS (Parsons et al., 2005). The ICP-MS instrument was calibrated with matrix-matched Hg standards traceable to NIST. In this analysis, matrix-matching requires the addition of a reference urine material to each calibration standard, since urine specimens are simply diluted with a reagent for analysis by ICP-MS. Four levels of IQC materials were prepared by supplementing human urine with Hg^{2+} and were included throughout each analytical run. Repeatability for urine Hg was 11% (at 2.21 μg/L, n = 127), 6.6% (at 6.28 μg/L, n = 123), 5.2% (at 24.6 μg/L, n = 103), and 3.8% (at 93.9 μg/L, n = 104). An additional 2.5% of all urine specimens were randomly selected for re-analysis, along with any specimen exceeding 10 μg/L.

Serum samples were extracted with a solid phase extraction (SPE) method with cartridges packed with Sepra C18-E and silica gel/sulfuric acid (2:1 w/w) for extraction and cleanup. PCBs, organochlorine pesticides, and most PBDEs (except BDE 196, BDE 197, BDE 203, BDE 207, and BDE 209) were analyzed using high resolution gas chromatography-high resolution mass spectrometry (HRGC-HRMS), as described elsewhere with some modifications (Ma et al., 2013; Sjödin et al., 2004). BDE 196, BDE 197, BDE 203, BDE 207, and BDE 209 were measured by gas chromatography quadrupole mass spectrometry (GC-MS). PFOS and PFOA were measured by high-performance liquid chromatography (HPLC) with electrospray tandem mass spectrometry (MS/MS) after ion-pairing extraction (Kannan et al., 2004). The GC-MS, HRGC-HRMS and LC-MS instruments were tuned and calibrated to ensure that the mass accuracy and isotope dilution mass spectrometry method was applied for all quantifications.

Laboratory measurements underwent extensive quality control and quality assurance review, including tolerance limits for operational parameters, the measurement of quality control samples in each analytical run to detect unacceptable performance in accuracy or precision, and verification of traceable calibration materials. Method accuracy was assessed by analyzing NIST SRM 1958 – PFOS, PFOA, PCBs, PBDEs and organochlorine pesticides in fortified human serum. IQC materials, two-three blank samples prepared with HPLC water and matrix matched calibration curves were included throughout each analytical run. Method performance was monitored through successful participation in four external quality assessment schemes for PFAS, PCBs, PBDEs and organochlorine pesticides in human serum that included investigated congeners in spiked serum, including the CDC proficiency testing and quality control schedule.

Serum cholesterol (Allain et al., 1974), triglycerides (Kohlmeier, 1986), and urine creatinine (Fabiny and Ertingshausen, 1971) were measured using a cobas 501 analyzer (Roche Diagnostics, Indianapolis, IN). Average coefficients of variation were: 1.3% (triglycerides); 1.0% (cholesterol); and 1.9% (creatinine). Total lipid was calculated using the Phillips short formula (Phillips et al., 1989) [total lipids (in mg/dL) = (2.27 × total cholesterol [in mg/dL]) + triglycerides (in mg/dL) + 62.3].

2.5. Data analysis

Descriptive analyses were conducted to summarize questionnaire responses and analyte concentrations using SAS version 9.4 (SAS Institute, Inc. Cary, NC). The common characteristics described for each group include demographic variables, lifestyle factors, employment and education history, and consumption of locally caught and store-bought fish. For the licensed anglers, total consumption of locally caught fish in the past 12 months was assessed by summing the consumption of all fish species. Among the Burmese participants, the total consumption in the past 12 months was assessed by season (consumption of fish in the spring season is not reported due to a high proportion of missing data).

For each analyte, we calculated the geometric mean (GM) and 95th percentile with 95% confidence intervals (CIs). We used SAS PROC SUMMARY to compute GMs and CIs, and for percentiles with 95% CIs we used SAS PROC UNIVARIATE with CIQUANTDF option to request distribution free CIs. To assess elevated body burdens of the environmental contaminants among study participants, we used NHANES data for adults 20 years and older for the GM and 95th percentile comparisons. The reference levels for blood metals, urinary Hg, and PFAS were derived from NHANES 2013–2014 data (Centers for Disease Control and Prevention [CDC], 2017). The reference levels for lipid-adjusted analytes (PBDEs, pesticides, and PCBs) were derived from NHANES 2003–2004 data since these analytes were last measured in individual samples in NHANES 2003–2004 and in pooled samples after 2004 (Centers for Disease Control and Prevention [CDC], 2017; Patterson et al., 2009). Statistical comparisons between the GMs of the two participant groups and those from NHANES were made using the one-sample Student’s *t*-test.

We calculated a sum of PCB congeners among participants and compared it to the “sum of 35 PCBs” from NHANES 2003–2004 data (Patterson et al., 2009). Due to different co-eluting PCB groups, a total of 36 PCBs or PCB groups were used in the calculation. In this study, the PCB congener groups that are different from NHANES 2003–2004 data are PCB 31/28, PCB 49/43, PCB 52/73, PCB 66/80, PCB 74/61, PCB 87/117/125/116/111/115, PCB 101/90/89, PCB 105/127, PCB 118/106, PCB 138/164/163, PCB 146/161, PCB 149/139, PCB 170/190, PCB 172/192, PCB 187/182.

Following guidelines for analysis of NHANES data, concentrations below the LOD were assigned a value equal to LOD/√2. GMs were not calculated in instances where more than 40% of the results were below the LOD. For chemicals measured in serum, concentrations are expressed per amount of total lipid. Urinary Hg concentrations are expressed per grams of creatinine (to adjust for urine dilution).

3. Results

3.1. Licensed angler subpopulation

3.1.1. Demographic and lifestyle characteristics—A majority of the licensed angler participants were male (86%), non-Hispanic White, (85%), and employed in the past year (71%). The median age was 54 years. About 22% were current smokers, and very few reported current use of chewing tobacco or snuff. A majority reported swimming, diving, or wading in local waters in the past year. About 81% reported being aware of NYSDOH advisories on eating fish caught in NYS waters (Table 1).

3.1.2. Fish consumption—Select fish consumption characteristics among licensed anglers are presented in Table 2. The median number of locally caught fish meals consumed by the licensed anglers in the past year was 16, with yellow perch and walleye being the most popular types of fish eaten. Sixty-six percent reported consuming fish or shellfish in the past week. Most anglers (59%) reported consuming more than half a pound serving of fish in a typical meal. NYS bodies of water most frequented by the anglers for fishing were Lake Erie (68%), Lake Ontario (67%), Upper Niagara River (42%), Lower Niagara River (36%), Irondequoit Bay/Creek (30%), and Eighteenmile Creek (22%). Filleting, removing of the skin, and gutting were the most common methods of cleaning fish; pan frying, deep frying, and baking/broiling were the most common cooking methods. Only 12% of all anglers consumed waterfowl or bear that were hunted from nearby waterbodies in the past year. Fish purchased from a store (i.e., grouper, shark, swordfish, and canned and uncanned salmon and tuna) were consumed a median of 22 times in the past year.

3.1.3. Analyte results—Results for metals and PFAS concentrations among licensed anglers are presented in Table 3. The licensed anglers had blood Cd GM concentrations similar to, and blood Pb and total blood Hg levels over 1.5 times that of NHANES 2013–2014 reference GM levels. Creatinine-adjusted urine Hg GM concentrations were lower than the U.S. adult population. PFOA and PFOS GMs were approximately 1.2 and 2.4 times that of NHANES reference levels, respectively.

Results for PBDEs, PCBs, and persistent organic pesticides are presented in Table 4. The five PBDE congeners that had at least 60% detectable results (BDE 28, BDE 47, BDE 99, BDE 100 and BDE 153) are reported. The GM concentrations of PBDE congeners (except BDE 28), three predominant PCB congeners/congener groups, and DDE, HCB, and *trans*-Nonachlor were either similar to or lower than reported NHANES 2003–2004 levels. DDT, mirex, and oxychlordane were detected in less than 60% of the samples; therefore, GMs for these analytes were not calculated. All toxaphene results were below the LOD.

3.2. Burmese subpopulation

3.2.1. Demographics and lifestyle characteristics—Select demographic and lifestyle characteristics of Burmese refugee participants are presented in Table 5. A majority of the participants were women, and the participant age distribution was similar for men and women. Most participants were aged 18–39 years and about 51% reported being of Karen ethnicity. Approximately two thirds of Burmese participants reported being literate. Almost all participants reported being born in Burma, 86% lived in a refugee camp prior to coming to the U.S., and 64% had lived in the U.S. for less than 5 years. A majority of the participants were currently unemployed and received food stamp program (SNAP) benefits. Approximately 22% of participants reported being current smokers, and approximately 29% reported currently using tobacco/snuff. Only about 12% reported swimming, diving, or wading in local waters in the past year. About 39% of the participants were aware of NYSDOH advisories on eating fish caught in local waters.

3.2.2. Fish and wildlife consumption—Select fish consumption characteristics among Burmese participants are presented in Table 6. Fish/shellfish were eaten in the past week by a majority of Burmese participants. Locally caught fish were eaten most frequently in the summer months (June, July, August), with a median of 39 meals eaten in the previous summer. A majority of the participants reported eating waterfowl, frogs, or toads in the past year.

About 92% of the participants reported consuming fish paste. Of those who consumed fish paste, 35% consumed homemade fish paste and 89% consumed store-bought fish paste. Most participants reported catching their own fish locally or receiving fish from friends and family. Participants most commonly fished from Upper Niagara River and Lake Erie. Most frequently eaten local fish species were quillback, common carp, minnow, white perch, white bass, brown bullhead, and channel catfish. Fish/shellfish purchased from a store (i.e., grouper, shark, swordfish, canned and uncanned salmon and tuna, shrimp, snails, and mussels) were consumed a median of 104 times in the past year. Shrimp was the most common store-bought fish/shellfish consumed. At least half of the participants reported preparing fish by removing viscera and scales but retaining the skin. A majority of the participants reported pan frying, deep frying, and drying the fish; smaller sized fish were used to make fish paste.

3.2.3. Analyte results—Results for metals, PFOA, and PFOS concentrations are presented in Table 3. The GMs for blood Cd, Pb, total Hg; creatinine-adjusted urine Hg; and PFOS were greater than the NHANES 2013–2014 reference levels (2.4 times, 3.2 times, 4.5 times, 1.4 times, and 6.5 times, respectively). The GM for PFOA was lower than the NHANES reference level.

Results for lipid-adjusted PBDEs, PCBs, and organochlorine pesticides are presented in Table 4. GMs for select PBDE congeners, three predominant PCB congeners/PCB groups, the sum of PCBs, HCB, and *trans*-Nonachlor were either similar to or lower than the reported NHANES 2003–2004 reference levels. For DDT, mirex, and oxychlordane, GMs were not calculated since at least 68% of measurements were below the LOD. For DDE, the

GM and 95th percentile were approximately 1.4 times and 2.3 times that of NHANES reference levels, respectively. DDT was higher at the 95th percentile as well. All toxaphene results were below the LOD.

4. Discussion

Over the years, fish sampling data from the Great Lakes and national human biomonitoring data have shown declining trends in legacy contaminant burden (Kato et al., 2011; Salamova et al., 2013; Sjödin et al., 2014). However, persistent exposures from fish caught in the Great Lakes remain a concern (Fitzgerald et al., 2004; He et al., 2001; Paliwoda et al., 2016).

Licensed anglers in the NYS Healthy Fishing Communities Program reported fish consumption rates (a median of 16 locally caught fish meals in the past year) that were slightly higher than rates reported in previous investigations of Great Lakes sportfish consumption among NYS anglers in the western regions (Spliethoff et al., 2008; Connelly et al., 1996). Compared to non-refugee populations, Southeast Asian refugees and immigrants in the U.S. consume more fish (Fan Anna, 2009). Hunting and fishing are of cultural significance among refugee communities and are economically resourceful ways of obtaining food (Schantz et al., 2010). The high level of fish consumption reported by Burmese participants in our program may not only be related to fishing for sustenance but also to low awareness of health advice related to consuming locally caught fish (Judelsohn et al., 2017).

Both participant groups in this study had higher GMs for blood Pb, total blood Hg, and PFOS compared to NHANES 2013–2014 reference levels. Pb and Hg, along with other heavy metals are known neurotoxins and endocrine disruptors and have been linked to adverse neurodevelopmental outcomes and developmental disabilities (Dzwilewski and Schantz, 2015; Grandjean et al., 1997; Iavicoli et al., 2009). Heavy metal contamination of Great Lakes waters is well documented (Forsythe et al., 2004; Forsythe et al., 2015). Higher total blood Hg levels as compared to the general U.S. population can be attributed to the dietary intake of Hg in its organic form (methyl Hg), most likely due to fish consumption (Evers et al., 2011; Hightower, O'Hare and Hernandez, 2006; McKelvey et al., 2007). Exposure to inorganic Hg, documented by high urinary Hg levels among our Burmese participants, could possibly be related to long-term use of adulterated foods, cosmetics, and herbal medicines (McKelvey et al., 2011). High Pb levels among the Burmese could be indicative of prior exposures, including exposures to leaded gasoline or contaminated car batteries and/or consumer products (Mitchell et al., 2012). Pb absorbed into the body is stored in multiple body tissues. Approximately 80%–95% of absorbed Pb is stored in bone with an estimated half-life of 10–30 years, so it is feasible that endogenous stored Pb may contribute to the current blood Pb levels (Barbosa et al., 2005). Since peak blood Pb levels during early life are unknown, we cannot be certain that endogenous sources account for all the Pb measured in blood, and other factors may well explain the higher Pb levels reported here. Additional analyses for this group examining duration of stay in refugee camps and related associations with blood Pb levels are planned.

Both groups also had substantially elevated levels of PFOS, which is a known immunotoxicant and thought to decrease disease resistance (National Toxicology Program [NTP], 2016). PFOS levels have been declining in the general U.S. population over time per NHANES data trends (Calafat et al., 2007; Kato et al., 2011). However, more data on PFOS levels in fish samples are needed. Annual PFOS measurements in Lake Ontario lake trout showed no clear trends between 1997 and 2008 (Gewurtz et al., 2012). However, PFOS measurements in lake trout and walleye from Lake Erie between 2008 and 2012 remained high (70 ng/g), as did levels in Lake Ontario trout (54 ng/g) (McGoldrick and Murphy, 2016).

Studies such as the New York State Angler Cohort Study (1992–1995), focusing on Lake Ontario sport fish and waterfowl consumption, have attempted to characterize exposure to contaminants, such as PCBs, methyl Hg, Pb, mirex, DDE, and HCB, among adult anglers in western NYS (Mendola et al., 1995; Vena et al., 1996). Results from these data suggest that long-term consumption of Lake Ontario sportfish can significantly contribute to serum levels of organochlorine compounds such as PCBs and mirex (Bloom et al., 2005). Moreover, PBDE levels have been shown to be positively associated with the number of years of consuming sportfish from Lake Ontario (Spliethoff et al., 2008). Globally, in Asia, Europe, and Oceania, fish and/or shellfish have been documented as major dietary exposure sources for PBDEs, Hg, PFAS, and PCBs (Bjermo et al., 2017; Castano et al., 2015; Duarte-Davidson and Jones, 1994; Haug et al., 2010; Helmfrid et al., 2015; Hu et al., 2018; Karatela et al., 2019; Na et al., 2013; Xu et al., 2017).

Body burdens of persistent chemicals in humans are influenced by exposure routes and length, half-lives, risky behaviors, dietary patterns, age, race and ethnicity, gender, and metabolism rates, among other factors (Brauner et al., 2011; Genuis et al., 2017; Inoue et al., 2006; Megson et al., 2013; Patterson et al., 2009). The Burmese subpopulation’s relatively recent residence in the area compared to the licensed anglers, combined with their high level of current local fish consumption, suggest recent and ongoing exposures to industrial legacy contaminants. As a result of their prior residence in less developed/less industrialized areas, this refugee group was likely less exposed to some legacy industrial chemicals, such as PCBs, which were used extensively in the U.S. prior to the 1970s (Markowitz and Rosner, 2018). As expected, Burmese participants in this program had lower body burdens of PCBs as compared to the general U.S. population, however, they had higher levels of DDE which is an indicator of past exposure. Since these chemicals (i.e. DDT) continue to be used internationally, the Burmese were likely exposed prior to coming to the U.S. (Peeters et al., 2015). Although health outcomes in humans are unknown at low environ-mental doses, DDT has been classified as a possible human carcinogen and animal studies have shown links to liver disease and adverse reproductive outcomes (Centers for Disease Control and Prevention [CDC], 2009b).

The Healthy Fishing Communities Program participants whose heavy metal levels exceeded NYS early reporting guidelines were notified of their results immediately. Program participants received letters with individual metals and select chemicals results, detailed information sheets on contaminants, graphic representations of individual results and NHANES reference levels, and local fish consumption advisories and fishing guidelines

(New York State Department of Health [NYSDOH], 2018). Translated materials were shared with non-English speaking participants, and interpreters assisted with message delivery and results explanations. Participants were encouraged to consult with their primary care providers with concerns about their own health or their family's health as it related to their individual test results. Program staff were available as a resource to primary care providers in case they had questions. Program outreach for the Burmese refugee participants was conducted in consultation with the advisory committee and in collaboration with community partners to ensure consistent delivery of health messages.

Non-traditional angler populations consume locally caught fish for cultural and economic reasons. Thus, outreach to participants did not discourage consumption of fish given the associated nutritional benefits (Mozaffarian and Rimm, 2006) but focused on informing people about reducing exposure to contaminants by choosing better fish to eat, better waters to fish from, and healthier ways to prepare fish. NYSDOH fish advisories provide information on making healthier choices about which fish to eat, including fish species to choose or avoid/limit. Advisories also provide specific fish consumption advice for women of childbearing age and children. Public health actions taken by the NYSDOH Outreach and Education Program have included developing maps for the western region showcasing local fishing waters and the applicable fish advisories.

Our study has some limitations. There is a possibility of selection bias among licensed anglers; those who participated in the program likely fished more and were more aware of local fish advisories, com-pared to non-participants (Lauber et al., 2017). Therefore, it is possible that some contaminant levels in the overall population of interest were somewhat different compared to results presented in our study. Although the response rate to the initial screening survey among licensed anglers was low (~16%), it is comparable to other angler surveys conducted in the U.S. (Shideler et al., 2015; Sohngen et al., 2015). The initial Burmese refugee 'seed' participants were selected in a non-random fashion per RDS methodology. However, RDS proved to be an effective methodology for recruitment, and the final sample represented the source population (Liu et al., 2018). Since survey data were self-reported, data quality could be limited by the participants' recall ability and ability to understand questions. However, interpreters were trained in all aspects of survey administration prior to program implementation, and interpreters were supervised by program staff. These procedures likely assisted with countering communication concerns that arose, minimizing some likelihood of information bias. Also, since being banned, levels of organochlorine pesticides, for example DDE, have continued to decline in the U.S. population over the past few decades (Centers for Disease Control and Prevention [CDC], 2009a). Thus, the use of NHANES 2003–2004 data for comparatively describing such contaminant levels among NYS Healthy Fishing Communities Program participants sampled in the year 2013 limit our discussion, not only because of declining background levels over time, but also because of possible exposures prior to coming to the U.S., specifically for the Burmese.

5. Conclusions

The descriptive information collected and analyzed as part of the NYS Healthy Fishing Communities Program is informative for both the licensed angler and Burmese refugee subpopulations in NYS but in different ways. For the licensed anglers, these data presumably capture body burdens of persistent chemicals that can be expected to represent lifetime exposure histories. For the Burmese subpopulation, apart from lifetime histories, these data also capture body burdens that could potentially be changing due to relatively new exposures to legacy contaminants such as PCBs. Our results add to existing data on human exposures to environmental contaminants among high-risk populations in the Great Lakes Basin.

The substantial levels of fish consumption from local waters in NYS reported by both groups highlight the need for ongoing outreach related to fishing and fish consumption. As reported in our study, the Burmese, specifically, are less likely to be aware of fish consumption and health advisories. Balanced messages highlighting the nutritional benefits of fish consumption while reducing exposures to Great Lakes contaminants are necessary. Additional research is needed among refugee populations to determine if body burdens of legacy contaminants will continue to increase with continued residence in the U.S. or decrease if fish consumption patterns change due to an increased under-standing of and adherence to local fish advisories.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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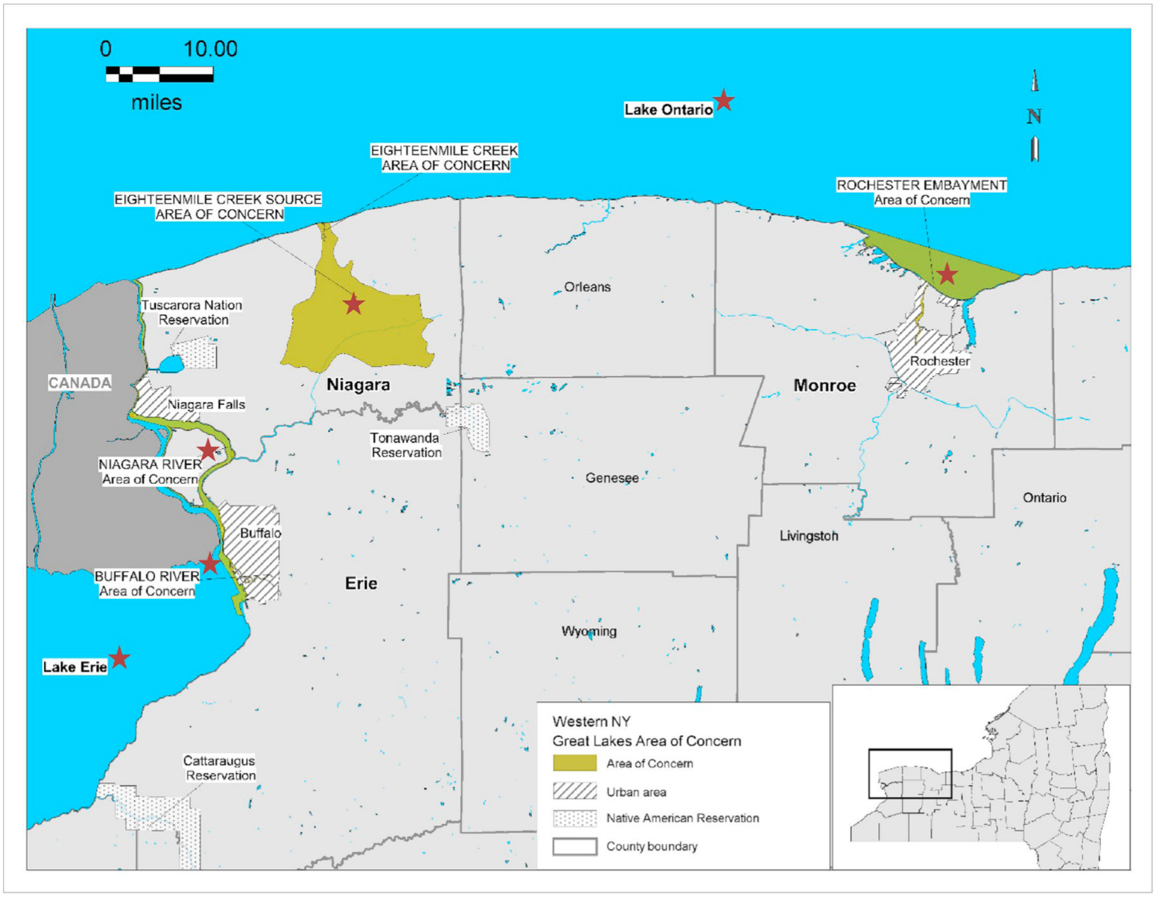

Fig. 1.

Map of the Great Lakes and Areas of Concern (AOCs) under focus in the NYS Healthy Fishing Communities Program. Waterbodies included in the program are labeled with a star: 4 AOCs (Buffalo River, Niagara River, Eighteenmile Creek, the Rochester Embayment), plus Lake Erie and Lake Ontario.

Table 1

Demographic and lifestyle characteristics of licensed angler participants of the NYS Healthy Fishing Communities Program (n = 409).

Characteristics	Categories	N (%) [a]
Male	Total	353 (86.3)
	19–39 years	62 (17.6)
	40–59 years	168 (47.6)
	60 years or older	123 (34.8)
Female	Total	56 (13.7)
	18–39 years	16 (28.6)
	40–59 years	28 (50.0)
	60 years or older	12 (21.4)
Race/Ethnicity	Hispanic	14 (3.5)
	Non-Hispanic White	344 (84.9)
	Non-Hispanic Black	37 (9.1)
	Non-Hispanic Other, including multiracial	10 (2.5)
Body Mass Index	Normal (< 25 kg/m^2)	68 (16.6)
	Overweight (25–29.9 kg/m^2)	152 (37.2)
	Obese (30 + kg/m^2)	189 (46.2)
Education	No high school diploma or GED	25 (6.1)
	High school diploma or GED	129 (31.5)
	Some college education (no diploma)	76 (18.6)
	College degree (including associate’s degree)	179 (43.8)
Employment history	Employed in the past 12 months	288 (70.6)
Annual income	Less than $35,000	73 (19.0)
	$35,000 - < $75,000	139 (36.2)
	$75,000 and more	172 (44.8)
Smoking and tobacco use	Current smoker	88 (21.7)
	Former smoker	176 (43.3)
	Never smoker	142 (35)
	Current use of chewing tobacco or snuff	15 (3.7)
Swam, dove, waded in local waters in the past year		245 (60.3)
Heard about health advice on eating fish from nearby waters		325 (80.6)

[a] Percentages are based on excluding missing values and responses such as ‘don’t know’ or ‘refused’.

Table 2

Fish consumption among licensed angler participants of the NYS Healthy Fishing Communities Program (n = 409).

Characteristics	Categories	N	Median (25th, 75th) [a]
Frequency of consumption of locally caught fish in past year		402	16 (6, 36)
Frequency of consumption of five most popular local fish species in the past year	Yellow perch	278	5 (2, 12)
	Walleye	209	5 (2, 12)
	Smallmouth bass	142	3 (2, 6)
	Rainbow/steelhead trout	123	3 (2, 6)
	Largemouth bass	109	3 (2, 7)
Frequency of consumption of select store-bought fish in the past year		409	22 (11, 45)

[a]25th,75th percentiles.

Table 3

Metals, PFOA, and PFOS concentrations among participants [a] of the NYS Healthy Fishing Communities Program and NHANES 2013–2014 participants.

Analyte	Licensed angler participants		Burmese participants		NHANES 2013–2014	
	Geometric mean (95% CI [b])	**95th PCTL [b] (95% CI [b])**	**Geometric mean (95% CI [b])**	**95th PCTL [b] (95% CI [b])**	**Geometric mean (95% CI [b])**	**95th PCTL [b] (95% CI [b])**
Blood cadmium (μg/L)	0.316 (0.289–0.345)	1.90 (1.41–2.42)	0.725 (0.663–0.793) [c]	2.43 (1.90–3.40)	0.297 (0.280–0.315)	1.36 (1.17–1.64)
Blood lead (μg/dL)	1.48 (1.40–1.57) [c]	4.08 (3.64–4.70)	3.13 (2.92–3.34) [c]	7.63 (6.03–9.75)	0.967 (0.921–1.02)	3.03 (2.65–3.55)
Blood mercury (μg/L)	1.50 (1.36–1.65) [c]	7.65 (6.39–9.79)	3.66 (3.36–3.98) [c]	11.0 (8.43–17.0)	0.814 (0.736–0.900)	4.88 (4.36–5.21)
Urine mercury (μg/g creatinine)	0.283 (0.256–0.313) [c]	1.63 (1.38–2.23)	0.430 (0.367–0.504) [c]	4.55 (3.29–10.9)	0.318 (0.291–0.349)	1.76 (1.50–1.88)
PFOA (μg/L)	2.49 (2.36–2.62) [c]	5.18 (4.77–5.67)	1.47 (1.37–1.58) [c]	3.16 (2.67–4.10)	1.98 (1.79–2.19)	5.60 (4.67–6.40)
PFOS (μg/L)	12.9 (11.9–13.9) [c]	53.9 (44.0–79.4)	33.8 (30.4–37.6) [c]	126 (95.9–166)	5.22 (4.70–5.81)	19.5 (15.8–23.0)

[a] Licensed anglers; n = 400 (blood metals), 405 (creatinine-adjusted urine Hg), 397 (serum PFOA and PFOS). Burmese refugees; n = 205 (blood metals), 204 (creatinine-adjusted urine Hg), 199 (serum PFOA and PFOS). Sample sizes do not equal 409 (licensed anglers) and 206 (Burmese refugees) because of missing values.

[b] CI; confidence interval, PCTL; percentile.

[c] Geometric means are significantly different compared to the NHANES geometric means (One-samplet-test, $p < 0.05$).

Table 4

PBDE, PCB, and organochlorine pesticide concentrations (in ng/g of lipid) among participants [a] of the NYS Healthy Fishing Communities Program and NHANES 2003–2004 participants.

Analyte	Licensed angler participants		Burmese participants		NHANES 2003–2004	
	Geometric mean (95% CI [b])	95th PCTL [b] (95% CI [b])	Geometric mean (95% CI [b])	95th PCTL [b] (95% CI [b])	Geometric mean (95% CI [b])	95th PCTL [b] (95% CI [b])
BDE 28	1.45 (1.32–1.59) [c]	7.46 (6.30–8.84)	1.14 (1.04–1.26)	3.97 (3.48–4.91)	1.17 (1.01–1.37)	8.20 (6.00–10.9)
BDE 47	7.95 (6.83–9.24) [c]	91.8 (70.1–143)	8.87 (7.73–10.2) [c]	38.5 (29.2–58.4)	19.5 (16.5–23.1)	163 (102–240)
BDE 99	2.39 (2.07–2.75)	33.2 (26.8–41.6)	1.77 (1.51–2.07)	13.8 (9.47–20.2)	NA [d]	41.6 (30.8–57.3)
BDE 100	2.49 (2.22–2.79) [c]	20.4 (13.3–30.5)	2.43 (2.19–2.70) [c]	7.89 (6.41–11.6)	3.77 (3.24–4.38)	36.6 (23.2–59.2)
BDE 153	5.31 (4.73–5.96)	36.3 (31.4–55.9)	1.80 (1.60–2.03) [c]	7.16 (6.06–10.9)	5.41 (4.83–6.05)	73.3 (58.2–90.4)
Sum of PCBs [e]	117 (104–132) [c]	546 (460–637)	70.4 (60.7–81.7) [c]	383 (286–608)	134 (129–140)	531 (498–570)
PCB 138/164/163 [f]	7.39 (6.01–9.09) [c]	70.7 (62.5–94.1)	6.41 (5.03–8.17) [c]	47.0 (38.8–71.0)	17.7 (16.5–19.0)	77.4 (72.3–87.7)
PCB 153 [f]	11.3 (9.18–13.9) [c]	103 (83.8–122)	5.35 (4.04–7.08) [c]	53.6 (41.1–109)	23.7 (22.3–25.1)	101 (92.9–119)
PCB 180 [f]	10.2 (8.32–12.5) [c]	91.2 (78.5–104)	3.53 (2.71–4.61) [c]	43.2 (28.3–76.7)	19.0 (17.9–20.1)	88.0 (77.8–96.7)
p,p’-DDT	NC [g]	1.60 (0.811–12.1)	NC [g]	247 (150–345)	NA [d]	20.7 (15.9–28.7)
p,p’-DDE	90.8 (76.2–108) [c]	560 (463–939)	378 (293–488) [c]	4526 (3301–9698)	268 (217–332)	1990 (1500–2470)
Mirex	NC [g]	18.6 (9.11–41.8)	NC [g]	3.22 (1.75–17.8)	NA [d]	15.4 (8.10–37.1)
HCB	7.32 (6.40–8.38) [c]	31.7 (27.3–42.9)	6.59 (5.71–7.61) [c]	20.5 (19.5–30.9)	15.5 (14.7–16.2)	29.0 (25.6–33.6)
trans-Chlordane	3.24 (2.58–4.07)	64.4 (45.9–87.9)	5.74 (4.51–7.31)	33.8 (28.6–56.5)	NA [d]	NA [d]
Oxychlordane	NC [g]	13.2 (9.91–20.5)	NC [g]	3.77 (< LOD [hi] –11.7)	10.6 (9.82–11.5)	39.2 (36.5–44.8)
trans-Nonachlor	9.37 (7.85–11.2) [c]	66.2 (52.8–79.4)	4.56 (3.91–5.32) [c]	21.0 (14.8–26.1)	16.9 (15.1–18.9)	74.7 (59.8–90.0)

[a] Licensed anglers; n = 396. Burmese refugees; n = 196. Sample sizes do not equal 409 (licensed anglers) and 206 (Burmese refugees) because of missing values.

[b] CI; confidence interval, PCTL; percentile.

[c] Geometric means are significantly different compared to the NHANES geometric means (One-sample *t*-test, $p < 0.05$).

[d]NA; NHANES reference level not available.

[e]NHANES comparisons for sum of PCBs are derived from Patterson et al. (2009) (persons 12 years of age and older, NHANES 2003–2004).

[f]Results for the three most predominant PCB congeners and congener group are presented. For the PCB group (which includes contribution from two or more congeners), the single congener that represents the NHANES reference level is bolded.

[g]NC (Not calculated); proportion of results below limit of detection was > 40%.

[h]< LOD; below the limit of detection.

[i]Lipid-adjusted LOD = 1.3 ng/g lipid.

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Table 5

Demographic and lifestyle characteristics of Burmese refugee participants of the NYS Healthy Fishing Communities Program (n = 206).

Characteristics	Categories	N (%) [a]
Male	Total	82 (39.8)
	18–39 years	43 (52.4)
	40–59 years	33 (40.2)
	60 years or older	6 (7.3)
Female	Total	124 (60.2)
	18–39 years	71 (57.3)
	40–59 years	46 (37.1)
	60 years or older	7 (5.6)
Ethnicity	Burman	38 (20.1)
	Karenni	27 (14.3)
	Karen	96 (50.8)
	Other	28 (14.8)
Body Mass Index	Normal (< 25 kg/m^2)	78 (38.4)
	Overweight (25–29.9 kg/ m^2)	90 (44.3)
	Obese (30 + kg/m^2)	35 (17.2)
Years of total school completed	None	56 (28.0)
	1–8 years	88 (44.0)
	9–12 years	49 (24.5)
	> 12 years	7 (3.5)
Currently unemployed		145 (71.1)
Country of birth	Burma/Myanmar	185 (97.4)
	Thailand	5 (2.6)
Length of residence in the U.S.	< 5 years	130 (63.7)
	5–13 years	74 (36.3)
Lived in a refugee camp		174 (86.1)
Ever breastfed their children [b]		84 (76.4)
Receive SNAP benefits		171 (83.8)
Receive WIC services		76 (38.4)
Smoking and tobacco use	Current smoker	45 (22.4)
	Former smoker	18 (9.0)
	Never smoker	138 (68.7)
	Currently uses chewing tobacco or snuff	59 (29.3)
Use of Thanakar (cosmetic paste)		90 (45.0)
Betel nut use	Store bought betel nut	37 (18.0)
	Natural betel nut	19 (9.2)
Use of supplements	Herbal medicine/supplements	10 (4.9)
	Fish oil	3 (1.5)

Characteristics	Categories	N (%) [a]
Swam, dove, waded in local waters in the past year		25 (12.3)
Heard about health advice on eating fish from nearby waters		79 (39.3)

[a]Percentages are based on excluding missing values and responses such as ‘don’t know’ or ‘refused’.

[b]Based on responses from women who ever gave birth (denominator = 110, excluding missing values).

Table 6

Fish, fish paste, waterfowl, and wild game consumption among Burmese refugee participants of the NYS Healthy Fishing Communities Program (n = 206).

Characteristics	Categories	N (%) [a]
Ate fish/shellfish in the past week		179 (89.1)
Ate wild birds or animals in the past 12 months	Waterfowl (ducks or geese)	141 (68.5)
	Frogs or toads	117 (56.8)
Ate fish paste		183 (92.4)
		Median (25th, 75th)[c]
Frequency of consumption of locally caught fish in the past year (including frozen fish), by season[b]	Summer	39 (26, 52)
	Fall	18 (9, 27)
	Winter	22 (0, 44)
	Total (3 seasons)	88 (44, 132)
Frequency of consumption of fish paste in the past year		156 (52, 364)
Frequency of consumption of select store-bought fish/shellfish in the past year		104 (36, 156)

[a]Percentages are based on excluding missing values and responses such as ‘don’t know’ or ‘refused’.

[b]Seasons were defined as follows: summer (June, July, August), fall (September, October), winter (November, December, January, February, March). Consumption of fish in the spring season (April and May) is not re-ported due to a high proportion of missing data.

[c]25th,75th percentiles.