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Fish consumption, awareness of fish advisories, and body burden of contaminants among the Milwaukee urban anglers: A biomonitoring study

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The Milwaukee Estuary Area of Concern (AOC) has been impacted by toxic pollutants, including polychlorinated biphenyls (PCBs) and heavy metals. During 2017-2019, the Wisconsin Department of Health Services conducted a biomonitoring study with the Agency for Toxic Substances and Disease Registry to examine contaminant exposures among Milwaukee urban anglers who consumed locally sport-caught fish. Questionnaires were administered to licensed anglers living within the Milwaukee AOC, and blood and urine samples were obtained for contaminant analysis. We conducted multivariable logistic regression analyses to examine associations with fish consumption, awareness of fish advisories, and protective behaviors. Contaminant concentrations among participants were compared to the U.S. population levels in the National Health and Nutrition Examination Survey (NHANES). Respondents completed the questionnaire (n=396) and provided biological samples (n=390). The median age was 51 years, and the majority were male (81%) and non-Hispanic white (81%). Most respondents were aware of safe-eating guidelines for fish caught in the Milwaukee AOC (63%) or Wisconsin (75%), but fewer than half reported close adherence to guidelines. Women and black respondents were less aware of Wisconsin and Milwaukee advisories than men and white respondents, respectively. Geometric mean concentrations of perfluorooctane sulfonate (PFOS), PCBs, and mercury were higher than NHANES estimates. Most anglers in the Milwaukee AOC did not reduce sport-caught fish consumption to avoid exposure to contaminants in Milwaukee waterways. Milwaukee urban anglers had higher PFOS, PCB, and mercury concentrations than those in U.S. adults. Further research is needed to examine the factors influencing anglers' adherence to safe-eating guidelines.

Key words: Urban anglers, fish consumption, contaminants, biomonitoring, fish advisories.

INTRODUCTION

The Great Lakes Basin has been impacted over time by toxic chemicals, resulting in human exposure to these contaminants via inhalation, dermal contact with water, soil and sediments, ingestion of municipal water drawn from the lakes, and consumption of local fish. The International Joint Commission Water Quality Board has identified 43 areas of concern (AOCs) in the United States that have been severely impacted by contaminants, five of which are located in Wisconsin. Of these, the Milwaukee Estuary AOC is of particular concern because the Milwaukee River Basin is located in the most densely populated area of Wisconsin, encompassing portions of seven counties, and is home to about 1.3 million people (EPA, 2016). The primary contaminants in this area are polychlorinated biphenyls (PCBs), heavy metals, and polycyclic aromatic hydrocarbons (PAHs) (EPA, 2019).

Many of the chemicals present in the Milwaukee AOC bioaccumulate up the food chain, making consumption of locally caught fish a key exposure pathway. Over the past 25 years, biomonitoring studies have been conducted in Wisconsin using convenience samples of at-risk populations, including charter boat captains and their families, women of childbearing age, and older males. These studies have revealed increased body burdens of PCB and per- and polyfluoroalkyl substances (PFAS) consistent with exposure via consumption of Great Lakes fish (Christensen et al., 2015; Turyk et al., 2006). These studies have also demonstrated associations between increased contaminant levels and adverse health effects, including diabetes (Turyk et al., 2006, 2015), thyroid and other hormone disorders (Turyk et al., 2015), cardiovascular disease (Raymond et al., 2016) and reduced birth weight (Weisskopf et al., 2005). In addition, anglers living near the impacted waterways often experience additional socioeconomic and environmental stressors that further increase their vulnerability (Corburn, 2002; Kalkirtz, 2008). Milwaukee County has one of the highest rates of children living in poverty and food insecurity in the state (University of Wisconsin Population Health Institute, 2015) and is a key destination for refugee populations who have limited economic resources and low health literacy (CDC, 2010).

Although the residents living in proximity to the Milwaukee Estuary AOC waterways presumably have an elevated risk of being exposed to contaminants, we have limited knowledge of their fish consumption and body burdens of environmental contaminants. Therefore, in 2017, the Wisconsin Department of Health Services conducted a geographically focused community biomonitoring study of Milwaukee urban anglers with the purpose of examining their exposure to contaminants on the local level and exploring how to best minimize risks from sport-caught fish consumption. The basic demographics of study participants were previously paper reports fish consumption behaviors and awareness of fish described in an overview article (Li et al., 2021). This advisories, as well as initial descriptive analyses of biomonitoring results.

METHODS

Recruitment

Four strategies were used to recruit respondents during 2017-2018: (1) mail recruitment of fish license registrants; (2) email recruitment of fish license registrants; (3) peer recruitment by study participants; and (4) shoreline recruitment at fishing venues. The study was originally designed to recruit representative samples of anglers using stratified random selection from a state fishing license database, but additional sampling strategies were implemented after a lower-than-expected response rate. Regardless of recruitment strategies, respondents were asked to complete a screening survey with the following: (1) “I have lived at my current address (within 5 miles radius of Milwaukee AOC) for one year or longer;” (2) “I am a male OR I am a female who is not currently pregnant;” and (3) “In the past 12 months, I ate at least one fish meal that was caught in any of the lakes, rivers, streams, or ponds pictured in the map printed on the back of this page” (Figure 1). Respondents were eligible to participate in our study if they answered “yes” to all three screening questions.

Data collection

All participants provided informed consent before participation. Upon enrollment, respondents were asked to complete a questionnaire and schedule an appointment to provide urine and blood samples. Respondents completed a mailed or web-based questionnaire regarding fish consumption and awareness of fish advisories before their appointment, but they were also given the option to complete it onsite. Respondents were asked about consumption of sport-caught fish, store-bought fish, and shellfish in the past 12 months. Awareness of fish advisories included awareness of Wisconsin fish advisories and Milwaukee-specific fish advisories. Information sources for fish advisories and safe fish cooking practices were also examined (Appendix 1 for the list of questions). Respondents’ urine and blood samples and body measurements (height, weight, and waist circumferences) were collected by certified phlebotomists. Serum samples for PCB, PFAS, and pesticide analyses were immediately frozen and stored at -20°F; whole blood for metals analysis was refrigerated for up to one week prior to freezing; and urine was immediately frozen after collection. Frozen biological samples were shipped overnight on dry ice to analytical laboratory in batches.

All study activities were approved by the federal Office of Management and Budget (Control Number 0923–0056). This study was supported by a cooperative agreement from the Centers for Disease Control and Prevention (CDC)/Agency for Toxic Substances and Disease Registry (ATSDR).

Human Subjects Protection Committee and did not require oversight or review by an institutional review board.

Laboratory analysis

The Division of Laboratory Sciences (DLS) within CDC’s National

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Figure 1. Milwaukee Urban Anglers study area map. Water bodies with dark yellow shade were included in this study.
Source: Authors

Center for Environmental Health conducted all laboratory analyses, following establish analytical methods, standard operating procedures, and quality control and quality assurance procedures.

Five metals (manganese, lead, cadmium, selenium, and mercury) were measured in whole blood samples using DLS Method 3040.1 by inductively coupled plasma triple quadrupole mass spectrometry. Nine PFAS chemicals were measured in serum by on-line solid phase extraction (SPE) liquid chromatography-tandem mass spectrometry (LC-MS/MS) (Kato et al., 2011), including 2-(N-methyl-perfluorooctane sulfonamido) acetate (MeFOSAA), perfluorohexane sulfonate (PFHxS), perfluorononanoate (PFNA), sum of perfluoromethylheptane sulfonate isomers (Sm-PFOS), n-perfluorooctane sulfonate (n-PFOS), perfluorodecanoate (PFDA), n-perfluorooctanoate (n-PFOA), perfluoroundecanoate (PFUnDA), and sum of branched perfluorooctanoate isomers (Sb-PFOA). Total PFOS and PFOA were calculated by summing the linear and branched isomers for each participant, in accordance with CDC's National Report on Human Exposure to Environmental Chemicals (CDC, 2021).

Serum samples were also analyzed for PCBs, polybrominated diphenyl ethers (PBDEs), polybrominated biphenyl (PBBs), and persistent pesticides (PPs) by gas chromatography isotope dilution high resolution mass spectrometry (Jones et al., 2012). Measured PCB congeners included PCB 28, 66, 74, 99, 105, 114, 118, 138-158, 146, 153, 156, 157, 167, 170, 178, 180, 183, 187, 189, 194, 196-203, 199, 206, and 209. All PCBs were summed to calculate the "total PCBs" in data analysis. Measured PBDE congeners included PBDE 17, 28, 47, 85, 99, 100, 153, 154, and 183. 2,2',4,4',5,5'-hexabromobiphenyl (BB-153) was also measured. PPs included hexachlorobenzene (HCB), β-hexachlorocyclohexane (β-HCH), oxychlordane, trans-nonachlor, 2,2-Bis(4-chlorophenyl) - 1,1-dichloroethene (p,p'-DDE), 2-(4-chlorophenyl)-2-(2-chlorophenyl)- 1,1,1-trichloroethane (o,p'-DDT), 2,2-Bis (4-chlorophenyl)-1,1,1-trichloroethane (p,p'-DDT), and Mirex. Urinary samples were analyzed for hydroxylated metabolites of PAHs, including l-hydroxynaphthalene (1-NAP), 2-hydroxynaphthalene (2-NAP), 2-hydroxyfluorene (2-FLU), 3-hydroxyfluorene (3-FLU), 1-hydroxyphenanthrene (1-PHE), 2-hydroxyphenanthrene and 3-hydroxyphenanthrene (2-, 3-PHE), and 1-hydroxypyrene (1-PYR). The analytical determination was performed by on-line SPE -LC-MS/MS (Wang et al., 2017).

Data analysis

For questionnaire results, descriptive analyses were conducted to summarize demographic characteristics, fish consumption, and awareness of fish advisories. Multivariable logistic regression analyses were used to estimate the odds of fish consumption (high fish consumption vs. low fish consumption) in relation to demographics, the odds of awareness of fish advisories in relation to demographics, and the odds of adopting protective fish consumption behaviors in relation to awareness of fish advisories and demographics. Log-linear regression was performed to examine the association between sport-caught fish consumption and demographics.

For biomonitoring results, descriptive analyses (that is, geometric means, 95th percentiles, and 95% confidence intervals) were conducted for all chemicals measured in the study. For chemicals with analytic results below the limit of detection, a value was imputed that is the limit of detection divided by the square root of 2 (CDC, 2018). Biomonitoring results for non-metals were corrected for lipids or creatinine. The urinary PAH concentrations were divided by the urinary creatinine concentration, and the creatinine-corrected PAHs were expressed as nanograms per gram of creatinine (ng/g). Concentrations of PCBs, PBDEs, PBB-153, and PPs were given as ng/g lipid weight (weight of serum lipids). The serum lipid concentration was determined using commercially available test kits for the quantitative determination of total triglycerides and total cholesterol.

These descriptive results were compared with the U.S. population (20 years and older) from the National Health and Nutrition Examination Survey (NHANES) 2015-2016. In the NHANES 2015-2016 laboratory data, PCBs, PBDEs, PBB-153, and PPs were presented as pooled samples; following the procedures proposed by Caudill et al. (2007), Caudill (2010, 2012) and Mee and Owen (1983), we estimated the bias-corrected geometric means, 95^{th} percentiles, and their 95% confidence intervals (CIs). For other chemicals measured in the study with individual samples in NHANES 2015-2016, including metals, PFAS and PAH metabolites, we used the geometric means, 95th percentiles and 95% CIs reported in CDC's National Report on Human Exposure to Environmental Chemicals (CDC, 2021). All statistical analyses were performed using SAS (Statistical Analysis Software 9.4, SAS Institute Inc, Cary, North Carolina, USA).

RESULTS

Survey respondents

Among the 2,239 screening survey responses we received, 949 respondents were eligible for participation. Of the eligible respondents, 396 completed the questionnaire, 390 provided blood samples, and 389 provided urine samples. The inclusion and exclusion steps for respondents are illustrated in Figure 2. Among the 396 respondents who completed the questionnaire, more than half were 50 years or older (51.7%, n=199, median: 51 years). The overwhelming majority were male (80.1%, n=314), white (86.2%, n=337), had bachelor's degree or higher education (88.2%, n=346), were married (73.6%, n=287), and lived in the Milwaukee area for more than 20 years (77.5%, n=303). Demographics of respondents who completed the questionnaire are summarized in Table 1.

Fish consumption

Respondents reported fish consumption in terms of number of meals, with a single meal equaling 6 ounces. The majority of our respondents (64.4%, n=255) ate less than one meal (6 ounces) of fish per week, which is lower than the Wisconsin fish advisory recommended fish consumption (1-2 fish meals per week) and the EPA/FDA recommended amount (8-12 ounces per week). Only a quarter of respondents (25.8%, n=102) reported consuming one to two meals (6-12 ounces) of fish per week. About one-tenth of respondents' (9.9%, n=39) fish consumption exceeded the Wisconsin fish advisory recommended amount.

Respondents (n=386) consumed an average of 53.7 fish meals annually (*Median*=39). In addition, the median number of store-bought fish meals (n=364, *Median*=16.0, *Mean*=26.1) was higher than that of their sport-caught fish meals (n=366, *Median*=12.0, *Mean*=22.3) and more than twice that of their shellfish meals (n=287, *Median*=7, *Mean*=10.71).

Multivariable logistic regression was conducted to examine the association between demographic characteristics and fish consumption. None of the demographic characteristics (that is, age, race, education, years in Milwaukee, and household income) were

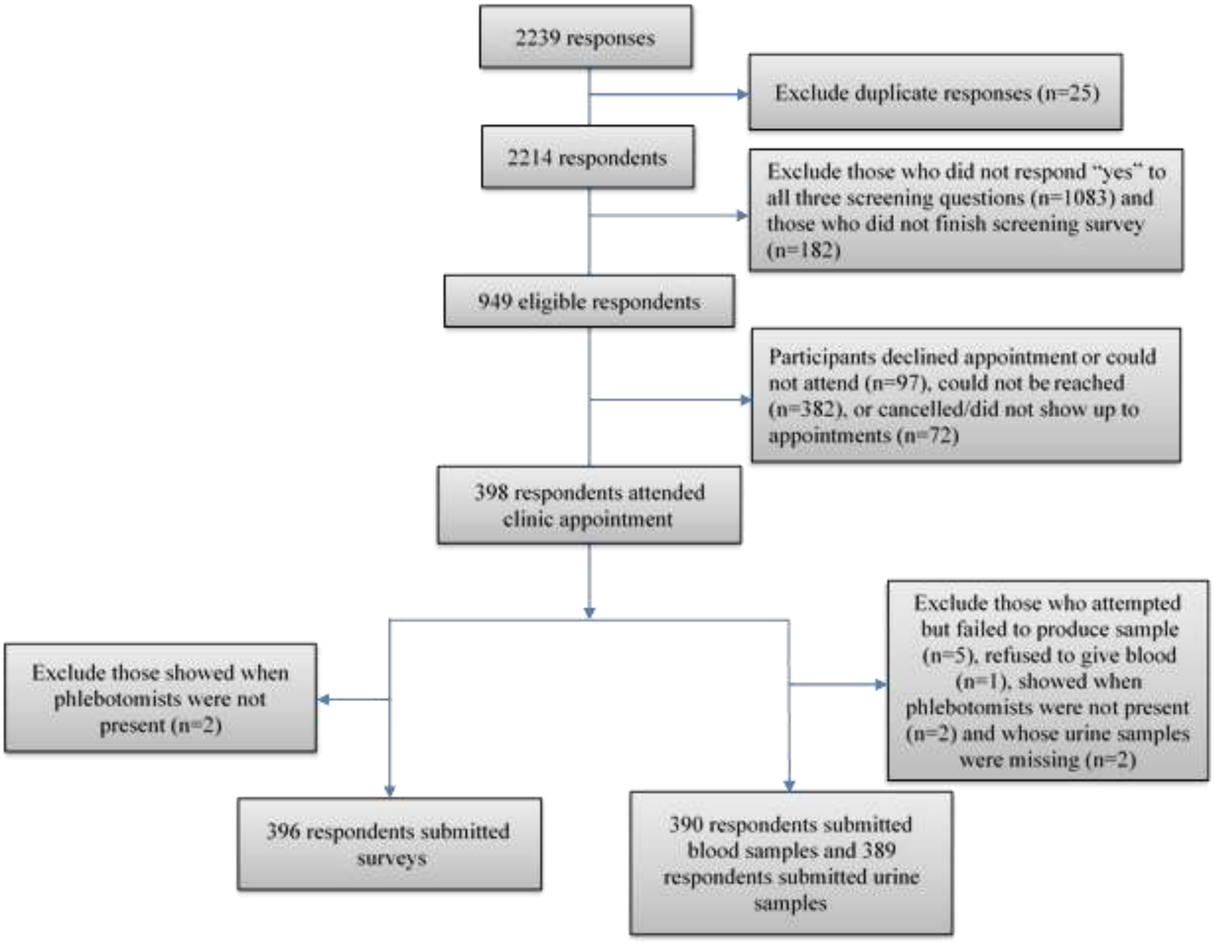

Figure 2. Respondents' inclusion and exclusion flowchart.
Source: Authors

T**able 1.** Demographics of respondents in the Milwaukee Urban Anglers Study who completed the questionnaire (n=396).

Variable	N (%)
Age (years)	
18-29	45 (11.7)
30-39	75 (19.5)
40-49	66 (17.1)
≥50	199 (51.7)
Unknown	11
Sex	
Male	314 (80.1)
Female	78 (19.9)
Unknown	4
Race	
White	337 (88.7)

Table 1. Contd.

Black or African American	32 (8.4)
Asian	10 (2.6)
American Indian or Alaska Native	1 (0.3)
Unknown	11
Hispanic or Latino	
Yes	11 (2.9)
No	368 (97.1)
Unknown	4
Household income	
Less than $25,000	27 (7.8)
$25,000 to less than $50,000	73 (21.2)
$50,000 to less than $100,000	132 (38.4)
$100,000 or more	112 (32.6)
Unknown	47
Education	
High school or less	45 (11.5)
Bachelor, associate, or some college	259 (66.0)
Postgraduate, professional, or doctoral	87 (22.3)
Unknown	4
Employment outside home	
Yes	249 (66.0)
No	128 (34.0)
Unknown	13
Marital status	
Married or living as married	287(74.4)
Not married	99 (25.6)
Unknown	4
Years lived in the Milwaukee, Wisconsin area	
1-20	88 (22.5)
21-40	119 (30.4)
41-60	118 (30.2)
≥61	66 (16.9)
Unknown	5
Living with household members	
Living with women of child-bearing age	124 (58.2)
Living with children <15 years	89 (41.8)
Unknown	2
Current smoker	
Yes	44 (24.9)
No	133 (75.1)
Unknown	1
Use smokeless tobacco	
Yes	17 (4.4)

Table 1. Contd.

No	371 (95.6)
Unknown	1

There were rounding errors, percentages may not add up exactly to 100%.
Source: Authors

Table 2. Number of fish consumption meals by high vs. low mercury concentrations.

Category of fish (high vs. low mercury)	N	Median	Mean	Min	25th quartile	75th quartile	Max
Sport-caught fish	366	12	22.3	1	5.5	24	507
High mercury	352	6	13.7	1	3	15	365
Low mercury	310	6	10.8	0	2	10	142
Store-bought fish	364	16	26.1	1	8	33.5	336
High mercury	248	5	10.0	1	3	10.5	272
Low mercury	352	14	19.8	1	6.3	25	186
Shellfish[1]	287	7	10.7	1	4	12	200
All fish	386	39	53.7	1	22	64	555
High mercury	369	12	19.8	1	5	21	365
Low mercury[2]	377	26	35.5	1	14	46	290

[1]Shellfish are low mercury. [2]Low mercury "all fish" include shellfish.
Source: Authors

associated with total fish consumption (≥104 fish meals per year or ≥2 fish meals per week vs. <104 fish meals per year or <2 fish meals per week), nor with sport-caught fish consumption. A log-linear model was also conducted to examine the association between sport-caught fish consumption and demographics and did not identify significant associations.

The fish species that participants reported consuming was summarized. The sport-caught fish species most consumed by participants was bluegill (n=232), followed by chinook or coho salmon (57.1%), walleye (55.1%), and yellow perch (39.1%). The store-bought species most consumed by respondents was cod (70.5%), salmon (58.1%), canned light tuna (52.3%), canned white tuna (n=41.2%), and tilapia (n=39.1%). The overwhelming majority of respondents consumed shellfish (n=72.5%).

Fish consumption was also summarized by mercury concentrations. We categorized sportfish according to the Wisconsin fish advisory (Wisconsin Department of Natural Resources, 2020) and categorized store-bought fish and shellfish according to FDA commercial fish and shellfish testing results (FDA, 2017). Low-mercury sportfish include bluegill, crappies, yellow perch, bullheads, and inland trout, while high-mercury sportfish include the remaining sportfish species in the questionnaire. High-mercury store-bought fish include king mackerel, shark, swordfish, canned white or albacore tuna, and halibut. Low-mercury store-bought fish include salmon (including canned salmon), canned light tuna, tilapia, and cods. Shellfish was categorized as having low-mercury concentration.

It was found that respondents' median number of high-mercury sport-caught fish meals was the same as that of low-mercury sport-caught fish meals. However, the median number of their high-mercury store-bought fish meals was about one-third that of their low-mercury store-bought fish meals. Because respondents consumed more store-bought fish than sport-caught fish, and shellfish was categorized as a low-mercury fish meal, their total fish meals reflect a greater number of low-mercury fish meals (Table 2).

Awareness of fish advisories for sport-caught fish

This study found that the majority of respondents were aware of Wisconsin fish advisories for fish caught in Wisconsin (72.8%) or Milwaukee fish advisories for fish caught in the Milwaukee and surrounding waterbodies (60.1%). However, only one-fifth of the respondents reported knowing "quite a bit" or "a great deal" about Wisconsin fish advisories (19.9%) or Milwaukee fish advisories (24.3%). Fewer than half of the respondents reported following the Wisconsin fish advisories (27.0%) or Milwaukee fish advisories (43.0%) very closely (Table 3).

Table 3. Awareness of Wisconsin and Milwaukee fish advisories.

Awareness	Wisconsin fish advisory [n (%)]	Milwaukee fish advisory [n (%)]
Yes	286 (72.8)	235 (60.1)
How much would you say that you know about these guidelines		
Nothing/Little	113 (39.5)	95 (40.4)
Some	116 (40.6)	83 (35.3)
Quite a bit/A great deal	57 (19.9)	57 (24.3)
How closely do you follow the advice provided in these guidelines		
Not at all/A little bit	90 (31.6)	56 (23.8)
Somewhat	118 (41.4)	77 (32.8)
Very/extremely	77 (27.0)	101 (43.0)
No	93 (23.7)	139 (35.6)
Don't know	14 (3.6)	17 (4.4)

(1) There were rounding errors and (2) the number of respondents who preferred not to answer was not reported in the table, percentages may not add up exactly to 100%.
Source: Authors

Licensed anglers' information source of fish advisories was the booklet accompanying the fishing license (68.0%), Wisconsin Department of Natural Resources website or publications (60.2%), signs at fishing locations (58.9%), friends or family (52.3%), and mass media (29.6%). The overwhelming majority of the respondents considered the information sources easy to understand and reported willingness to use them when making decisions about eating fish.

The associations between demographics and awareness of Wisconsin and Milwaukee fish advisories, respectively were further examined (Table 4). Logistic regression results showed that sex, race, and years living in Milwaukee were statistically significantly associated with awareness of Wisconsin and Milwaukee fish advisories. Specifically, compared to men, women were less likely to be aware of Wisconsin fish advisories (OR_{adj} =0.3, 95% CI: 0.2, 0.5) or Milwaukee fish advisories (OR_{adj} =0.4, 95% CI: 0.2, 0.8). Compared to white respondents, black respondents were about one-third as likely to be aware of Wisconsin fish advisories (OR_{adj} =0.3, 95% CI: 0.1, 0.7) or Milwaukee fish advisories (OR_{adj} =0.4, 95% CI: 0.1, 0.9). Compared to respondents who lived in Milwaukee for 1-20 years, respondents who lived in Milwaukee for 41-60 years were over six times as likely to be aware of Wisconsin fish advisories (OR_{adj} =6.5, 95% CI: 2.4, 17.5) and over three times as likely to be aware of Milwaukee fish advisories (OR_{adj} =3.6, 95% CI: 1.6, 7.8).

It was also surveyed whether to what extent respondents ate specific parts of fish or prepared meals using fish parts, because Wisconsin fish advisories provide steps people can take to reduce their contaminant intake (Table 5). It is worth noting that although almost all respondents reported never eating fish head (90.4%) or guts, organs, or other innards (97.2%), more than half of the respondents reported eating fish skin (57%). Regarding the cooking methods, the overwhelming majority of respondents reported never using fish or fish parts to make broth/stock, curry, or soup (83.6%) or fish paste (93.2%). However, most respondents reported deep-frying fish (78%).

Of particular note, although most respondents reported being aware of Wisconsin or Milwaukee fish advisories, only about one-fifth of the respondents reported reducing fish consumption (21.7%) or eating different types or species of fish (24.2%) to avoid contaminants. Only 42.9% of the respondents reported avoiding certain parts of the fish (n=170) or avoiding eating fish from certain locations (51%). About one-fifth of respondents (20.5%) reported not performing any protective behaviors to avoid contaminants in fish.

A series of multivariable logistic regression analyses were conducted to examine the impact of awareness of Wisconsin and Milwaukee fish advisories on the adoption of protective behaviors, adjusted for demographic characteristics (that is, age, sex, race, income, education, and years in Milwaukee). The results showed that respondents were more likely to perform protective behaviors in general and avoid eating fish head, fat, belly, and skin if they were aware of Wisconsin or Milwaukee guidelines. Respondents were more likely to eat different types of fish or avoid eating fish from certain fishing locations if they were aware of Milwaukee guidelines.

Table 4. Association between demographics and awareness of Wisconsin (n=379)[a] and Milwaukee fish advisory guidelines (n=374)[b].

Characteristics	Wisconsin fish advisory		Milwaukee fish advisory	
	Awareness [% (n)] Total n=286	OR_{adj} (95% CI)	Awareness [% (n)] Total n=235	OR_{adj} (95% CI)
Age (years)				
18-29	59 (26)	Ref	44 (18)	Ref
30-39	70 (52)	1.9 (0.8, 4.6)	60 (43)	2.2 (0.95, 4.9)
40-49	68 (43)	0.8 (0.3, 2.0)	61 (38)	1.4 (0.6, 3.5)
≥50	84 (160)	2.0 (0.8, 5.1)	70 (134)	2.1 (0.9, 5.0)
Sex* [c]**				
Male	81 (247)	Ref	54 (203)	Ref
Female	53 (39)	0.3 (0.2, 0.5)	9 (32)	0.4 (0.2, 0.8)
Race*				
White	79 (258)	Ref	65 (209)	Ref
Black	48 (14)	0.3 (0.1, 0.7)	41 (12)	0.4 (0.1, 0.9)
Other	55 (6)	0.6 (0.1, 2.2)	55 (6)	0.8 (0.2, 3.0)
Income ($)				
<25,000	63 (17)	Ref	59 (16)	Ref
25,000-49,999	65 (43)	0.8 (0.3, 2.3)	58 (40)	0.6 (0.2, 1.7)
50,000-99,999	75 (95)	0.8 (0.3, 2.2)	66 (82)	0.7 (0.3, 1.9)
100,000 or more	84 (92)	1.4 (0.4, 4.2)	65 (70)	0.6 (0.2, 1.7)
Education				
High school or less	76 (34)	Ref	66 (29)	Ref
Some college	69 (94)	0.7 (0.3, 1.8)	58 (79)	0.8 (0.3, 1.7)
College graduate	81 (91)	1.8 (0.6, 5.1)	70 (77)	1.5 (0.6, 3.7)
Postgraduate	79 (66)	1.3 (0.4, 3.7)	60 (50)	0.9 (0.4, 2.1)
Years in Milwaukee*				
1-20 years	68 (57)	Ref	52 (42)	Ref
21-40 years	64 (75)	1.1 (0.6, 2.2)	56 (65)	1.3 (0.7, 2.5)
41-60 years	90 (100)	6.5 (2.4, 17.5)	78 (87)	3.6 (1.6, 7.8)
≥61 years	84 (54)	2.1 (0.7, 6.2)	63 (40)	1.3 (0.6, 3.2)

[a]17 respondents who did not answer whether they were aware of Wisconsin guidelines were excluded from the analysis. [b]22 respondents who did not answer whether they were aware of Milwaukee guidelines were excluded from the analysis. [c]*** indicates p<0.001 and * indicates p<0.05.
Source: Authors

Table 5. How often respondents ate specific parts of fish or prepared meals using fish parts.

Variable	Responses [n]	Never [n (%)]	Sometimes [n (%)]	Always [n (%)]	Don't know or prefer not to answer [n (%)]
Skin	391	163 (41.7)	189 (48.3)	34 (8.7)	5 (1.3)
Head	386	349 (90.4)	29 (7.5)	4 (1.0)	4 (1.0)
Guts, organs, or other innards	388	377 (97.2)	6 (1.6)	3 (0.8)	2 (0.5)
Belly fat	388	275 (70.9)	94 (24.2)	9 (2.3)	10 (2.6)
Pan fry, grill, roast	364	22 (6.03)	330 (90.7)	12 (3.3)	0
Deep fry	372	82 (22.0)	238 (64.0)	52 (14.0)	0
Boil or poach	357	247 (69.2)	100 (28.0)	6 (1.7)	4 (1.1)
Use fish or fish parts to make broth/stock, curry, or soup	360	301 (83.6)	55 (15.3)	1 (0.3)	3 (0.8)
Use fish to make fish paste	351	327 (93.2)	20 (5.7)	3 (0.9)	1 (0.3)

Source: Authors

Detailed results were summarized in Appendix 2.

Biomonitoring results

The descriptive results of chemical measurement were summarized in Table 6. The geometric mean of serum PFOS in our study population was 8.64 (95% CI: 7.98-9.36) ng/mL which was twice of national estimate for adult population based on NHANES 2015-2016 [5.02, (95% CI: 4.64-5.43)]. PFDA also had higher geometric mean (0.222, 95% CI: 0.207-0.238) than NHANES (0.160, 95% CI: 0.144, 0.178). The geometric means of the remaining PFAS compounds were similar to those in the NHANES. The geometric mean of blood mercury [1.4, (95% CI: 1.3-1.6)] was nearly twice that seen in the NHANES [0.8, (95% CI: 0.7-0.9)], while the other four blood metals measured were at similar levels as NHANES. The geometric mean of the sum of PCB congeners [77.8, (95% CI: 71.4-84.8)] in serum was higher than that in the NHANES sample [55.2, (95% CI: 47.1-64.7)], although it should be noted that our participants were older than the NHANES adult sample. Overall, the geometric means of serum PBDE and most urinary PAHs were similar to those in the NHANES samples, except for the phenanthrene metabolites that were higher in this cohort. The pesticide concentrations in serum in our study were similar to or lower than those in the NHANES sample.

DISCUSSION

The overwhelming majority of the Milwaukee urban anglers in the present study were non-Hispanic white men with college or higher educational level. Our study participants ate an average of 53.7 fish meals (the median number of 39 total fish meals including a median number of 12 sport-caught fish meals) per year. Previous studies on Wisconsin older male anglers showed higher fish consumption. For example, a 2011-2012 cohort of anglers whose average age was 60 years old consumed a median number of 74 fish meals including a median number of 28 sport-caught fish meals per year (Imm et al., 2013); a 2012-2013 cohort of anglers whose average age was 61.7 years old consumed a median number of 66.5 fish meals per year (Christensen et al., 2016a). As the average age of the study participants was 49.6, which is about 10 years younger than the other two samples of Wisconsin anglers, it is possible that older people consumed more fish. The present study results showed that the average fish meals consumed by participants aged over 50 years was significantly higher than that consumed by participants aged 50 and younger. However, it is also worth noting that the study population was not a random sample and may not represent the fish consumption behaviors of all Wisconsin licensed anglers.

Previous studies show that urban anglers with lower income and less education tend to depend

Table 6. Contaminant concentrations in Milwaukee Urban Anglers Study vs. NHANES aged 20 years and older (2015-2016).

Parameter	This Study (n=389)			NHANES 2015-2016		
	% below LOD	Geometric mean (95% CI)	95th percentile (95% CI)	% below LOD	Geometric mean (95% CI)	95th percentile (95% CI)
Serum PFAS (ng/mL)[a1]						
PFOA	N/A	1.53 (1.46, 1.60)	3.24 (2.82, 3.65)	N/A	1.60 (1.51, 1.71)	4.27 (4.07, 4.97)
PFOS	N/A	8.64 (7.98, 9.36)	40.5 (32.4, 48.6)	N/A	5.02 (4.64, 5.43)	19.1 (15.8, 24.4)
PFDA	15.7	0.222 (0.207, 0.238)	0.942 (0.767, 1.16)	33.9	0.160 (0.144, 0.178)	0.700 (0.500, 1.00)
PFHxS	1.0	1.29 (1.21, 1.38)	4.08 (3.44, 4.73)	1.4	1.22 (1.11, 1.34)	5.00 (4.10, 6.20)
PFNA	1.3	0.632 (0.596, 0.670)	1.96 (1.72, 2.20)	1.3	0.591 (0.546, 0.640)	1.90 (1.60, 2.30)
PFUnDA	49.9	* [a2] (<LOD)	0.387 (0.336, 0.437)	62.3	* (<LOD)	0.400 (0.300, 0.500)
MeFOSAA	57.1	* (<LOD)	0.550 (0.326, 0.774)	60.7	* (<LOD)	0.600 (0.500, 0.700)
Blood metals (μg/L or μg/dL)[b1-4]						
Cadmium (μg/L)	3.9	0.245 (0.228, 0.264)	1.25 (0.602, 1.90)	25.6	0.300 (0.280, 0.310)	1.35 (1.22, 1.48)
Manganese (μg/L)	0	9.40 (9.15, 9.66)	15.9 (14.0, 17.7)	0	9.34 (9.11, 9.58)	16.1 (15.6, 16.9)
Lead (μg/dL)	0	1.18 (1.11, 1.25)	3.64 (3.01, 4.26)	0.1	0.920 (0.860, 0.980)	2.89 (2.65, 3.07)
Selenium (μg/L)	0	197 (195, 199)	242 (235, 249)	0	194 (190, 198)	237 (230, 243)
Mercury (μg/L)	2.1	1.44 (1.31, 1.56)	6.94 (5.73, 8.16)	25.5	0.810 (0.740, 0.890)	4.66 (3.91, 5.96)
Serum PCBs (ng/g lipid)[c1-2]						
PCB sum	N/A	77.8 (71.4, 84.8)	3680 (304, 431)	N/A	55.2 (47.1, 64.7)	393.0 (348.0, 454.0)
PCB105	4.9	0.926 (0.851, 1.008)	5.13 (3.94, 6.32)	5.3	0.494 (0.415, 0.86)	4.17 (3.64, 4.86)
PCB114	36.0	0.345 (0.318, 0.373)	1.76 (1.52, 1.99)	41.9	0.257 (0.220, 0.300)	1.75 (1.55, 2.01)
PCB156	2.3	2.00 (1.82, 2.21)	10.0 (8.94, 11.2)	5.3	1.43 (1.18, 1.73)	15.8 (13.6, 18.8)
PCB157	28.5	0.460 (0.4, 0.5)	2.36 (2.14, 2.57)	38.3	0.359 (0.304, 0.425)	2.89 (2.54, 3.37)
PCB167	27.5	0.479 (0.437, 0.524)	3.00 (2.71, 3.28)	31.5	0.361 (0.306, 0.426)	2.71 (2.39, 3.15)
PCB189	46.0	0.263 (0.246, 0.280)	0.978 (0.881, 1.075)	54.0	0.209 (0.187, 0.234)	0.832 (0.764, 0.922)
5 highest PCBs (ng/g lipid)						
PCB153	0	15.5 (14.2, 16.9)	81.7 (69.7, 93.6)	0	12.1 (10.3, 14.2)	89.4 (79.0, 104)
PCB180	0	11.4 (10.4, 12.6)	61.6 (53.9, 69.2)	0	7.34 (6.08, 8.87)	76.1 (65.7, 90.4)
PCB138_158	0.8	8.82 (8.04, 9.66)	50.5 (42.1, 58.8)	0	5.88 (4.98, 6.95)	46.5 (40.8, 54.0)
PCB187	0.8	4.18 (3.79, 4.61)	23.5 (19.2, 27.8)	1.5	2.60 (2.17, 3.12)	24.3 (21.1, 28.7)
PCB118	0	4.10 (3.80, 4.43)	21.2 (16.4, 26.0)	0	2.87 (2.46, 3.36)	19.8 (17.6, 22.8)
Serum BFRs (ng/g lipid)[d1-d2]						
PBDE47	4.4	4.95 (4.47, 5.49)	33.7 (22.0, 45.3)	0	5.98 (4.85, 7.39)	81.8 (69.1, 98.4)

Table 6. Contd.

PBDE99	26.0	0.900 (0.810, 0.990)	6.95 (4.71, 9.18)	0	1.07 (0.848, 1.35)	18.6 (15.4, 22.7)
PBDE153	0	4.50 (4.16, 4.87)	28.9 (12.2, 45.6)	0	5.51 (4.58, 6.63)	54.4 (46.9, 64.0)
PBDE209	32.2	1.38 (1.30, 1.47)	4.69 (3.99, 5.39)	3.8	1.34 (1.17, 1.55)	7.69 (6.87, 8.70)
PBB153	6.7	1.33 (1.20, 1.46)	7.17 (4.68, 9.65)	17.0	0.960 (0.763, 1.21)	16.5 (13.8, 20.2)
Urine PAH metabolites (µg/g creatinine or ng/g creatinine)[e1-2]						
2-FLU (ng/g creatinine)	0.3	2.14 (1.97, 2.32)	17.3 (12.5, 22.2)	0.1	2.06 (2.00, 2.12)	13.4 (12.2, 14.7)
3-FLU (ng/g creatinine)	0.8	0.934 (0.851, 1.02)	8.18 (4.67, 11.7)	2.5	0.925 (0.893, 0.958)	9.13 (8.37, 9.89)
1-NAP (µg/g creatinine)	0.5	16.6 (148, 187)	189 (125, 253)	0.2	16.6 (15.9, 17.3)	190 (172, 209)
2-NAP (µg/g creatinine)	0	54.5 (50.3, 59.1)	253 (186, 319)	0	51.6 (50.2, 53.1)	224 (212, 236)
1-PHE (ng/g creatinine)	0.5	1.40 (1.33, 1.49)	4.00 (3.41, 4.60)	1.2	1.01 (0.99, 1.04)	3.30 (3.07, 3.54)
2-, 3-PHE (ng/g creatinine)	0.3	1.64 (1.54, 1.74)	5.77 (4.89, 6.66)	0.5	1.32 (1.29, 1.35)	4.56 (4.26, 4.86)
1-PYR (ng/g creatinine)	28.5	1.46 (1.37, 1.56)	6.10 (5.07, 7.13)	23.6	1.53 (1.49, 1.56)	5.51 (5.15, 5.88)
Serum Pesticides (ng/g lipid)[f1-2]						
β-HCH	55.2	1.10 (1.02, 1.18)	5.91(3.44, 8,38)	26.42	1.80 (1.41. 2.31)	38.2 (31.6, 43.8)
HCB	0.3	8.08 (7.84, 8.33)	13.3 (11.9, 14.8)	0	8.02 (7.53, 8.55)	17.7 (16.8, 18.7)
Mirex	41.8	1.49 (1.39, 1.61)	6.41 (5.05, 7.77)	41.1	1.23 (1.02, 1.49)	13.2 (11.4, 15.7)
Oxychlordane	6.2	4.60 (4.26,4.97)	16.8 (14.6, 19.0)	2.3	5.64 (4.85, 6.55)	36.1 (32.2, 41.4)
p,p'- DDE	0	77.3 (72.2, 82.8)	329 (234, 424)	0	103 (84.4, 126)	1180 (1010, 1420)
p,p'-DDT	24.5	1.57 (1.47, 1.68)	5.72 (3.86 7.58)	5.0	1.702 (1.39, 2.09)	18.7 (16.0. 22.5)
Trans-Nonachlor	1.6	7.04 (6.49, 7.64)	32.3 (27.0, 37.7)	0.8	8.97 (7.65, 10.5)	65.3 (57.7, 75.6)

[a1] For those PFAS compounds whose values were below the limit of detection, the limit of detection (LOD)/sqrt(2) was imputed. LOD for PFAS compounds: 0.1 (Reference: https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/PFAS_I.htm). Geometric mean and 95th percentile for NHANES 2015-2016 aged 20 years and older were cited from CDC, 2021. [a2] * Not calculated: proportion of results below limit of detection was too high to provide a valid result. [b1]For those whose value was below the limit of detection; the limit of detection (LOD)/sqrt(2) was imputed. LOD for cadmium: 0.1; lead: 0.07; manganese: 0.99; mercury: 0.28; selenium: 24.48 (Reference: https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/PBCD_I.htm). Geometric mean and 95th percentile for NHANES 2015-2016 aged 20 years and older were cited from CDC, 2021. [b2]The number of samples with large clots and was not analyzed: 27. [b3]The number of samples with micro-clots and was not analyzed in our study population: n=7. [b4]We treated all zero values as the values that were below the limit of detection (i.e., limit of detection/square(2)). [c1]For those whose PCBs values were below the limit of detection; the limit of detection (LOD)/sqrt(2) was imputed. LOD for PCB28:0.61; PCB66: 0.46; PCB74: 0.44; PCB99, PCB114, PCB138, PCB146, PCB153, PCB156, PCB157, PCB167, PCB170, PCB178, PCB180, PCB183, PCB187, PCB189, PCB194, PCB196/203, PCB199, and PCB209: 0.18; PCB105: 0.21; PCB118: 0.27; PCB206: 0.36. [c2] # of non-reportable due to interference or co-elution for PCBs: PCB15: n=2; PCB66: n=1; PCB74: n=24; PCB99: 1; PCB105: n=2; PCB114: n=2; PCB118: n=2; PCB146: n=4; PCB153: n=1; PCB157: n=1; PCB167: n=4; PCB170: n=2; PCB178: n=8; PCB183: n=10; PCB187: n=8; PCB189: n=2; PCB194: n=1; PCB199: n=6; PCB206: n=2; PCB138_158: n=6; PCB196_203: n=8. [d1]For those whose BFRs values were below the limit of detection, the limit of detection (LOD)/sqrt(2) was imputed. LOD for BFRs: PBDE47: 1.3; PBDE153: 1.0; PBB153: 1.0; PBDE209: 3.5; PBDE99: 1.1 # of non-reportable due to interference or co-elution for BRFs: PBDE47: n=2; PBDE99: n=2; PBDE153:n=2; PBB153:n=2; PBDE209: n=9. [d2] # of non-reportable due to interference or co-elution for PAHs: 2-FLU: n=1; 3-FLU: n=6; 1-NAP: n=11; 2-NAP: n=1. [e1]PAHs. For those whose PAHs values were below the limit of detection, the limit of detection (LOD)/sqrt(2) was imputed. LOD for NAP_1: 60; 2-NAP: 90; 3-FLU: 8; 2-FLU: 8; 1-PHE:9; 2-, 3-PHE:10; 1-PYR: 70 (Reference: https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/PAH_I.htm). Geometric mean and 95th percentile for NHANES 2015-2016 aged 20 years and older were cited from CDC, 2021. [e2]Non-reportable due to interference or co-elution: n=13 . [f1]For those whose pesticides values were below the limit of detection; the limit of detection (LOD)/sqrt(2) was imputed. LOD for pesticides: 0.92. [f2]Non-reportable due to interference or co-elution: β-HCH: n=3; p,p'-DDT: n=1; Trans-Nonachlor: n=1; Oxychlordane: n=3.
Source: Authors

on sport-caught fish for food and nutritional sources (Silver et al., 2007; Stevens et al., 2018). However, in the present study, only about 10% of the anglers' fish consumption exceeded 12 ounces per week (the upper limit of EPA/FDA recommended fish consumption amount) and about two-thirds of the anglers ate fewer than one fish meal (6 ounces) per week, which is lower than the EPA/FDA lower limit of recommended fish consumption amount (8 ounces). This is similar to results from previous studies that found 78%-87% of the Great Lakes region participants ate fewer fish than the EPA/FDA recommended amount (Connelly et al., 2012, 2019). Although eating fewer fish may reduce exposure to contaminants in fish, it also reduces intake of nutritional sources in fish (e.g., omega-3 fatty acids). Previous research on awareness of risks and benefits of fish consumption found that women were more likely to perceive fish as a healthy food that reduces the risk for coronary heart disease (Verbeke et al., 2005). The findings highlight the need for a clear messaging to educate anglers on how to balance the risks and benefits of fish consumption (Sherer et al., 2008; Engelberth et al., 2013).

Most participants in the present study reported being aware of Wisconsin or Milwaukee fish advisories. Encouragingly, it was found that awareness of Wisconsin or Milwaukee fish advisories were associated with some protective health behaviors such as eating different types of fish, avoiding eating fish from certain contaminated locations, avoiding eating fish parts (e.g., head, fat, belly, and skin) that tend to accumulate contaminants. However, only about one-fifth of the participants reported knowing "quite a bit" or "a great deal" about these advisories. Moreover, we found that being aware of fish advisories did not necessarily lead to a reduction in sport-fish consumption, which was consistent with previous findings among other residents in the Great Lakes basin (Krabbenhoft et al., 2019). Participants reported eating the same median number of high-mercury sport-caught fish as that of low-mercury sport-caught fish. The biomonitoring results corroborated this finding by showing that participants' blood mercury concentration was more than two times that reported in the NHANES. Comparable elevations in blood mercury concentrations were observed among licensed anglers who participated a biomonitoring project in New York state (Hsu et al., 2022). The implications of these findings are two-fold. First, anglers may not have adequate knowledge about safe fish consumption. Second, even when anglers had adequate knowledge, they may not necessarily act upon their knowledge, as a previous study showing that people's perceived risk of being exposed to mercury did not significantly impact their fish consumption amount (Birch and Lawley, 2012; Verbeke et al., 2005).

Given the frequent consumption of high mercury-containing caught fish, it is plausible that the present study participants did not have adequate knowledge of how to choose fish with low mercury, even with high awareness of fish advisories. A study of New York Bight anglers showed that people lack knowledge of which fish are high in PCBs or mercury and therefore cannot make informed decisions when eating the fish they catch (Burger and Gochfeld, 2009). The choice of low-mercury fish species is particularly important because the contaminant cannot be removed by cooking. Field experiment results showed that anglers often imperfectly recalled which were the most highly contaminated fish and thus failed to avoid these (Roosen et al., 2009; Verger et al., 2007). A clear and simple fish guide is needed for respondents to make healthy choices.

In addition, the study participants did not perform recommended fish cleaning and cooking practices. Of the participants, 71% reported that they "never" trimmed fish belly fat and 42% "never" removed fish skin when they cooked. Only 2% "always" trimmed fish belly fat and 9% of them "always" removed fish skin. These findings indicated that the lack of knowledge about safe cooking practices persisted over time among Wisconsin anglers as reported in studies conducted in the past twenty years (Anderson et al., 2004; Christensen et al., 2016a; Gliori et al., 2006), highlighting the need to enhance anglers' knowledge about safe fish cleaning and cooking practices.

Besides mercury, PFOS concentration among the study participants was twice the concentration in the NHANES. Currently, there is still limited advisory information regarding this emerging contaminant in Wisconsin. Since cooking is not effective in removing PFAS from fish in a consistent way (Bhavsar et al., 2014; Taylor et al., 2019), choices of fishing locations and fish species/sizes are particularly important. In addition, we found that the concentrations of persistent pesticides in the present study population were lower than or similar to those in the NHANES sample; similarly low pesticide concentrations were also observed in a biomonitoring study of Michigan shoreline anglers (Wattigney et al., 2019). Plausibly, this is due to the steady decline of persistent pesticides in Great Lakes fish (Zhou et al., 2018).

In the present study, it was observed that Milwaukee anglers consumed fewer fish than the amount recommended by EPA/FDA, which means that they had a decreased intake of nutrients from fish; however, at the same time, the study participants had higher levels of PFOS, PCBs, and mercury compared to the U.S. population. There is a clear need to develop health messaging that could help people avoid contaminated fish while still benefiting from nutrients in fish. Well-defined communication is needed to educate target populations on risks and benefits of fish consumption and safe fish-eating practices (Frewer et al., 2016). Messaging must incorporate continually evolving scientific understanding of the health risks associated with contaminants, particularly PFAS (Christensen et al., 2016b; National Academies of Sciences, Engineering, and Medicine, 2022). Further efforts (e.g., focus groups) will be needed to understand anglers' risk/benefits perceptions regarding safe fish consumption and consider these when developing actionable and concrete recommendations.

One limitation of the current study was that the study sample was not representative of the urban anglers living near the Milwaukee impacted waterways. Although the study design originally planned for a statistically representative sampling of licensed anglers based on random selection of fish license registrants, the study had to adapt the recruitment strategy after a significantly lower than expected response rate over a prolonged period. This change in recruitment method limits generalizability of the results, as it may have biased our sample toward certain demographics and resulted in underrepresentation by persons identifying as female. Another limitation was that the study was cross-sectional, and we were not able to determine the temporality of being aware of fish advisories and adopting safe fish consumption behaviors or the temporality of consuming fish and accumulating contaminants in the body. Third, the higher levels of PCBs observed in the study population may be due to the fact that the study population was older than the NHANES population, and the higher PCBs concentrations may reflect our participants' past exposures to PCBs from sportfish or other sources over the years. Further analysis needs to be conducted to examine whether Milwaukee licensed anglers consumed more PCBs-contaminated fish and whether this consumption contributes to higher PCBs concentrations compared to other U.S. adults with the same age distribution. Finally, recall bias around participants recalling their fish consumption and social desirability (when participants reported being aware of fish advisories when they were not) may affect the accuracy of the self-reported results on fish consumption and awareness.

Conclusion

Most urban anglers in the Milwaukee area were aware of Wisconsin and Milwaukee advisories in this study, and their awareness was associated with protective behaviors, such as avoidance of eating particular parts of the fish, eating different type of fish, or avoidance of eating fish from certain areas. However, the anglers in this study did not necessarily reduce their sport-caught fish consumption, especially the high-mercury containing species, to avoid exposure to contaminants in the Milwaukee waterways. Biomonitoring results show that the Milwaukee urban anglers had higher body burden levels of mercury, PCBs, and PFOS, and lower persistent pesticide levels than the U.S. population. More effective health education strategies need to be developed to increase anglers' knowledge about the risks and benefits of fish consumption and promote safe fish consumption behaviors.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interest.

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