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Biomonitoring programs in Michigan, Minnesota and New York to assess human exposure to Great Lakes contaminants

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Abstract

Over the past century, industrialization and urban practices have resulted in the contamination of the Great Lakes ecosystem—the world's largest surface freshwater system—that provides drinking water and recreation to more than 40 million residents. In 2010, the Great Lakes Restoration Initiative was launched to accelerate efforts to protect and restore the Great Lakes and surrounding areas. Funded by GLRI, the Agency for Toxic Substances and Disease Registry initiated the Biomonitoring of Great Lakes Populations (BGLP) program. The objective of the program is to assess human exposure to legacy and emerging contaminants in the Great Lakes by measuring the body burden of contaminants in potentially susceptible populations. The BGLP program consists

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the position of the CDC and ATSDR.

Appendix A. Supplementary data

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of a series of cross-sectional studies carried out collaboratively with states that are funded through ATSDR. The first BGLP Program (BGLP-I) began in 2010 and was completed in September 2015 through cooperative agreements with state health departments in Michigan, Minnesota, and New York. The three state programs targeted susceptible adult populations living in designated areas of contamination. Contaminants measured in all populations include mercury, lead, mirex, hexachlorobenzene, dichlorodiphenyltrichloroethane, and selected polychlorinated biphenyl congeners. In addition, some chemicals of emerging concern, such as per- and polyfluoroalkyl substances, were measured in several populations. The biomonitoring results helped guide public health actions to mitigate chemical exposures in these vulnerable Great Lakes populations. We provide an overview of the BGLP-I program's study populations, designs, and general methods. This overview provides a lead-in for subsequent manuscripts that present human biomonitoring data for legacy and emerging contaminants in culturally diverse susceptible populations—i.e., shoreline anglers, sport anglers, American Indians, and Burmese immigrants—residing in seven areas of concern.

Keywords

Biomonitoring; Great lakes; Persistent toxic substances

1. Introduction

The Great Lakes region, recognized as the ancestral lands of the Algonquin, Iroquois, and Dakota nations, are an important part of the cultural heritage of North America. The Great Lakes and connecting waterways provide drinking water and recreation to the basin's more than 40 million residents. Over the past century, the Great Lakes ecosystem has been subjected to pollution from various sources, such as agricultural runoff, municipal wastewater, industrial discharge, and disposal site leachate. Cleanup and pollution control efforts by local, state and federal agencies in the U.S. and Canada have reduced the levels of many contaminants in the Great Lakes and surrounding areas. However, legacy pollutants and emerging contaminants continue to pose environmental and public health concerns. Legacy pollutants include heavy metals (such as lead and mercury), polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and dioxin. These chemicals, mostly banned or phased out decades ago, entered the environment as the result of industrial accidents or spills, or through the disposal of hazardous materials, and persist in soil and aquatic sediments. They also bioaccumulate and biomagnify, meaning that the concentration in animal tissues increases from bottom-dwelling microorganisms up the food web to increasingly larger fish and wildlife (ATSDR, 1999; ATSDR, 2007; EPA, 2016). Great Lakes fish monitoring studies indicate a considerable decline in legacy pollutant concentrations throughout the 1970s and 1980s. However, the decline began to slow around 1990, and mercury concentrations started to increase in recent years (Carlson et al., 2010; French et al., 2011; Rasmussen et al., 2014; Zhou et al., 2017). In addition to well-known legacy pollutants, chemicals of emerging concern released to the Great Lakes ecosystem are being detected in water, sediments, fish, and wildlife. Chemicals of emerging concern identified as threats to the Great Lakes watershed include per- and polyfluoroalkyl (PFAS), polybrominated diphenyl ethers (PBDEs) and current use pesticides (Klecka et al., 2010).

People residing in areas known to be contaminated in the Great Lakes basin are at risk of exposure through inhalation, dermal contact with water, soil and sediments, ingestion of municipal water drawn from the lakes and surrounding waters, and eating local food sources.

The public health and environmental impacts of persistent toxic pollutants have been the focus of scientific research and public health worldwide (EPA, 2016). In the U.S. and Canada, research in the Great Lakes region has focused on identified environmentally degraded surface water systems called “Areas of Concern” (AOCs) (EPA, 2017a). Since the 1970s, research conducted within communities living near AOCs has contributed to our knowledge of at-risk populations and possible health effects (Johnson et al., 1998; De Rosa et al., 2006). Studies on the human health effects of mercury and PCBs have long indicated a link between exposure and adverse reproductive outcomes, neurological effects, developmental disabilities, and endocrine disorders (Dzwilewski and Schantz, 2015; Eubig et al., 2010; Karmaus and Zhu, 2004; Schantz et al., 2001; Stewart et al., 2008). More recently, studies in vulnerable communities have found that elevated body burdens of metals and PCBs are associated with liver disease, diabetes, and cardiovascular disease (Cave et al., 2010; Christensen et al., 2013; Genchi et al., 2017; Silverstone et al., 2012; Turyk et al., 2009). Vulnerable populations include women of childbearing age, pregnant women, fetuses, nursing infants, children, the elderly, certain ethnic groups, and anglers (Johnson et al., 1998). Urban communities living in or near contaminated watersheds and indigenous communities that live off the land in the Great Lakes basin are at risk of high exposure through eating locally caught fish, aquatic plants, and wildlife (Fitzgerald et al., 2004; Schaeffer et al., 2006; Turyk et al., 2006; Knobeloch et al., 2009; Christensen et al., 2016a).

Since 2010, Congress has appropriated funds to the U.S. Environmental Protection Agency (EPA) for the Great Lakes Restoration Initiative (GLRI) to accelerate remediation efforts in the Great Lakes basin and to prevent associated human health problems (EPA, 2017b). GLRI 5-year Action Plans outline work carried out in major focus areas, including actions to clean up contaminated areas (EPA, 2017b).

Under the auspices of the GLRI, the Agency for Toxic Substances and Disease Registry (ATSDR) established the Biomonitoring of Great Lakes Populations (BGLP) Program, an applied public health program designed to assess the human body burdens of persistent toxic substances in potentially susceptible subpopulations and factors that are associated with those body burdens concurrently with the GLRI environmental remediation process. The BGLP program consists of a series of cross-sectional studies carried out collaboratively with state health departments that includes culturally diverse target populations deemed at potential high risk of exposure to Great Lakes contaminants. Certain elements of each program, such as eligibility criteria and sampling strategy, were specific to the program's target population. The BGLP program also aims for state and local health department to use the biomonitoring information to guide public health actions to protect the targeted communities within their jurisdiction.

The first BGLP Program (BGLP-I) began in 2010 and was completed in September 2015 through cooperative agreements with state health departments in Michigan, Minnesota, and New York. The three state programs targeted four adult populations—i.e., shoreline anglers,

sport anglers, American Indians, and Burmese immigrants—living in or near seven AOCs (Fig. 1). This paper provides an overview of the BGLP-I program and describes study populations, designs, and general methods. For each BGLP-I target population, we describe the sampling strategy, recruitment methods, data collection, analytes measured, and respondents. This overview provides a lead-in for upcoming manuscripts that present human biomonitoring data for legacy and emerging contaminants in culturally diverse susceptible subpopulations in the Great Lakes area.

2. Methods

Federally sponsored information collections from the public, such as these undertaken in this program, must comply with the Paperwork Reduction Act (PRA). The BGLP-I program received PRA clearance in October 2012 (OMB Control No. 0923–0044, expiration date 10/31/2015) (OMB, 2012). The Michigan and New York State health departments obtained institutional review board (IRB) review and approval for their respective data collections. The Minnesota Department of Health (MDH) conducted a program jointly with the Fond du Lac Band of Lake Superior Chippewa Human Services Division (FDL HSD) with approval from FDL's governing body, the Reservation Business Committee. The FDL HSD IRB and the FDL Biomonitoring Study Advice Council reviewed and approved the study protocol and participant communications materials prior to data collection. All respective parties approved data sharing agreements with ATSDR.

2.1. Target populations and sampling strategies

Each cooperative agreement program set recruitment goals and target population(s) as part of their funding proposal. Each program aimed to assess exposure to toxic substances in residents within their jurisdiction conducting population-based biomonitoring of susceptible population(s). All programs elected to target adults who had lived in a selected Great Lakes AOC for at least one year and were medically able to donate the required blood sample. For the proposed sample sizes, we assessed the ability to detect analyte levels above the most recent geometric mean (GM) reported for the adult U.S. population (NCEH, 2015) assuming 80% power and a one-sided test of significance at $p = 0.05$. Standard deviations for the U.S. population GMs were assumed the same for the BGLP-I program target populations. For core contaminants, sample sizes were sufficient to detect analyte levels 2-fold or higher than U.S. population levels. Recruitment goals and criteria are summarized in Supplemental Table 1.

Biomonitoring of Persistent Toxic Substances in Michigan Urban Anglers: The Michigan Department of Health and Human Services (MDHHS) biomonitoring project targeted “shoreline anglers,” defined as urban Michigan residents who fish from the riverbank and regularly consume their catch from the targeted areas of the Detroit River and the Saginaw River/Bay (Supplemental Figure 1). While these waterways are contaminated with mercury and other metals, PCBs, dioxins, and furans, they also are important resources for urban anglers, many of whom are low-income and fish for sustenance as well as for recreation (Kalkirtz et al., 2008).

MDHHS used a modified venue-based sampling (VBS) process to establish a sampling frame for shoreline anglers. Urban anglers often fish without a license, thus limiting sampling from existing fishing registries (ASA, 2007). VBS is a probability-based strategy for recruiting members of a hard-to-reach population assembling at discrete locations (Mackellar et al., 1996). VBS proceeds through a preparatory or primary enumeration phase and a secondary enumeration phase. Under contract with the MDHHS, Wayne State University (WSU) faculty designed and implemented the VBS activities and initial screening survey of shoreline anglers. In the summer of 2011, WSU conducted venue-based primary enumeration sampling activities to obtain visual estimates of the density of shoreline anglers on certain days of the week and at specific times of the day at identified fishing venues. During this phase, staff used a clicker counter to make headcounts of persons, congregating in venue-day-time units (VDTs), who appeared to fit the inclusion criteria of being an angler at least 18 years old. Staff collected data along the Detroit River for 35 days and along the Lower Tittaba-wassee and Saginaw Rivers for 21 days. Findings were used to establish a calendar of the VDTs for the next phase of data collection (i.e., “Belle Isle South Pier, Tuesday, 7:15 a.m. to 7:30 a.m.”). In constructing the calendars, VDTs were randomized using a random number generator and clustered geographically to make traveling from one venue to the next feasible. Prior to data collection, WSU confirmed the primary enumeration data and finalized the VDT sampling schedule. At each selected VDT, trained interviewers administered a brief survey to shoreline anglers to determine eligibility and willingness to participate in the biomonitoring study. All approachable anglers were asked questions about eating locally caught fish; their age, gender, and race/ethnicity; and their interest in participating in the study. Participation in the biomonitoring project was limited to adults, at least 18 years of age who ate at least two meals per month of locally caught fish from the Detroit River or the Saginaw River/Bay AOCs in the past year. Based on responses to the venue-based interviews, MDHHS staff randomly conducted follow-up phone interviews with eligible VDT respondents to further confirm eligibility and schedule biomonitoring clinic appointments. At this stage, MDHHS staff asked questions to exclude respondents who lost more than 15 pounds in the past year and woman currently pregnant or who have breastfed in the past six months. These conditions can effect steady-state body burdens of lipophilic target analytes. Biomonitoring study clinics were held from June 2013 through November 2013 at church facilities, community centers and local health departments in the Detroit River and Saginaw River/Bay areas.

The Fond du Lac Community Biomonitoring Study, Minnesota: The Fond du Lac (FDL) Band of Lake Superior Chippewa Reservation is located in the Great Lakes basin and within the St. Louis River Area of Concern (SLRAOC). The Minnesota Department of Health (MDH) partnered with the FDL Band of Lake Superior Chippewa to conduct a population-based biomonitoring study of American Indians affiliated with the FDL Band or other tribes, who live near the SLRAOC (herein called the “FDL Community”). Relying on the historical activities of the Chippewa Indians living near the SLRAOC, it was assumed that the FDL Community may experience greater exposure to contaminants within the Lake Superior Basin due to consumption of traditional foods from local aquatic environments. The target population was adult American Indians, including enrolled members of any federally recognized tribe and their descendants, who lived in Carlton County and in the

southern half of St. Louis County in Minnesota (Supplemental Figure 2). Eligibility criteria required participants to be 18 years or older, living in the study area for at least 12 consecutive months prior to study enrollment, not pregnant, and willing and medically able to donate blood and urine specimens. Per request by the FDL Biomonitoring Study Advice Council, the FDL project did not include an eligibility criterion based on a minimum number of fish meals. The FDL Biomonitoring Study Advice Council also deemed it culturally inappropriate to take blood from an expectant woman when it is not necessary. Only a portion of the FDL Community members who participated in the BGLP-I were enrolled members of the FDL Band of Lake Superior Chippewa tribe. Thus, not all study participants shared the same hunting, fishing, and gathering rights pursuant of the Treaty of 1854. As a result, the FDL Community as defined herein was heterogeneous and not representative of FDL Band members, American Indians that practice traditional lifeways, or those that exercise treaty harvest activities. It could not be assumed that the FDL Community is more susceptible than the general population living within the SLRAOC.

The FDL Community is eligible to receive a variety of health and social services from the FDL Human Services Division (FDL HSD). Because the FDL community uses the services provided extensively, the FDL Human Services “Client List” was used to create a sampling frame restricted to one record per client with a home address within study area zip codes. Each client record was assigned a unique random number. These random numbers were ordered numerically to determine the sequence in which FDL HSD employees recruited and enrolled potential participants. The FDL HSD is permitted, pursuant to Section 164.512 (b) of the HIPAA Privacy Rule, to use its Client List for public health practice activities without client authorization.

Healthy Fishing Communities Project, New York State: The New York State Department of Health (NYSDOH) program targeted two susceptible adult populations that were sampled, recruited, and enrolled independently. The first target population was licensed anglers living in proximity to four AOCs of interest, i.e., the Buffalo River, Niagara River, Eighteenmile Creek, and Rochester Embankment, and who ate locally caught fish (Supplemental Figure 3). The licensed angler population consisted of persons aged 18–69 years who purchased a state seasonal or lifetime fishing license, listed a residential address in the study areas, and fished and ate fish caught from the AOCs of interest in the past year. A sampling frame was created using the New York State Department of Environmental Conservation (NYSDEC) 2010–2011 database of fishing licenses. A sampling frame of 94,077 licensed anglers aged 18–69 years living within a 10-mile buffer of the NYSDOH program areas of concern was extracted from the 2010–2011 NYSDEC fishing license database. Recruitment packages were mailed to 13,369 randomly selected licensed anglers, and recipient could complete the eligibility screening survey and return it by mail or complete the survey online. The recruitment package included a cover letter, a fact sheet about the project, the eligibility screening survey along with maps of local waterways of interest, and a stamped return envelope. Of the 2126 respondents from whom surveys were received, 883 met the eligibility criteria for the biomonitoring study. To be eligible, an adult licensed angler must have lived at the address on the fishing license for at least one year, and have eaten at least one fish caught in the AOCs within the past 12 months. Reporting of at

least one meal of highly contaminated Lake Ontario sportfish species is consistent with the criteria used to classify participants in the New York Angler Cohort study as consumers of sportfish (Bloom et al., 2005). Eligible respondents were called by interviewers and invited to participate in the biomonitoring study, and if confirmed, an appointment was scheduled.

The NYSDOH's second population of interest was refugees and immigrants from Myanmar (also known as, Burma) and their descendants who lived in the City of Buffalo and who ate fish caught in the area. Due to economic and cultural factors, recent Southeast Asian refugee populations tend to engage in subsistence fishing and frequently consume locally caught fish (Schantz et al., 2010). Many of the refugees from Burma in Buffalo reside in neighboring communities which border the Upper Niagara River and are within three to five miles of the Buffalo River. Respondent-driven sampling (RDS) was used to sample and recruit the Burmese refugee and immigrant target population, and details of the recruitment strategy are described in a previous publication (Liu et al., 2018). RDS has been shown to increase efficiency and decrease cost compared to other sampling designs and has been shown to be suitable for refugee populations (Sabin, 2011). For several reasons, RDS was an effective approach for recruiting the Burmese. First, by virtue of being refugees, the Burmese are socially connected culturally, geographically, and, to some extent, politically. Second, the Burmese living in Buffalo knew each other's fishing and fish consumption habits. Third, high participation rates can be achieved because RDS uses peer-recruitment. The initial recruits, referred to as seeds, were well connected and respected in the community. To be eligible, adult refugees and immigrants from Burma must have lived in the City of Buffalo or its surrounding communities for at least one year, and have eaten at least 12 meals in the past year of fish caught in the area. Because this population, in part, subsists on fish caught in the area, the fish consumption eligibility criterion was set higher than for the licensed anglers. The NYSDOH worked closely with Jericho Road Community Health Center (JRCHC) for refining the questionnaires, identifying seeds, and employing interpreters for the project. JRCHC, a faith-based organization, is dedicated to facilitating wellness and self-sufficiency in the lives of refugee community members in Buffalo.

2.2. Interviews

Questionnaire interviews were conducted to collect information on respondent characteristics and possible sources of exposure to the environmental contaminants of interest. ATSDR and the state programs collaboratively developed survey questionnaires through a process of adopting questions from established surveys, reviewing questions/response options, and revising items according to group consensus. Demographic information such as race and ethnicity adhered to federal standards as required by the Office of Management and Budget (OMB). The questionnaires included a set of core sections devoted to demographic information, residential history, housing characteristics, job history, smoking history, dietary intake, and recreational water activities in contaminated areas. Much of the interview was devoted to questions about consumption of locally caught fish. Participants were asked how many years they have eaten fish of any type caught from local waters, to identify the location and species of locally caught fish eaten, and then asked to recall the number of times each species was eaten in the past 12 months. Similar questions were asked for wildlife, including birds and other animals that were consumed in the past 12

months. Visual aids were used to assist in referral to specific waterways, fish species, wild game, and fish portion size. The interview also collected information on the frequency of commercially purchased fish eaten in the past 12 months for specific species or species groupings. In addition to core questionnaire items, the biomonitoring interview for each state program was tailored to fit local concerns and cultural practices, and designed to assist in the interpretation of contaminant levels in the target population. For example, traditionally harvested wild plants such as locally cultivated wild rice were included in the FDL Community study interview; and, questions on fish consumption were framed in the context of traditional methods of catch and by season. Another example is inclusion of culturally relevant questions for the Burmese population in Buffalo, NY. For the Burmese, consumption of homemade or commercially prepared fish paste and the use of thanaka, a cosmetic made from ground bark, were of interest. State programs identified an advisory board or Advice Council (for FDL study) of local stakeholders and subject matter experts at the onset of program planning.

2.3. Data and biological specimen collection

For all BGLP-I biomonitoring clinics, study participants provided written informed consent, responded to a face-to-face standardized questionnaire interview, provided blood and urine samples, and had their height, weight, and blood pressure measured. Phlebotomists screened each subject to determine if they were medically able to give blood. For Michigan and New York State, eligibility to provide the blood sample was based on the Red Cross criteria — i.e., blood pressure greater than 80 systolic/50 diastolic and less than 180 systolic/100 diastolic, no blood clotting disorders, and weight of at least 110 lbs. (American Red Cross). Laboratory standard operating procedures determined the aggregate minimum blood volume specified by each program. At the end of the clinic visit, participants received remuneration for their time and effort. Area-specific fish advisory brochures and “eat safe fish” guidelines were distributed to participants at the end of the clinic visit and/or in participant results mailings (MDHHS, 2018a; MDHHS, 2018b; NYSDOH, 2017).

2.4. Analytes measured

All state programs were required to measure a core set of pollutants including lead, mercury, PCBs, and several organochlorine pesticides (OCPs) that included: hexachlorobenzene, mirex, DDT, and dichlorodiphenyldichloroethylene (DDE). Programs were also encouraged to measure additional pollutants of regional or local concern such as dioxins, furans, speciated mercury, toxaphene, PBDEs, and PFAS. While each state program has its own designated laboratories to conduct measurements, ATSDR implemented specific steps to ensure consistency across laboratories. In accordance with ATSDR program requirements, the designated laboratories provided documentation of Clinical Laboratory Improvement Act of 1988 (CLIA) certification, participated in appropriate external proficiency testing programs, provided proficiency testing results, and provided standard operation procedure for all analytical methods including detailed quality control and quality assurance procedures.

Table 1 presents an overview of chemical analytes measured and biological matrices. For the MDHHS shoreline anglers study, the MDHHS Analytical Chemistry Section performed

laboratory analysis of all analytes except dioxins, furans, co-planar PCBs, total cholesterol and triglycerides, which were measured by the Centers for Disease Control and Prevention (CDC) National Center for Environmental Health laboratories. Additionally, creatinine was measured at Sparrow Laboratories in Lansing, Michigan. For the FDL Community study, the MDH Public Health Laboratory measured mercury, lead, cadmium, PFAS, bisphenol A, triclosan, and 1-hydroxypyrene in biological specimens; selenium in urine was measured by the Colorado Public Health Laboratory; and PCBs, OCPs, and toxaphene were measured by the MDHHS Analytical Chemistry Section. Saturated and unsaturated fatty acids in blood plasma, additional biomarkers of fish consumption, were measured by the MDH Public Health Laboratory. Total cholesterol, hemoglobin A1C, creatinine and cotinine were also measured. Hemoglobin A1C and total cholesterol were measured as a public health service to participants at the request of the FDL Biomonitoring Study Advice Council; the results were not kept by MDH or ATSDR. For the New York State program, the chemicals measured and laboratory analysis methods were the same for both the licensed anglers and Burmese populations. In addition to the PCBs, OCP and metals measured by each state program, the NYSDOH program measured predominant PBDE congeners and PFAS. PBDEs are emerging chemicals of concern in the Great Lakes basin and Lake Ontario (Klecka et al., 2010). Lake Ontario, which contains several NYS's AOCs, has some of the highest levels of PBDEs reported in the US Great Lakes (Venier et al., 2014). PFAS measured in sediment samples from the Niagara River over the period 1980–2002 showed an increasing trend (EPA, 2007). All analytical tests were conducted at the Wadsworth Center, NYSDOH.

3. Results: recruitment and participation

Biomonitoring of Persistent Toxic Substances in Michigan Urban Anglers:

WSU interview teams made 439 VDT visits at 19 fishing venues along the Detroit River over 35 days, and 306 VDT visits at 11 fishing venues along the Saginaw River/Bay over 21 days. Of the 2660 Detroit River anglers interviewed, 1261 were not eligible, 582 were eligible but refused further participation, and 817 were eligible and willing to participate. Of the 843 anglers on the Saginaw River/Bay, 113 were eligible and willing to participate, 104 were eligible but refused further participation, and 626 were ineligible. The MDHHS aimed to collect biomonitoring study data from 200 anglers from each area for 400 study participants. While the target number of participants was met for the Detroit River area (n = 287), only 38 anglers from the Saginaw River/Bay area participated. Recruitment was limited to one fishing season, and severe spring flooding during the VDT screening phase that year limited the number of participants screened in the Saginaw River/Bay area. Furthermore, the majority of anglers in the Saginaw River/Bay area who were screened reported eating less than the required minimum of two meals per month of locally caught fish. Study results will only be presented for the Detroit River area participants. The recruitment process and outcome for the Detroit urban angler study is illustrated in Fig. 2.

The Detroit River angler participants were primarily male (81%), 40–59 years old (58%), African American of non-Hispanic origin (80%), and lived in the Detroit area for ≥ 21 years (86%) (Table 2). Non-response bias assessment based on venue-based screening

questionnaire data was conducted for the Detroit River angler cohort at each of the two sampling phases. During the VDT enumeration phase, the 818 individuals who were eligible and willing to continue in the study were compared to the 582 individuals who were eligible but refused further participation. Eligible anglers willing to participate were significantly more likely to have been eating fish from the Detroit River for “more than 10 years,” 70% versus 62%. Demographic characteristics were similar between these two groups. In the second sampling phase non-response bias assessment, characteristics for the 287 anglers who completed the full biomonitoring study were compared to the 510 individuals who did not participate. Demographic differences were not noted between the two groups, but participants were more likely to be aware that some fish have harmful chemicals in them (91% versus 81%).

The Fond du Lac Community Biomonitoring Study, Minnesota:

The FDL HSD service area covers a large land base, including multiple towns and cities within its boundaries (Supplemental Figure 2). The sampling frame for the FDL Community Biomonitoring Study started with a pool of 4732 potentially eligible participants included on the FDL HSD Client List. A random sample of 1421 people were selected from this pool and invited to participate in the study. Subsequently, nine people were identified as deceased and 69 had invalid contact information that couldn't be successfully updated resulting in a total of 1343 invitees. During recruitment, a total of 60 individuals were determined to be ineligible, and 278 invitees were either unable or unwilling to schedule a biomonitoring clinic appointment (refusals). An additional 514 couldn't be contacted by either mail or phone. Data collection occurred from January 2013 through October 2013 at two FDL clinic sites: The Min No Aya Win Human Services Center on the FDL reservation and the Center for American Indian Resources in Duluth. The target number of participants was 500; however, the FDL HSD clinic contract expired just short of this goal. Study staff successfully enrolled 491 participants (Fig. 3).

FDL Community Biomonitoring Study participants were primarily female (57%); 37% aged 18–39 years, 42% aged 40–59 years, and 21% aged 60 years or older; and 83% had lived in the study area for 21 years or longer (Table 2). To provide an overview of the representativeness of the study sample, the age/gender distribution of study participants was compared to the total pool of 4732 potentially eligible participants. The FDL Community Biomonitoring study sample tended to underrepresent the total population until the late 30's for women and late 40's for men, had more people of both genders after that until the late 70s, at which point men were again underrepresented.

Healthy Fishing Communities Project, New York State:

The enrollment goal for the licensed angler target population in NYSDOH's Healthy Fishing Communities Project was 400 licensed anglers. A total of 409 licensed anglers participated in the biomonitoring study clinics that were held at local health departments from February through October 2013 (Fig. 4). Participants were mostly non-Hispanic whites (83%), males (86%), aged 40–59 years (48%), and had lived in the area for 21 years or longer (90%) (Table 2). Non-response bias was assessed among the 883 respondents to the initial screening survey. Characteristics for the 409 anglers who completed the full biomonitoring

study were compared to the 474 individuals who did not participate. Participants were more likely to be 60 years of age or older (33%) compared to nonparticipants (23%). No gender differences were noted between these two groups.

To facilitate NYSDOH's study of Burmese immigrants, the program worked closely with the JRCHC, a faith-based organization dedicated to facilitating wellness and self-sufficiency in the lives of refugee and low-income community members in Buffalo, NY. This collaboration was critical for refining the questionnaire interviews, identifying seeds, and employing interpreters for the project. The enrollment goal of 200 Burmese immigrants was quickly met using RDS with 209 participants (Liu et al., 2018). Clinics were held at the JRCHC one evening per week from July through October 2013 and served as recruitment, screening and data collection venues. The Burmese participants included slightly more females (60%) than males and 55% were aged 18–39 years, and 52% had lived in Buffalo for at least 4 years with only 18% having lived elsewhere in the United States (Table 2).

4. Discussion

The BGLP-I program is the most comprehensive biomonitoring program—to our knowledge — to evaluate subpopulations' exposure to a wide range of environmental contaminants in the Great Lakes region. The program includes a diversity of communities in areas of contamination across three states, 14 required analytes measured in all participants, and over 50 optional analytes measured in state-specific populations. The biomarkers and detailed exposure surveys augment previous exposure studies in Great Lakes populations, and provide a picture of human exposure concurrent with the onset of GLRI actions. To ensure statistically valid sampling strategies and harmonization of data collection, ATSDR provided oversight, scientific guidance, and technical support for all aspects of the program.

The exposure assessment results from the BGLP-I program will expand and enhance the chemical exposure information reported by other studies in the Great Lakes region.

The Great Lakes Fish Eater study (He et al., 2001; Hoving et al., 1993; Humphrey, 1988; Humphrey and Budd, 1996; Humphrey et al., 2000) and the Great Lakes Charter Boat Captain study (Anderson et al., 1996, 1998, 2008; Hanrahan et al., 1999) are two earlier chemical exposure studies of local-caught fish consumers who live in the Great Lakes basin. These and other studies indicate that consumption of locally-caught fish over several years can result in two-to-five fold elevations of PCB, p,p'-DDE, or dioxin-like compounds in people who ate locally caught fish and who were largely white and middle-income, compared with non-Great Lakes fish consuming populations (Falk et al., 1999; Fiore et al., 1989; Knobeloch et al., 2009; Persky et al., 2001; Schantz et al., 2001; Turyk et al., 2006). Some studies reported a decreasing trend in PCB and DDE exposure in Great Lakes sport-caught fish consumer cohorts, however, levels of these contaminants remained higher than the general population (Turyk et al., 2012). In 2012–2013, the Wisconsin Departments of Health Services conducted a biomonitoring study of male anglers aged 50 years and older. Participants (n = 154) had somewhat higher blood mercury levels compared with the U.S. general population, and the consumption of fish from the Great Lakes area was associated with higher levels of blood mercury, PCBs and PFAS (Christensen et al., 2016a, 2016b).

The BGLP-I Detroit urban angler cohort represent a low-income minority subpopulation who are likely to eat more contaminated fish, such as catfish or bass, out of necessity, cultural preference, or a lack of awareness of fish advisories in the study areas (West et al., 1993; Kalkirtz et al., 2008). Few studies have focused on urban Great Lakes fish consumers. One study was conducted on low-income city dwelling pregnant African American women who gave birth in Chicago hospitals from 1994 to 1999. The study reported higher body burdens of DDE and PCB congeners 138, 153, and 180 among high end sport fish consumers (≥ 1 meal per week) compared to non-sport fish consumers (McGraw and Waller, 2009).

The 1992–1995 New York Angler Cohort Study characterized exposure to PCB congeners, DDE, hexachlorobenzene, and mirex in western New York state anglers from 18 counties, aged 18–40 years, who consumed Lake Ontario sport fish and waterfowl. Lipid-adjusted serum values for PCB congeners and mirex were significantly correlated with an index of fish consumption (Vena et al., 1996; Bloom et al., 2008). The BGLP-I New York State licensed angler study includes an expanded list of legacy contaminants (adding lead, mercury, DDT) and area-specific emerging chemicals of concern which contributes additional and up-to-date estimates of these chemical body burdens that coincide with the GLRI program period. The NYSDOH BGLP-I study of the Immigrant Community from Burma in Buffalo, NY is a unique biomonitoring effort in the Great Lakes region. A study that assessed exposure to contaminants among immigrants from Southeast Asia living in Green Bay, Wisconsin found that serum PCB concentrations were significantly associated with locally caught fish consumption, DDE was associated with the number of years spent in a Thai refugee camp, and mercury exposure was low in this Hmong population (Schantz et al., 2010).

Several studies of American Indian populations in the Great Lakes region described mercury, PCB and organochlorine pesticide biomarkers in relation to eating harvested fish. Since tradition and culture emphasize the use of local resources for food, contamination of fish and wildlife is a concern among indigenous people. Some of the first studies of mercury exposure associated with eating fish from Great Lakes waters were conducted among First Nations of Canada people, and these studies continue today (Ripley et al., 2018). Since 1986, the Mohawk Nation at Akwesasne located in upper NYS and Canada has focused research on environmental exposure to Great Lakes contaminants and associated health effects (Fitzgerald et al., 2004, 2007). The Ojibwe Health Study collected biological samples from tribes in the states of Wisconsin, Michigan, and Minnesota beginning in 1993 through 2000. The study found that total serum PCBs and total blood mercury concentrations were only moderately elevated compared to other studies of subsistence fishing populations (Dellinger, 2004). In 1991, the ATSDR and the Indian Health Service Bemidji Service Area Office conducted a methylmercury exposure study among the FDL Band in northern Minnesota in relation to fish consumption. Investigators found a positive association between blood mercury levels greater than or equal to 10 μg/L and consumption of bass, fish from one section of the St. Louis River, and more than one-half meal of fish per week (ATSDR, 1994). The BGLP-I FDL Community Biomonitoring Study greatly expands the list of Great Lakes legacy and emerging contaminants that have not been previously assessed in American Indians in northern Minnesota.

4.1. MDH-led tribal and state partnership

From inception of the FDL Community Biomonitoring Study, the MDH-led initiative recognized FDL's sovereign status – a key element for conducting culturally competent projects with American Indian tribes. Staff from MDH and FDL developed a collaborative partnership through a series of educational and administrative exchanges to design and conduct the study. The majority of study activities (community outreach, participant recruiting, interviews, and specimen collection) took place at the Min No Aya Win Clinic by staff hired by the FDL Band from within the FDL Community. The FDL Biomonitoring Study Advice Council, comprised mainly of tribal members, reviewed all proposed plans, draft materials and procedures, and offered guidance on topics related to cultural appropriateness, community collaboration and involvement, results communication, and protections for participants. Recommendations from the FDL Biomonitoring Study Advice Council were incorporated into the study design wherever feasible.

The need for conducting a biomonitoring study with a potentially susceptible population living within the SLRAOC was the key factor that led MDH to initiate the partnership with the FDL Band. Study results established baseline measurements of exposure to environmental contaminants which has laid the groundwork permitting later study, if the tribe should choose, to access time trends and changes affecting the FDL Community. Furthermore, MDH collaborated with FDL to implement a broader array of culturally congruent public health activities related to Great Lakes contaminants of concern and safe fish consumption. The relationship between MDH and FDL has been characterized by mutual trust, respect, and commitment. As a result, this MDH-led tribal community biomonitoring study serves as an example of how state agencies can successfully collaborate with sovereign tribes.

4.2. Limitations

The BGLP-I program has several limitations. First, the program aimed to assess contaminant exposure in target Great Lakes populations deemed to be at high risk of exposure and did not collect health outcome information. Hence, we cannot identify potential adverse health outcomes associated with chemical exposure. Second, the program consists of diverse target populations and certain elements of each state program's study designs were specific to the respective populations. As an applied public health program, it was not the intent to directly compare analyte levels across target populations nor to combine the information collected as part of the three separate programs. We also acknowledge that the study objectives could have been strengthened had it been feasible to include non-contaminated reference sites to compare the results for each target population as opposed to using the general U.S. population for comparisons. Third, the program bears the same limitations inherent to biomonitoring, such as inability to distinguish sources and route of exposure based purely on biomonitoring results. Nevertheless, questionnaire results are expected to provide information about exposure sources (e.g., eating locally caught fish) within the target communities, which allows the study of association between biomonitoring results and specific sources of interest, and guide public health actions by state health departments to protect these communities within their jurisdiction.

A few state-specific limitations are noted. The NYSDOH licensed angler cohort included sport anglers who tend to practice catch-and-release, thus reducing their chances for dietary exposure. In addition, severe spring flooding in Michigan's Saginaw River/Bay area during the study period limited fishing events. The study period included only one fishing season and recruitment in the Saginaw AOC resulted in only 38 participants, which is not a large enough sample size to support generalizable results.

5. Conclusion

Health departments and associated environmental programs are responsible for addressing public health concerns in their respective states, including the promulgation and dissemination of fish consumption advisories for bodies of water in their jurisdictions. BGLP-I programs supported three state health departments to assess exposure to legacy and emerging contaminants in the Great Lakes basin through biomonitoring. These biomonitoring results along with analysis of questionnaire items, including potential exposure sources, have enabled public health and tribal officials to work with their communities to create culturally and literacy appropriate educational and advisory messages on the risks and benefits of eating locally-caught fish and other traditional foods. For example, the MDHHS developed and distributed educational materials specific to the Detroit area (MDHHS, 2018b; MDHHS, 2018c). The BGLP-I program provided a coordinated effort in assessing exposure of a wide range of environmental contaminants in multiple populations and across multiple geographic areas. The study results also provide biomarkers of environmental contaminants in targeted subpopulations at the onset of GLRI activities that would otherwise be missed in general population biomonitoring studies. This report provides an overview of the BGLP-I program and sets the stage for upcoming manuscripts presenting human biomonitoring data for legacy and emerging contaminants in susceptible subpopulations in the Great Lakes area.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

AOC	Area of Concern
ATSDR	Agency for Toxic Substances and Disease Registry
BGLP	Biomonitoring of Great Lakes Populations
BGLP-I	The first BGLP program, 2010–2015
CDC	Centers for Disease Control and Prevention
CLIA	Clinical Laboratory Improvement Act of 1988
FDL	Fond du Lac
FDL HSD	FDL Band of Lake Superior Chippewa Human Services Division
GLRI	Great Lakes Restoration Initiative
GM	Geometric mean
IRB	Institutional Review Board
JRCHC	Jericho Road Community Health Center
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OMB	Office of Management and Budget
PFAS	Per- and polyfluoroalkyl substances
OCP	Organochlorine pesticides

PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated biphenyls
PRA	Paperwork Reduction Act
RDS	Respondent-driven sampling
SLRAOC	St. Louis River Area of Concern
VDTs	Venue-day-time units
WSU	Wayne State University

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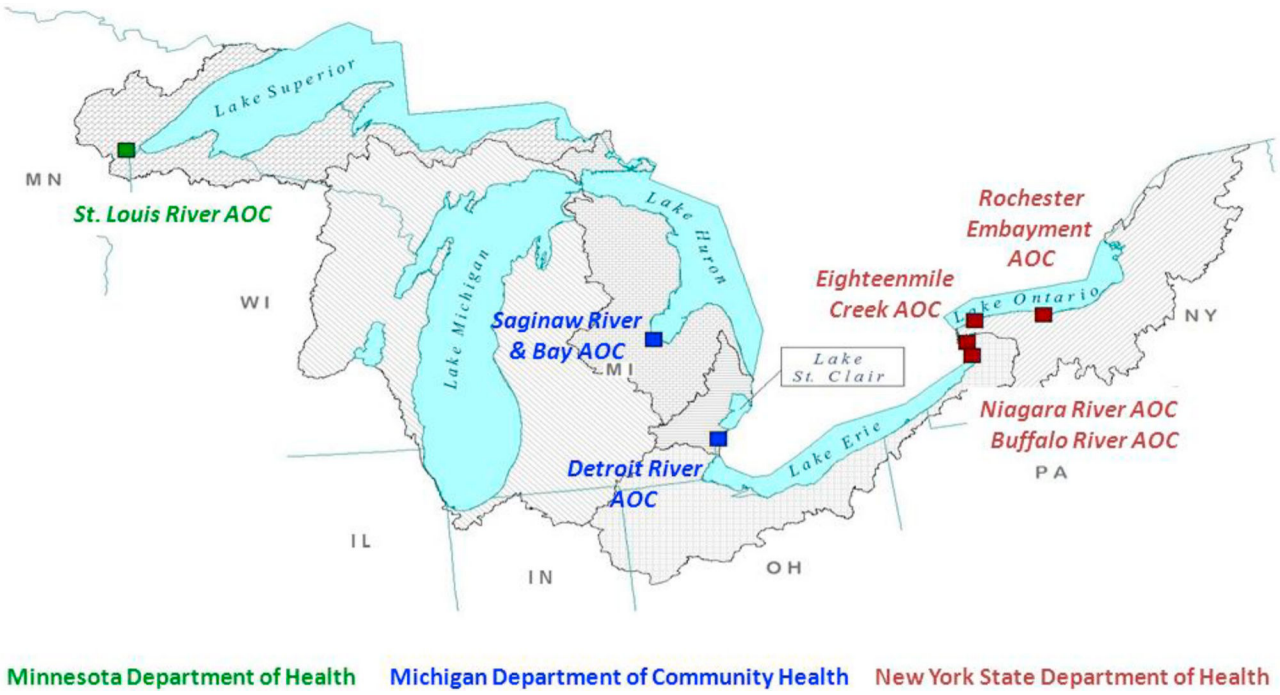

Fig. 1.

Map of the Great Lakes and Great Lakes Basin indicating the Biomonitoring of Great Lakes Populations – I Programs and Areas of Concern (AOC)*.

See: https://www.epa.gov/great-lakes-aocs for information on each AOC.

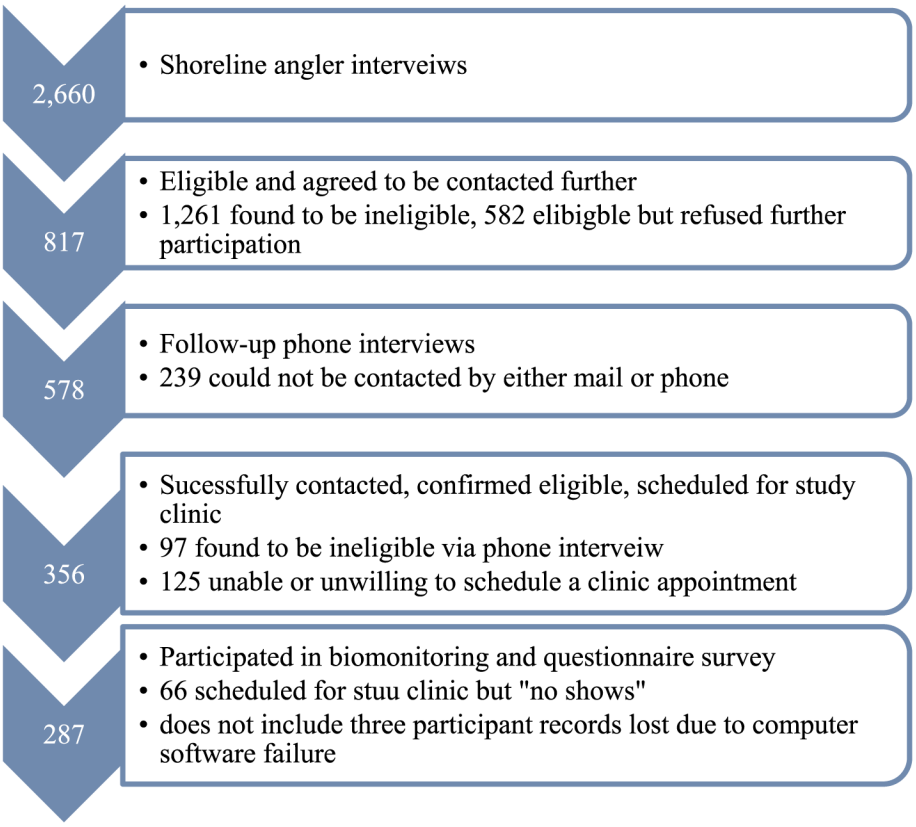

Fig. 2.
Detroit, Michigan urban angler study recruitment.

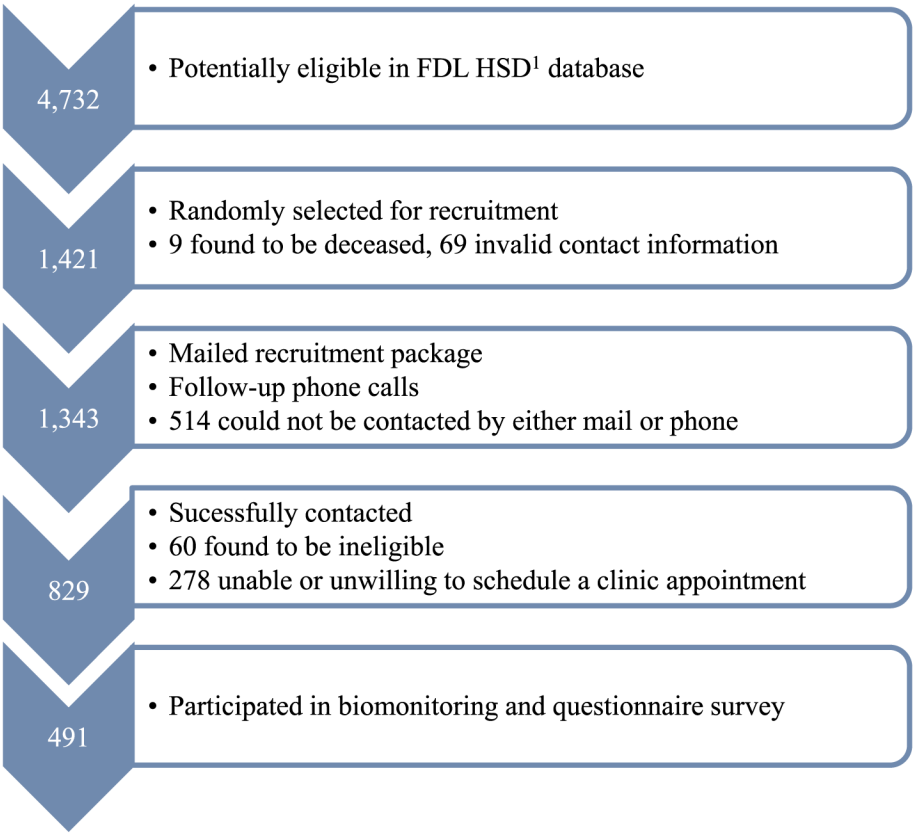

Fig. 3.
Fond du Lac Community Study, Minnesota Recruitment.

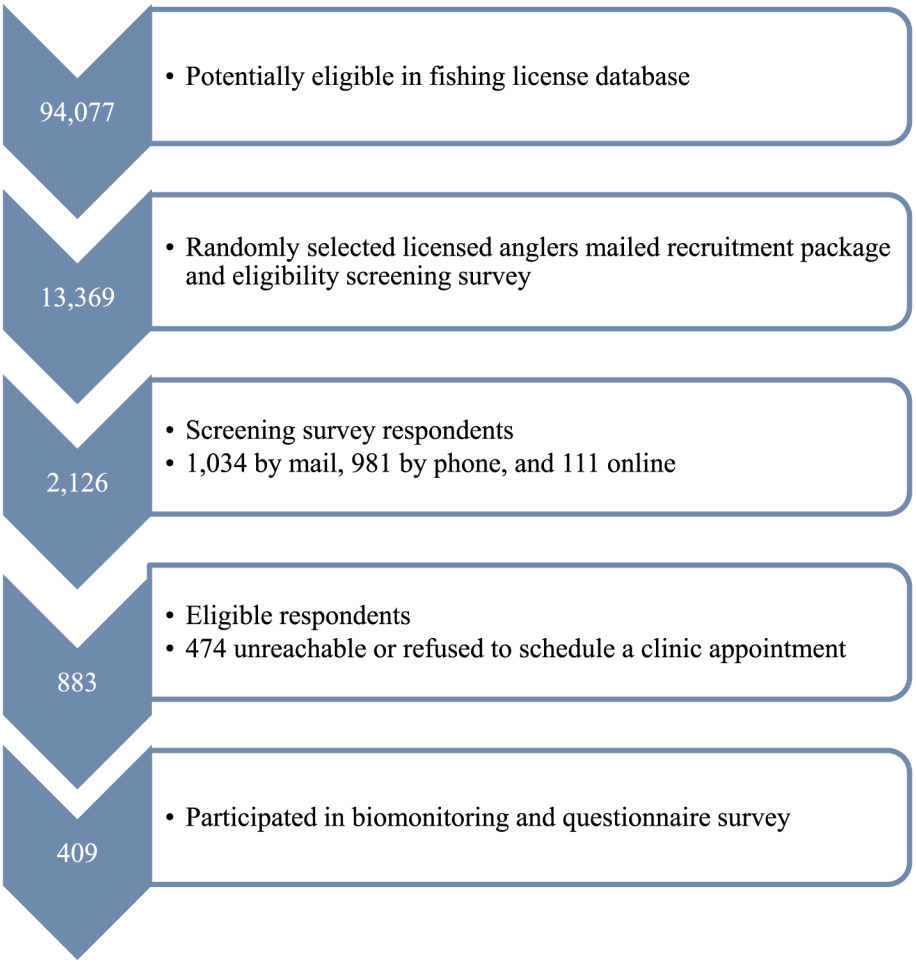

Fig. 4.
New York state licensed angler study recruitment.

Table 1

Biomonitoring of great lakes populations program I: Chemical analyte overview.

Analyte	Biological Matrix		
	Michigan Department of Health and Human Services	Minnesota Department of Health	New York State Department of Health
Environmental Phenols			
Bisphenol A		Urine[a]	
Triclosan		urine[a]	
Insecticides/Pesticides			
Chlordane	Serum[b]		serum[c]
Oxyehlordane	serum[b]		serum[c]
trans-Nonachlor	serum[b]		serum[c]
Dichlorodiphenyltrichloroethane (DDT)	serum[b]	serum[b]	serum[c]
Dichlorodiphenyldichloroethylene (DDE)	serum[b]	serum[b]	serum[c]
Hexachlorobenzene	serum[b]	serum[b]	serum[c]
Lindane	serum[b]		
Mirex	serum[b]	serum[b]	serum[c]
Toxaphene		serum[b]	
Metals			
Total Arsenic	urine[b]		
Cadmium	urine[b]	blood[a]	blood[c]
Lead	blood[b]	blood[a]	blood[c]
Manganese	blood[b]		
Total Mercury	blood[b]	blood[a,g]	blood[c]
Inorganic Mercury	Urine[b]		urine[c]
Selenium		urine[d]	
Polychlorinated Biphenyls (PCBs)			
Non-dioxin-like PCBs: 28, 52, 101, 138/158, 153, and 180	serum[b]	serum[b]	serum[c]
Mono-*ortho*-substituted PCBs: 105 and 118	serum[b]	serum[b]	serum[c]
Coplanar PCBs	Serum[e]		
Other Pollutants			
1-Hydroxypyrene		urine[a]	
Polychlorinated Dibenzo-p-dioxins (PCDDs)	serum[e]		

Analyte	Biological Matrix		
	Michigan Department of Health and Human Services	Minnesota Department of Health	New York State Department of Health
Polychlorinated Dibenzofurans (PCDFs)	serum[e]		
Per- and polyfluoroalkyl substances (PFAS)		serum[a]	serum[c]
Polybrominated Biphenyl (PBB)	serum[b]		
Polybrominated Diphenyl Ethers (PBDEs)			serum[c]
Other Auxiliary			
Total lipids	serum[f]	serum[f]	
Total cholesterol	serum[f]	serum[f]	serum[c]
Triglycerides	serum[f]		serum[c]
Creatinine	urine[f]	urine[f]	Urine[c]
Hemoglobin A1C		plasma[f]	
Cotinine		urine[f]	
Fatty acids		plasma[a]	

[a]Minnesota Department of Health Public Health Laboratory.

[b]Michigan Department of Human Health Services Laboratories.

[c]New York State Department of Health, Wadsworth Center Laboratories.

[d]Colorado Department of Health Public Health Laboratory; 10.0μg/mL is the minimum reporting limit for selenium.

[e]Centers for Disease Control and Prevention National Center for Environmental Health Laboratories.

[f]Commercial Laboratory.

[g]Mercury samples above the U.S. EPA reference level of 5.8 μg/Liter were further analyzed to quantify organic versus inorganic forms of mercury at the Brooks Rand Laboratory.

Table 2

Biomonitoring of Great Lakes Populations Program I: Study populations by age and gender.

Detroit, Michigan urban anglers			
	Male (n = 232)	**Female (n = 55)**	**Total (n = 287)**
Age group			
18–39 years	16%	26%	18%
40–59 years	61%	45%	58%
60 years or older	23%	29%	24%
Lived in the study area 21 years or longer			86%
The Fond du Lac Community, Minnesota			
	Male (n = 213)	**Female (n = 278)**	**Total (n = 491)**
Age group			
18–39 years	39%	35%	37%
40–59 years	43%	42%	42%
60 years or older	18%	23%	21%
Lived in the study area 21 years or longer			83%
New York State licensed anglers			
	Male (n = 353)	**Female (n = 56)**	**Total (n = 409)**
Age group			
18–39 years	17%	29%	19%
40–59 years	48%	50%	48%
60 years or older	35%	21%	33%
Lived in the study area 21 years or longer			
New York State Burmese immigrants			
	Male (n = 82)	**Female (n = 124)**	**Total (n = 206)**
Age group			
18–39 years	52%	57%	55%
40–59 years	40%	37%	38%
60 years or older	7%	6%	7%
Lived in the U.S. 4 years or more (maximum is 13)			59%
Lived in Buffalo, NY 4 years or more (maximum is 9)			52%