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Results of a national survey of high-frequency fish consumers in the United States[☆]

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ABSTRACT

Exposure to contaminants in fish may be associated with adverse health outcomes even as fish consumption is generally considered beneficial. Risk assessments conducted to support regulatory analyses rely on quantitative fish consumption estimates. Here we report the results of a national survey of high-frequency fish consumers (n = 2099) based on a survey population statistically representative of ~17.6 million U.S. individuals consuming three or more fish meals per week. The survey was conducted during 2013 using an on-line survey instrument. Total fish consumption averaged 111 g/day from market, restaurant and self-caught sources. Depending on the season, the incidence of individuals reporting consumption of self-caught species ranged between 10–12% of our high-frequency fish consuming demographic, averaging approximately 30 g/day and comprising 23% of total fish consumption from all sources of fish. Recreational or self-caught consumption rates vary regionally and are poorly understood, particularly for high-frequency consumers, making it difficult to support national-scale assessments. A divergence between sport-fishing and harvesting of fish as a food-staple is apparent in survey results given differences in consumption patterns with income and education. Highest consumption rates were reported for low income respondents more likely to harvest fish as a food staple. By contrast, the incidence of self-caught fish consumption was higher with income and education although overall consumption rates were lower. Regional differences were evident, with respondents from the East-South Central and New England regions reporting lowest consumption rates from self-caught fish on the order of 12–16 g/day and those from Mountain, Pacific and Mid-Atlantic regions reporting highest rates ranging from 44 to 59 g/day. Respondent-specific consumption rates together with national-level data on fish tissue concentrations of PCBs, MeHg, and PFOS suggest that 10–58% of respondents reporting self-caught fish consumption are exposed to concentrations of these contaminants that exceed threshold levels for health effects based on a target hazard index of one, representing 2.3 M to 19 M individuals. The results of this nationwide survey of high-frequency fish consumers highlights regional and demographic differences in self-caught and total fish consumption useful for policy analysis with implications for distributional differences in potential health impacts in the context of both contaminant exposures as well as protective effects.

1. Introduction

Bioaccumulative contaminants such as methylmercury (MeHg), polychlorinated biphenyls (PCBs) and poly and perfluoroalkyl substances (PFASs) are commonly detected in fish from United States (U.S.) (US EPA, 2009, 2013a). These contaminants have been associated with a suite of adverse health outcomes such as negative neurodevelopmental outcomes in children (Oken et al., 2008; Orenstein et al., 2014; Shayler, 2008), cardiovascular health (Karagas et al., 2012; Roman et al., 2011) as well as endocrine disruption, metabolic disorders, and cancer (Stahl et al., 2011; Suja et al., 2009; Blum et al., 2015). In the U.S., only the highest level fish consumers consistently exceed safety thresholds for MeHg and PCB exposures (Mahaffey et al., 2004, 2009). Data on these high-frequency consumers are limited and site-specific dietary recall surveys cannot be extrapolated because they are not statistically representative of a census region or demographic group (Karimi et al., 2012; 2014; Mayfield et al., 2007; Tsuchiya et al., 2008). Exploring and developing national consumption rates of high-frequency

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fish consumers can benefit regulatory analyses, for example, for deriving ambient water quality criteria (US EPA, 2000) or the Mercury and Air Toxics Standards (US EPA, 2011a).

We developed a nationwide survey of high-frequency fish consumers (defined as individuals consuming three or more fish meals per week, approximately equivalent to the 95th percentile of fish consumption as reported in the National Health and Nutrition Examination Survey or NHANES (US EPA, 2011b; Birch et al., 2014)) to better understand reported consumption patterns and species preferences. This study further characterizes recreational and self-caught fish consumption based on and in the context of this nationally-representative survey of high-frequency fish consumers. We use the term “fish” for all types of finfish and shellfish.

Recreational anglers represent an important component of frequent fish consumers and their self-caught fish consumption rates are known to vary regionally (U.S. EPA, 2013b; Schaefer et al., 2014; Moya et al., 2008; Moya, 2010). Those studies that have evaluated both self-caught and overall fish consumption have all focused on specific regions as opposed to a national overview (Angert, 2013; Moya et al., 2008; Burger, 2000, 2002, 2013; Dong et al., 2015; Lincoln et al., 2011; Mayfield et al., 2007; Perkinson et al., 2016; Polissar et al., 2012; Weintraub and Birnbaum, 2008). A subset of respondents to this survey reported consuming self-caught fish and we focus on these respondents for specific analyses as recreational or self-caught fish consumption in the context of overall fish consumption is rarely examined (Burger, 2013).

In addition, these survey data provide an opportunity to estimate respondent-specific back-calculated risk-based concentrations of PCBs, MeHg, and PFASs in recreationally-caught fish tissue, which can then be compared to fish tissue data from national monitoring programs (EPA 2016; Wathen et al., 2015; Stahl et al., 2009, 2014). Individuals consuming fish integrate exposure over varying temporal and spatial scales. Given the national scale of this survey and the statistical approach to fish sampling by the EPA (US EPA, 2013b, 2016), we combine consumption preferences from the survey with fish concentration data to identify the percentage of recreational fish consumers whose risk-based back-calculated tissue concentrations fall below the mean of the national distribution for each contaminant for self-caught species.

We provide descriptive statistics and an exploratory analysis of fish consumption preferences and patterns based on a nationwide survey of high-frequency fish consumers with a particular emphasis on those respondents who indicated consuming self-caught fish in addition to commercially-sourced fish. Respondent-specific self-caught fish consumption rates are used to develop risk-based back-calculated fish concentrations, which we compare to nationwide monitoring data. Finally, we discuss the implications of these data for risk-based decision making more broadly.

2. Methods

2.1. Study population and survey design

Working with an established online survey research firm, we recruited a cross-sectional cohort ($n = 2099$) of U.S. individuals that reported consuming three or more fish meals per week. This corresponds to the 90–95th percentile seafood consumer in the National Health and Nutrition Examination Survey (NHANES). Cross-sectional data were collected in April (n = 685), July (n = 689), and September (n = 725) of 2013 to account for seasonal variability in fish consumption. Participants were selected to be statistically representative of the U.S. Census from a panel maintained by GfK Knowledge Networks (GfK), a professional organization specializing in survey research (Callegaro and DiSogra, 2011; Yeager et al., 2011) augmented by non-panel respondents to ensure sufficient sample sizes (DiSogra et al., 2012a, 2012b). Research protocols, consent procedures and the survey instrument were reviewed and approved by the Harvard T.H. Chan School of Public Health Human Subjects Committee prior to recruitment. Details of recruitment methods and survey design can be found in the Supplemental Material S1 and Li et al. (2016). In short, the web-based survey was administered by GfK and included one-month and three-month recall periods. Survey participants were asked to recall their overall seafood meal frequency over the past one and three months as well as meal sizes prompted by visual cues and fish preparation methods. They were also asked to identify where they obtained their fish (e.g., self-caught, commercial market, restaurant) and the magnitudes and quantities of individual types of species-specific seafood consumed. Recall was aided by a list of commonly consumed fish species based on data reported in Mahaffey et al. (2011). Respondents were also asked to identify fish species not specifically listed in the survey.

2.2. Contaminants in fish tissue

Data on contaminants in fish fillets were obtained from the National Study of Chemical Residues in Lake Fish Tissue and the National Rivers and Streams Assessment Fish Tissue Study, the first national assessments of freshwater fish contamination in the United States for which sampling sites were selected according to a statistically-based design (http://www2.epa.gov/fish-tech/studies-fish-contamination) for lakes, rivers, and streams. We extracted data for PCBs (Stahl et al., 2009; US EPA, 2009, 2016; Batt et al., 2017; Scott et al., 2009), PFASs (expressed as PFOS as this represented > 95% of PFASs detected in fish tissue nationwide) (Stahl et al., 2014; US EPA, 2009, 2016; Ye et al., 2008; Delinsky et al., 2010), and MeHg (Peterson et al., 2007; US EPA, 2009, 2016; Wathen et al., 2015).

2.3. Data analysis

We develop descriptive statistics for overall survey respondents and self-caught anglers to compare them to data from the U.S. Census. We explore species preferences and estimated g/day annualized consumption rates and g/kg-day consumption rates to compare to published results from other surveys. We develop these for overall fish consumption from all sources as well as just the amount reflecting self-caught fish consumption for all survey respondents. A further set of descriptive statistics and analyses focus on the subset of exclusively self-caught anglers (e.g., those respondents reporting 100% of fish consumption as self-caught).

Fish consumption frequency is converted into a fish consumption rate (g/d) using the reported meal sizes and frequencies reported by each respondent. A general fish consumption rate (FCR) is calculated based on overall reported fish consumption. A species-specific FCR is calculated as the sum of FCRs across all species as well as only the self-caught species. Since over reporting is consistently observed for species-specific consumption rates (Björnberg et al., 2005; Lincoln et al., 2011), we corrected and scaled values for individual species using overall fish consumption rates.

We back-calculate risk-based PCB, PFOS, and MeHg concentrations in fish for each individual reporting self-caught fish consumption using his or her individual intake rate and body weight, an assumption of exposure over 26 years per US EPA guidance (US EPA, 2014), and a target hazard quotient as shown in Eq. (1). The target hazard quotient is a risk management decision defined by the regulatory context and is generally based on 1.0 for individual contaminants or may be adjusted to account for multiple and cumulative exposures (see, for example, guidance under the US EPA Superfund program recommending THQs of 1.0 and 0.1; https://www.epa.gov/risk/regional-removal-management-levels-rmls-users-guide). Toxicity values were expressed as Reference Doses (RfD) in mg/kg-day as published by the U.S. EPA (www.epa.gov/iris) for each contaminant. PCB toxicity was expressed in terms of Aroclors, the commercial mixture sold and released into the environment and the basis of published toxicity values.

$$C_{fish} = \frac{THQ*AT*BW}{EF*ED*FCR*\frac{1}{RfD}} \quad (1)$$

where:

C_{fish} = Backcalculated risk-based concentration in self-caught fish (mg/kg).

THQ = Target hazard quotient (unitless) 1 or 0.2.

AT = Averaging time (days) 365 days/year * 26 years.

BW = Respondent-specific body weight (kg).

EF = Exposure frequency 350 days/year.

ED = Exposure duration 26 years.

RfD = Contaminant-specific reference dose (mg/kg d) obtained from the U.S. EPA Integrated Risk Information System (www.epa.gov/iris).

Aroclor 1016: 0.00007 mg/kg d.

Aroclor 1254: 0.00002 mg/kd d.

PFOS: 0.00003 mg/kg d.

MeHg: 0.0001 mg/kg d.

FCR = Respondent-specific self-caught fish consumption rate (mg/day).

We then compare these individual risk-based contaminant concentrations to monitoring data for freshwater fish from the national datasets described previously to identify the percentage of respondents whose risk-based back-calculated tissue concentrations fall below nationally-observed means on a species-specific basis. We also estimate the number of individuals these percentages represent on a national basis using statistics obtained by the U.S. Census from the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (US Census 2011). All descriptive and statistical analyses were conducted using JMP Pro 12 from SAS Corporation.

3. Results

3.1. Demographics of national high-frequency seafood consumers

The mean inclusion rate in our survey across seasons was 7.5%, consistent with our assumption that these high-frequency fish consumers represent approximately 5% of the general population. Since our survey is statistically representative of the U.S. population above age 18 (234 million in 2010), this leads to approximately 17.6 million high-frequency fish consumers across the United States. Reported mean fish consumption (111 g/day or 1.5 g/kg-bw/day) is higher than has been reported for many tribes and recreational anglers (Table 1). Men consume more fish (~ 25 g/day) than women but body weight normalized results show no statistically significant differences by gender (Table 2). Individuals with incomes of > $50 K per year, some college, and > 65 years of age are also more prevalent as compared to the U.S. Census (Fig. 1). Older individuals (> 65 years) consume the lowest overall magnitudes of seafood, while those with less than high school education and low household incomes report the highest consumption (Fig. 1).

We observe significantly elevated ethnic representation among the "Black, non-Hispanic" and "Other, non-Hispanic" groups for these high frequency fish consumers. The statistical incidence of frequent fish consumers in the "Other" demographic (Asian, Pacific Islander, and Native American descent) suggest they include 2.0 million U.S. individuals identified in many previous studies as a vulnerable sub-population (e.g., Mahaffey et al., 2004; Xue et al., 2012). Mean consumption rates (109 g/day) and species preferences are similar to the general survey population (Table 2). The "Black, non-Hispanic" demographic in our survey represents approximately 3.2 million U.S. individuals who have not been identified in prior work as a potentially vulnerable population. Relative to their distribution across the U.S., we observe black high-frequency fish consumers are concentrated in the South Atlantic and Great Lakes regions. They report the highest mean fish consumption (124 g/day, Table 1) with higher tilapia consumption, as compared to other ethnic groups.

3.2. Demographics of respondents reporting self-caught fish consumption

Respondents reporting self-caught fish consumption (n = 208) represented approximately 10% of this overall high-frequency fish consuming cohort (7.7%, n = 65 from the winter sampling timeframe, 10%, n = 82 from the summer sampling timeframe, and 12%, n = 79 from the fall sampling timeframe) based on results from respondents representing 37 states. The US recreational fishing population consuming frequent seafood meals based on survey results varies between 1.9 and 2.8 million individuals and is larger in the spring and summer as compared to winter. This represents between 6–8% of the total 33.1 million US recreational fishing population (U.S. Census Bureau 2011). Fig. 1 provides summary information for survey respondents as compared to U.S. Census data. Self-caught fish consumers were predominantly male (63%) and White (57%) with at least a college education. Self-caught anglers show a higher proportion of males relative to females. Although respondents overall were predominantly white,

Table 1
Comparison of consumption rates among high-frequency seafood consumers.

Target population	Mean (g/kg-day)	Mean (g/day)	References
High-frequency seafood consumers (≥ 3 meals/week)			
All	1.5 (1.4–1.6)	111 (106–116)	This study
Recreational / self-caught anglers	1.7 (1.5–2.0)	130 (116–145)	This study
Exclusively self-caught anglers	1.5 (1.2–1.9)	115 (92–138)	This study
US general population			
95th percentile of NHANES 2003–2006 surveys	1.3	NA	U.S. EPA (2011a, 2011b)
95th percentile of CSFII 1994–1996, 1998 surveys	1.6	102	U.S. EPA (2002)
Vulnerable populations			
Minnesota (tribal)	0.2	11.7	U.S. EPA (2013b)
North Dakota (tribal)	0.4	15.3	U.S. EPA (2013b)
Suquamish Tribe (Washington) adult	2.7	NA	The Suquamish Tribe (2000)
Tulalip and Squaxin Island tribe (Washington) adult consumers	1.0	NA	Polissar et al. (2012)
Asian Pacific Islanders	1.9 (1.8 – 2.0)	NA	Sechena et al. (1999)
Recreational anglers			
Minnesota	0.3	20.9	U.S. EPA (2013b)
North Dakota	0.3	19.5	U.S. EPA (2013b)
Connecticut	0.6	47.5	U.S. EPA (2013b)
Louisiana	NA	90.3	Lincoln et al. (2011)
Grand Lake watershed (Oklahoma)	0.7	58	Dong et al. (2015)

Table 2
Dietary consumption rates of U.S individuals consuming ≥ 3 seafood meals per week.

Demographic Group	No. of survey respondents	Fish consumption Mean (95% CI) (g/day)	Mean (95% CI) (g/kg-day)
All	2037	111 (106-116)	1.5 (1.4-1.6)
Gender			
Male	1024	124 (115-132)	1.5 (1.4-1.6)
Female	1009	99 (93-105)	1.5 (1.4-1.6)
Women of childbearing age (16-49)	462	112 (99-122)	1.7 (1.5-2.0)
Age			
18-<25 years	159	127 (104-150.5)	2.0 (1.5-2.4)
25-<45 years	569	122 (112-132.7)	1.7 (1.5-1.8)
45-<65	757	105 (99-111.0)	1.4 (1.3-1.4)*
>65 years	552	98 (86-109.3)	1.3 (1.1-1.4)*
Race/Ethnicity			
White, Non-Hispanic	1330	107 (101-114)	1.4 (1.3-1.5)
Black, Non-Hispanic	263	124 (110-137)	1.5 (1.4-1.7)
Hispanic	215	109 (94-123)	1.6 (1.3-1.9)
Other, Non-Hispanic	150	109 (92-126)	1.6 (1.3-1.9)
2+ Races, Non-Hispanic	79	121 (93-146)	1.5 (1.1-1.8)
Education			
Less than high-school	70	149 (111-185)	2.1 (1.5-2.6)*
High school	324	109 (69-120)	1.4 (1.3-1.6)
Some college	664	116 (104-126)	1.5 (1.4-1.7)
Bachelor's degree or higher	976	102 (96-108)	1.4 (1.3-1.5)*
Household income			
Less than $20K	283	136 (112-156)	1.9 (1.6-2.2)*
$20K - <50K	516	105 (98-113)	1.4 (1.3-1.5)
$50K - <100K	713	111 (101-120)	1.5 (1.4-1.6)
≥100K	520	104 (96-112)	1.4 (1.3-1.5)
Regions			
East-North Central	296	106 (95-119)	1.4 (1.2-1.6)
East-South Central	95	111 (92-129)	1.3 (1.1-1.6)
Mid-Atlantic	320	112 (97-125)	1.6 (1.3-1.8)
Mountain	140	108 (79-136)	1.4 (1.1-1.8)
New England	95	120 (84-154)	1.7 (1.1-2.3)
Pacific	381	106 (95-117)	1.5 (1.3-1.6)
South Atlantic	434	112 (101-122)	1.5 (1.4-1.7)
West-North Central	98	108 (86-131)	1.5 (1.1-1.9)
West-South Central	174	118 (102-134)	1.6 (1.3-1.8)

*Results in red are statistically significantly different from other groups at $p<0.05$.

the subset of self-caught anglers showed fewer Whites, proportionally, as compared to the U.S. Census. A greater proportion of self-caught anglers attended some college as compared to the U.S. Census and to the survey overall, while at the same time the proportion of respondents with a less than high school education was higher in the self-caught cohort as compared to the survey overall, but similar to the U.S. Census. Self-caught anglers tended to have higher incomes as compared to the U.S. Census and even to the survey overall. Finally, in terms of geographic distribution, proportionally more self-caught anglers were from the South Atlantic, West-South Central, and East-South Central areas.

3.3. Seafood consumption rates of self-caught population

Approximately 15% of the 208 self-caught respondents reported consuming exclusively (i.e., 100%) self-caught fish, representing some 660,000 individuals in the U.S. population. The average percentage of fish consumption from self-caught fish was 26% and the median 10%, reflecting the long right tail with most respondents consuming some 10–20% of self-caught fish. The average consumption rate is approximately 30 g/day from self-caught species alone, and the overall consumption rate is 130 g/day from all sources of seafood (Tables 1, 3).

Although small sample sizes limit statistical interpretation, we observe variability across demographic covariates for the self-caught anglers (Fig. 2). For example, respondents with a less than high school education reported consuming between two and three times more self-caught fish on a g/day basis than others and their overall fish consumption is also higher although not to that magnitude. Respondents from the East-South Central reported consuming nearly five times less self-caught fish than respondents from the Mountain region, and the smallest percentage of self-caught fish relative to overall fish consumption across regions.

Some of the highest proportion of self-caught fish for both men and

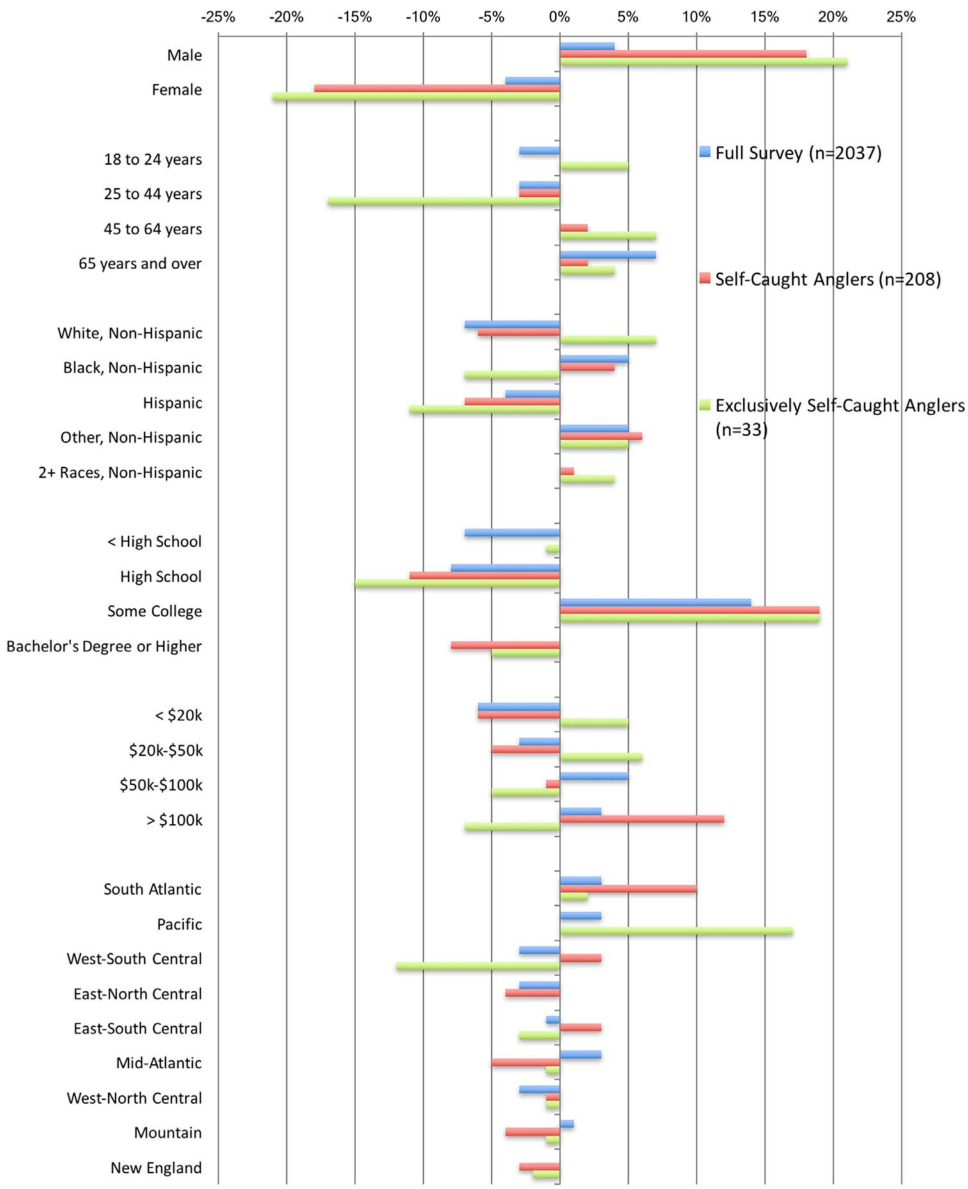

Fig. 1. Difference in Demographics for Overall Survey Respondents, Self-Caught Seafood Consumers, and Exclusively Self-Caught Seafood Consumers as Compared to Demographics from the U.S. Census (2011).

Table 3
Selected Percentiles and Summary Statistics for Self-Caught and Total Seafood Consumption Among Respondents Reporting any Self-Caught Fish (n = 208).

Recreational Anglers	10th	50th	90th	Max	Mean (95% CI)
Self-caught seafood consumption (g/day)	2.4	11	78	336	30 (24–37)
Self-caught seafood consumption as a percentage of total fish consumption	2%	10%	100%	100%	27% (22–31%)
Total seafood consumption from all sources (g/day)	55	104	211	933	130 (116–145)
Self-caught seafood consumption (g/kg-day)	0.03	0.2	1.0	4.6	0.4 (0.3–0.5)

women is in the lowest income category, particularly for the East-South Central and Mid-Atlantic regions, while for the remaining regions, self-caught consumption is higher for those individuals with somewhat higher incomes. Taken as a whole, these data suggest two different groups of fish high-frequency consumers relying on self-caught fish: the recreational sportfishing subpopulation, consisting of older, well-educated and reasonably affluent individuals and a less affluent, less educated subpopulation likely consuming self-caught fish for nutrition and subsistence rather than purely recreation. These data additionally suggest that these populations are somewhat regionally distinct.

3.4. Species preferences

Species preferences reported by respondents are shown in Fig. 3. Panel (a) provides an overview of all species consumed by all respondents in the survey, while Panel (b) provides the self-caught proportion for each species. Panel (c) provides species preferences for the further subset of respondents who reported consuming exclusively self-caught fish (e.g., 100% of their fish consumption was reported as self-caught species). For the most part, self-caught species tend to be freshwater species, although clearly some marine species are included for coastal areas. Eight species (trout, freshwater bass, salmon, cod, crappie, carp, catfish, and perch) represent over 80% of total consumption for those respondents consuming only self-caught fish. The entire subset of self-caught anglers reported consuming 10% more catfish, and nearly 10% less trout than those respondents consuming only self-caught fish.

For all survey respondents, shrimp, tuna, and salmon together account for over 50% of total fish consumption (Fig. 3a), similar to their

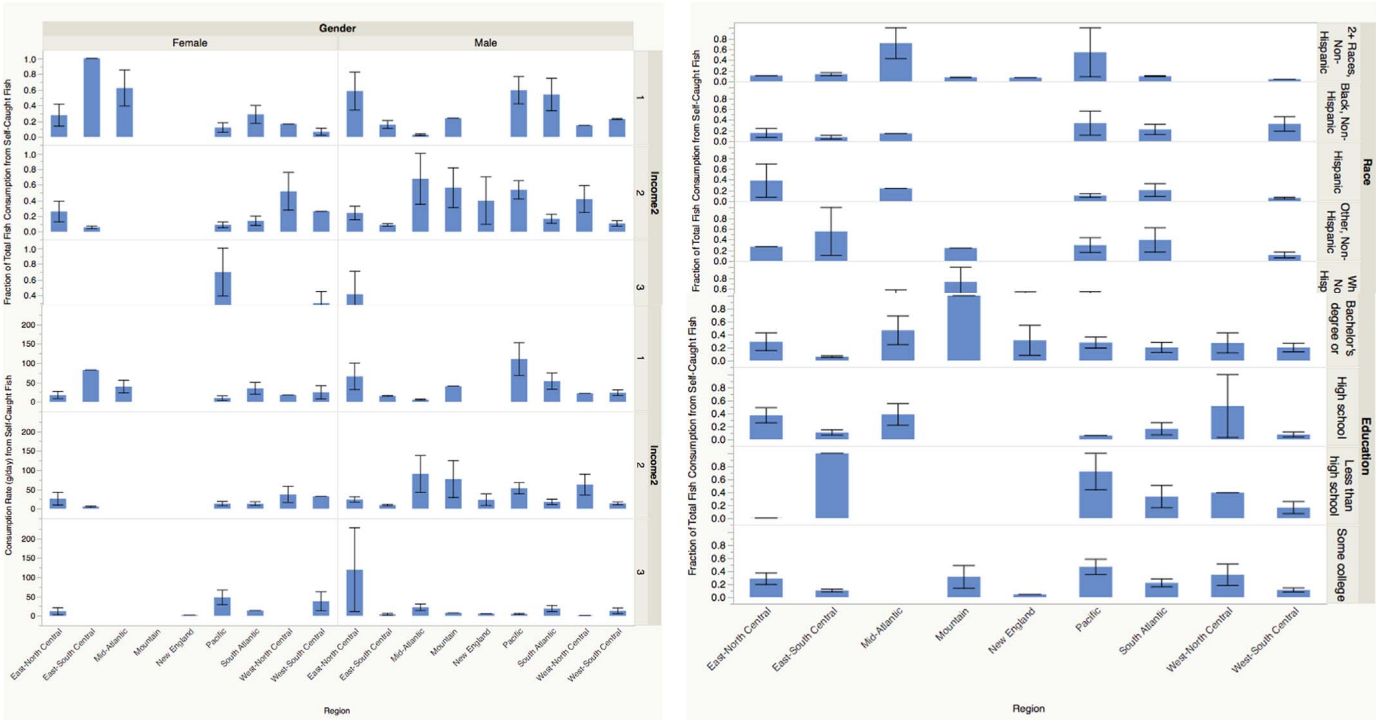

Fig. 2. Self-Caught Seafood Consumption (n = 208) Stratified by Region, Gender, Income, and Race Income 1 = $0-$25,000; Income 2 = $26,000 - $125,000; Income 3 = $125,001 and higher.

proportion of edible supply in the U.S. commercial market (Sunderland, 2007). Their predominance persists across the country, most demographic groups, age, gender and most income categories. Exceptions include high crab consumption by individuals with income < $20 K, tilapia consumption by the "Black, non-Hispanic" demographic, and locally harvested crayfish consumed by individuals in the West-South Central Region (Hobbs III et al., 1989). Consumption of salmon as a fraction of the overall seafood diet increases with household income.

A comparison of species preferences between self-caught anglers and all survey respondents reveals some differences. Shrimp and salmon remain the most popular, followed by canned tuna, tilapia and scallops for the survey overall, while self-caught anglers also prefer shrimp and salmon, but followed by other finfish (e.g., primarily those species shown in Fig. 1b), catfish, crab (not self-caught), trout and freshwater bass.

3.5. Back-calculated Risk-based Fish Concentrations

We develop summary statistics for contaminants in fish tissue by region from a nationally-representative dataset to compare to back-calculated "allowable" threshold concentrations for each respondent. Supplementary Fig. S1 provides mean and associated standard errors for contaminant concentrations by EPA region for the most commonly consumed self-caught species based on the nationally-representative sampling of lakes and rivers conducted by EPA during 2004–2008 (US EPA, 2009, 2016). While these data highlight the potential for regional differences in observed fish tissue concentrations, they do also represent a distribution of tissue concentrations at a national scale based on freshwater lakes, rivers and streams likely to be areas that are recreationally or subsistence fished. Because individuals consuming fish integrate exposure over different temporal and spatial scales, and given

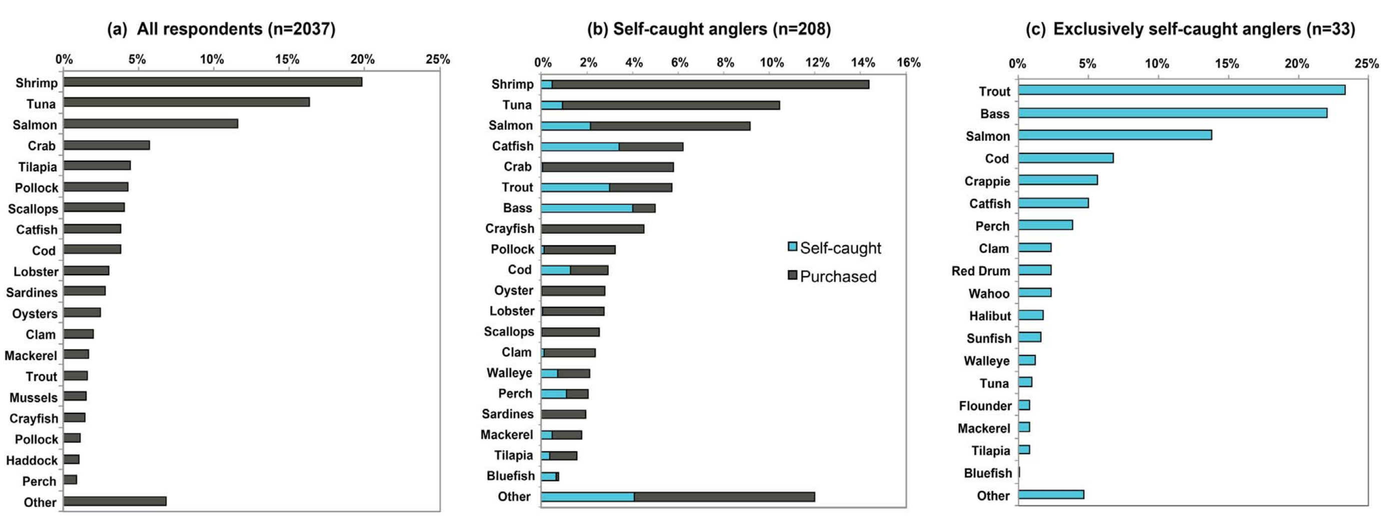

Fig. 3. Species preference of survey population (a), self-caught anglers (b), and exclusively self-caught anglers (c) Notes: The 'other' in panel b from self-caught includes (% from high to low): crappie, flounder, sunfish, yellowtail, eel, mullet, carp, snappers, whiting, pompano, halibut, red drum, wahoo, whitefish, gobbleguts, unidentified fish. Panel b addresses all top nine species for self-caught fish.

Table 4
Comparisons of Risk-Based Backcalculated Respondent-Specific Fish Tissue Concentrations to Mean Observed National Levels (Target Hazard Quotient =1).

Species[a]	Mean PCB Concentration in Fish Tissue[b] ng/g (ppb)	Percentage of Respondents Falling Below the Mean for Aroclor 1016 RfD[c]	Percentage of Respondents Falling Below the Mean for Aroclor 1254 RfD[d]	Mean PFOS Concentration in Fish Tissue[b] ng/g (ppb)	Percentage of Respondents Falling Below the Mean for PFOS RfD[e]	Mean MeHg Concentration in Fish Tissue[b] ng/g (ppb)	Percentage of Respondents Falling Below the Mean for MeHg RfD[f]	Number of Individuals for Aroclor 1016[g]	Number of Individuals for Aroclor 1254[g]	Number of Individuals for PFOS[g]	Number of Individuals for MeHg[g]
Bass (22%)	60.4	8%	27%	30.2	10%	318.30	28%	840,000	3,012,800	1,131,200	3,091,200
Trout (23%)	226.4	28%	71%	14.8	4%	154.60	18%	2,008,800	5,112,000	288,000	1,310,400
Catfish/ Bullhead (5%)	129.8	21%	53%	15.9	4%	110.20	12%	1,491,000	3,689,000	294,000	819,000
Salmon (18%)	374.5	45%	86%	23.4	7%	102.10	11%	179,200	345,200	27,200	42,000
Walleye (26%)	53.0	6%	26%	29.7	10%	273.60	26%	427,000	1,792,000	686,000	1,813,000
All Other (panfish) (6%)	57.4	7%	27%	19.2	5%	172.00	21%	525,600	1,934,500	328,500	1,503,800
Weighted Average[h]	156.5	24%	58%	23.9	7%	210.93	24%	8,019,000	18,975,000	2,310,000	7,788,000

Notes:
Target hazard index = 1

[a] Percentages in parentheses represent the proportion of respondents reporting self-caught consumption of these species
[b] Data from the National Lakes, Rivers and Streams Survey
[c] RfD (Reference Dose) for Aroclor 1016 = 70 ng/kg d
[d] RfD (Reference Dose) for Aroclor 1254 = 20 ng/kg d
[e] RfD (Reference) for PFOS = 30 ng/kg d
[f] RfD (Reference Dose) for MeHg = 100 ng/kg d
[g] Number of individuals = percentages from first column multiplied by number of individuals reporting self-caught consumption of that species from the US Census (2011)
[h] Weighted average in fish estimated from proportion of survey respondents consuming that species*concentration in that species

Table 5
Comparisons of Risk-Based Backcalculated Respondent-Specific Fish Tissue Concentrations to Mean Observed National Levels (Target Hazard Quotient = 0.2).

Species[a]	Mean PCB Concentration in Fish Tissue[b] ng/g (ppb)	Percentage of Respondents Falling Below the Mean for Aroclor 1016 RfD[c]	Percentage of Respondents Falling Below the Mean for Aroclor 1254 RfD[d]	Mean PFOS Concentration in Fish Tissu[eb] ng/g (ppb)	Percentage of Respondents Falling Below the Mean for PFOS RfD[e]	Mean MeHg Concentration in Fish Tissue[b] ng/g (ppb)	Percentage of Respondents Falling Below the Mean for MeHg RfD[f]	Number of Individuals for Aroclor 1016[g]	Number of Individuals for Aroclor 1254[g]	Number of Individuals for PFOS[g]	Number of Individuals for MeHg[g]
Bass (22%)	60.4	36%	80%	30.2	41%	318.30	81%	4,009,600	8,904,000	4,603,200	9,038,400
Trout (23%)	226.4	81%	100%	14.8	25%	154.60	57%	5,860,800	7,200,000	1,821,600	4,118,400
Catfish/ Bullhead (5%)	129.8	63%	97%	15.9	26%	110.20	45%	4,403,000	6,783,000	1,792,000	3,171,000
Salmon (18%)	374.5	94%	100%	23.4	34%	102.10	42%	374,000	400,000	136,000	166,400
Walleye (26%)	53.0	33%	78%	29.7	41%	273.60	78%	2,289,000	5,446,000	2,849,000	5,467,000
All Other (panfish) (6%)	57.4	35%	79%	19.2	28%	172.00	60%	2,525,800	5,737,800	2,014,800	4,394,600
Weighted Average[h]	156.5	71%	99%	23.9	34%	210.93	68%	23,364,000	32,736,000	11,319,000	22,473,000

Target hazard index = 0.2
[a] Percentages in parentheses represent the proportion of respondents reporting self-caught consumption of these species.
[b] Data from the National Survey on Lakes, Rivers and Streams.
[c] RfD (Reference Dose) for Aroclor 1016 = 70 ng/kg d.
[d] RfD (Reference Dose) for Aroclor 1254 = 20 ng/kg d.
[e] RfD (Reference) for PFOS = 30 ng/kg d.
[f] RfD (Reference Dose) for MeHg = 100 ng/kg d.
[g] Number of individuals = percentages from first column multiplied by number of individuals reporting self-caught consumption of that species from the US Census (2011)
[h] Weighted average in fish estimated from proportion of survey respondents consuming that species*concentration in that species.

the national scale of this survey together with the statistical approach to fish tissue sampling allows us to identify the percentage of respondents whose allowable back-calculated tissue concentrations fall below the mean of the national distribution for each contaminant as shown in Tables 4, 5. The respondent-specific back-calculated risk-based tissue levels are the concentrations at which adverse effects are not expected to occur based on published RfDs in US EPA's IRIS database (Rice et al., 2000; Schoeman et al., 2009; www.epa.gov/iris). We compare the distribution of these concentrations to the mean of nationally-observed tissue concentrations and calculate the percentage of respondents whose allowable tissue concentrations fall below that observed mean for the most commonly consumed self-caught species, as well as using a weighted average based on the percentage of each species consumed as shown in Fig. 2.

For a target hazard quotient of one, Table 4 shows the percentage of respondents whose risk-based mean fish tissue concentrations fall below nationally-observed mean levels (e.g., populations potentially at risk) based on RfDs for Aroclors 1016 and 1254 (PCBs), PFOS, and MeHg by specific self-caught species as well as a weighted average of all species. For PCBs, the highest percentage below the mean are for salmon (45% for Aroclor 1016 and 86% for Aroclor 1254), translating to between 179,200 and 345,200 individuals, followed by trout at 28% and 71% for Aroclors 1016 and 1254, respectively. Many more individuals reported consuming trout in the 2011 U.S. Census survey, so these percentages translate to between roughly two million and five million individuals nationwide. For PFOS and MeHg, by contrast, the highest percentages falling below the mean are for bass and walleye. Across all species, percentages range from 11% to 28%, translating to some seven million individuals overall.

Exposure to PCBs and MeHg are both associated with potential adverse developmental health effects, suggesting they may share biological targets. Consequently, some regulatory programs would suggest a target hazard quotient of 0.2 rather than one to account for multiple exposures likely to result in similar health outcomes on a cumulative basis. Table 5 shows what the resulting percentage allowable concentrations would be given a target hazard quotient of 0.2 for each respondent. In this case, 100% of back-calculated fish tissue levels fall below the national mean observed concentration for trout and salmon based on the RfD for Aroclor 1254, and are no lower than nearly 80% for Aroclor 1254.

4. Discussion

4.1. Differences between national and regional estimates of recreational fish consumption

The results of this survey provide insight into species preferences and consumption rates for high-frequency fish consumers who reported consuming self-caught fish. Most studies of recreational fish consumption have focused on specific regions, making it difficult to generalize results or provide perspective on differences across regions without additional information and analysis with respect to differences in survey designs and subsequent analyses. The results presented here offer a cross-sectional snapshot of regional and demographic differences in self-caught fish consumption based on a single nationwide survey using a consistent and standard survey instrument, allowing for direct albeit qualitative comparisons across regions. As regulatory decision making and policy development (e.g., ambient water quality criteria (US EPA, 2002), Mercury and Air Toxics Standard (US EPA 2011)) rely on national rather than regional estimates of recreational fish consumption, results presented here also provide a quantitative basis for risk assessors and policy makers to explore regional differences in fish consumption rates. Although issues of recall and other sources of bias in surveys of this kind still exist, one source of bias that is removed is the impact of survey design and specific questions as these were, by definition, the same across the entire survey. Rather than integrating results across regional-based surveys, this survey provides a national perspective on recreational and self-caught fish consumption. The goal was not only to explore fish consumption rates for self-caught fish, but also to gain insight into species preferences and demographic differences in frequent fish consumers from across the United States using a consistent, standardized survey instrument.

A key difference between regional surveys and this survey is that the regional surveys focus on anglers and are almost always conducted at fishing or sportsmen's derbies. Anglers attending those kinds of events will clearly consume a high fraction of self-caught fish relative to the general population, and this survey provides some perspective on the distribution and proportion of these anglers in the context of the general public. In fact, differences between this survey and the results of regional surveys are apparent and highlight the variability in frequent fish consumption generally and self-caught fish consumption specifically. Moya et al. (2008) summarized and reanalyzed the results of several regional fish consumption surveys conducted in CT, ND, MN and FL that explicitly distinguished self-caught from purchased fish consumption. Across those four surveys, the proportion of self-caught fish consumption ranged from 39% to 53% across all consumers, as compared to closer to 10–12% as reported in this survey of high-frequency fish consumers only. Self-caught fish consumption averaged 0.16, 0.21 and 0.76 g/kg-d in MN, ND and FL, respectively, and was estimated at approximately 0.5 g/kg-d in MN and ND, 1.3 g/kg-d in CT, and 2.3 g/kg-d in FL at the 95th percentile, as compared to a mean of 0.4 and 95th percentile of 1.5 g/kg-d from this survey.

A regional, saltwater angler-based survey in New Jersey (Burger, 2013) showed both considerably higher consumption rates and differences in species preferences as compared to this national survey. In terms of species preferences, flounder, striped bass, and tuna (not canned) followed by black sea bass and bluefish topped the list of preferred species for these anglers (including both self-caught and purchased). Although a total consumption rate was not reported, species-specific annualized consumption rates ranged from 2.1 to 21.6 g/day. A similar in-person angler survey at a sportsmen's conference in South Carolina showed the percent of self-caught fish meals increased with the mean monthly meal rate for both men and women (Burger, 2000). For men and women who ate more than 10 fish meals per month, 90% was self-caught (Burger, 2000). Additionally, there were ethnic differences with blacks consuming significantly more self-caught fish than whites (mean of 171 g vs. 39 g/day), a difference not evident in this national survey.

Similarly, a study conducted in Washington State (Mayfield et al., 2007), found mean freshwater fish consumption rates of 26, 13, 8, 6 g/day for African American, Asian and Pacific Islander, Caucasian, and Hispanic respondents, respectively. Although sample sizes were too small to draw statistically meaningful conclusions, these studies nonetheless suggest quantitative differences in fish consumption rates by ethnic group.

A study of Asian and Pacific Islanders conducted in 1999 (Sechena et al., 1999) found consumption rates of 1.9 g/kg-day in this community, as compared to 1.5–1.6 g/kg-day in this study (Table 1), with some 3–16% of overall consumption from self-caught species (as compared to 27% overall in this survey) with salmon, tuna, and shrimp amongst the highest consumed species.

4.2. Risk-based fish tissue concentrations

Back-calculated risk-based fish tissue concentrations for each respondent based on RfDs for PCBs, PFOS, and MeHg show that on a nationwide basis, self-caught fish consumption may contribute to the potential for adverse effects at the mean of observed concentrations nation-wide, recognizing there is variability in regional tissue concentrations (see Supplemental Fig. S1). That said, the variability in self-caught consumption rates, body weights, and species preferences are captured by the respondent-specific back-calculations, given a diverse representation of survey respondents.

Concentrations of PCBs and MeHg in fish tissues represent the primary contributors to fish consumption advisories nationwide (US EPA, 2013b). PFASs (such as PFOS) are now ubiquitous in the environment (Stahl et al., 2009). In a study of lakes and rivers in the Midwest, PFOS contributed over 80% of total PFAS composition in fish, with median PFOS concentrations of 24.4, 31.8, and 53.9 ng/g wet weight in the Missouri, Ohio, and Mississippi Rivers, respectively (Ye et al., 2008), concentrations higher than those incorporated in this analysis. At least 10 samples with PFOS concentrations above 200 ng/g were broadly scattered across all three rivers, providing evidence of the widespread presence of this compound in US waterways (Ye et al., 2008; Delinsky et al., 2010).

Xue et al. (2015) developed a national model of tribal exposures to MeHg and used a similar dataset of fish tissue concentrations, although the mean species-specific concentrations in that study tended to be higher than the results presented in Tables 4, 5. For example, mean walleye concentrations as presented in Xue et al. (2015) were estimated at 420 ng/g as compared to 274 ng/g in Tables 4, 5; similarly bass (470 ng/g versus 318 ng/g). Increasing fish tissue concentrations would have the effect of increasing the number of individuals potentially at risk.

Respondent-specific back-calculated risk-based threshold concentrations combined with data on tissue concentrations suggest that some 2.3 M to nearly 19 M individuals consuming self-caught fish in the U.S. may be at risk for adverse health effects (Table 4) based on a THQ of one. Reducing this THQ to 0.2 to account for multiple exposures increases the number of individuals potentially at risk to 11.3 M to nearly 33 M as shown in Table 5. Recognizing that fish consumption also provides benefits from omega-3 fatty acids, a more refined analysis would incorporate both benefits and potential risks.

The choice of THQ is defined by the regulatory and risk management context. For example, the U.S. EPA recommended regional screening levels (https://www.epa.gov/risk/regional-screening-levels-frequent-questions-may-2016) suggest using a THQ of one for an individual contaminant, and reducing that to 0.1 to account for multiple exposures under an assumption of additivity of potential effects. Both MeHg and PCB exposures are associated with neurodevelopmental outcomes, which would support the use of a lower THQ.

5. Conclusions

Overall, the results of this nationally-representative survey provide insight into species preferences and consumption rates for a sample of high-frequency seafood consumers. These results can be used to inform regulatory analyses and risk-based evaluations of policy alternatives at a national scale. The results also highlight qualitative regional and socioeconomic differences on species preferences and consumption rates. In addition, this survey provides a context for regional consumption surveys and offers an internally consistent basis for exploring patterns in self-caught fish consumption (e.g., removes differences in survey design and methodology that can be challenging when comparing results from highly localized surveys), and suggests two broad categories of self-caught seafood consumers. The first, an ethnically diverse, lower income and education cohort that may be consuming self-caught fish for subsistence purposes, and the second, a higher income and education cohort likely to be more of an avid recreational angler rather than subsistence angler. Finally, combined with data on mean nationwide fish tissue concentrations, these results provide perspective on the percentage of the American population potentially at risk from exposure to contaminants in self-caught fish with implications for consumption advisories and policy development more broadly.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2017.05.042.

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