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Blood mercury levels among Ontario anglers and sport-fish eaters ☆

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Abstract

We conducted two surveys of Ontario (Canada) fishers: a stratified sample of licensed anglers in two Lake Ontario communities (anglers, $n = 232$) and a shore and community-based sample in five Great Lakes' Areas of Concern (AOC eaters, $n = 86$). Among the 176 anglers consuming their catch, the median number of sport-fish meals/year was 34.2 meals and 10.9, respectively, in two communities, with a mean blood total mercury level among these sport-fish consumers of 2.8 μg/L. The vast majority of fish eaten by AOC eaters was from Ontario waters (74%). For AOC eaters, two broad country-of-origin groups were assembled: Euro-Canadians (EC) and Asian-Canadians (AC). EC consumed a median of 174 total fish meals/year and had a geometric mean total mercury level of 2.0 μg/L. Corresponding AC figures were 325 total fish meals/year and 7.9 μg/L. Overall, mercury levels among AOC eaters were higher than in many other Great Lakes populations but lower than in populations frequently consuming seafood. In multivariate models, mercury levels were significantly associated with levels of fish consumption among both anglers and EC AOC eaters. Given the nutritional and social benefits of fish consumption, prudent species and location choices should continue.

Keywords: Environmental exposure; Mercury; Food contamination; Fisheries; Ethnic groups; Canada

1. Introduction

Over the last two decades, evidence that individuals who eat considerable amounts of Great Lakes fish have greater exposure to toxic substances has continued to mount, resulting in concerns about the adverse effects on human health (Johnson et al., 1999). Environmental management responses have included the development of multistakeholder Remedial Action Plans in locally contaminated Areas of Concern (AOC) (Krantzberg, 1998). The public health response has been twofold: the development of fish consumption advisories (OMEE, 1995; Health Canada, 2001; Mahaffey, 1999) based on fish contaminant monitoring programs (e.g., Scheider et al., 1998); and research on body tissue contaminant levels (e.g., Kearney et al., 1999) and associated adverse health effects (e.g., Buck et al., 2000) in sport-fish consumers.

For several decades, national programs of mercury monitoring were carried out in First Nations populations primarily because of the intake through fish consumption (Wheatley and Paradis, 1996). Based on outbreaks of mercury poisoning, of particular concern has been the exposure of women of reproductive age (Wheatley and Paradis, 1996; USEPA, 1992, as cited in Mahaffey, 1999). Mercury contamination contributes to a large proportion of sport-fish consumption advisories in Ontario (Canada). As part of a program of research on contaminant exposures among Ontario fishers, we determined levels of mercury in blood during two

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surveys: one among licensed anglers in two Lake Ontario communities, henceforth referred to as the Anglers' Study in 1992–1993 (Kearney et al., 1995), and one of shore and community recruits from five Ontario AOC, henceforth referred to as the AOC Eaters Study from 1996–1999 (Sheeshka and Cole, 2000). For clarity, we shall describe methods separately, present results jointly, and discuss both studies in relation to other relevant studies of fishers and fish consumption.

2. Methods

2.1. Anglers' study

2.1.1. Population

For the anglers, we selected two Lake Ontario communities that had active local fishing groups and fish consumption advisories in effect for some local species, Cornwall and Mississauga. Details on participant selection have been previously described (Kearney et al., 1999). In brief, recruitment involved a multistage sampling design based on a 1988 Ontario sport-fishing license holder database, with oversampling for women and selection to increase contrasts between more frequent Great Lakes and less frequent Great Lakes consumers. Anglers were screened to determine their eligibility for blood sampling (i.e., no use of anti-coagulants, no history of bleeding disorders, no seizures or fainting with venipuncture). Overall participation was 33%. One hundred forty-six men and 86 women participated, ranging in age from 23–69 years (mean of 44).

2.1.2. Measures

The questions on fish, aquatic wildlife, and waterfowl consumption were based on methods described in the literature (USEPA, 1992). For consumption in the last 12 months, participants were asked the sport-fish species and number of meals, by season if possible, with location for the top three species consumed. Sport-fish included all fish from the Great Lakes (GL) and inland lakes (IL). To improve validity (Cavan et al., 1996), data were collected by interview to improve comprehension, meal size estimates were obtained using plastic models as prompts, and fish pictures were used to improve species identification (Kearney and Cole, 2003). Additional questions documented purchased, shellfish, and other seafood consumption. Information on sociodemographic variables (age, gender) and possible confounders (e.g., occupation, other exposures) was also collected.

Study participants were requested to avoid eating fish during the 72 h prior to blood sampling (to avoid spikes in the levels). A sample for metal analyses was collected into a 7-mL royal-blue-top, metal-free Vacutainer containing the anti-coagulant sodium heparin (Becton Dickinson No. 6527, Polo Alto, CA, USA). The sample was then refrigerated, stored in a protective styrofoam mailer, delivered to the laboratory within 48 h in a shipping cooler with freezer packs, and stored under refrigeration (no freezing) for a few days to weeks. Total and inorganic mercury were analyzed on whole blood at Health Canada Medical Services Branch laboratories using graphite-furnace atomic-absorption spectrophotometry with Zeeman background correction (Ebbestadt et al., 1977). The laboratory was participating in an international interlaboratory quality assurance program along with the Quebec Toxicology Centre (CTQ—see below) and had a method limit of quantification (LOQ) of 1.10 μg/L. Methyl (organic) mercury levels were calculated by subtracting the inorganic mercury level from the total mercury level (when the total mercury level was above the detection limit and the inorganic mercury level was not missing).

2.1.3. Statistical analyses

All data management and analysis was done on a SUN SPARC workstation using SAS/UNIX software. Total blood mercury was used because many inorganic levels were below the LOQ. For analysis purposes, one-half the LOQ was substituted for levels below the LOQ. Levels were natural log transformed for stepwise regression models that included the key covariates sport-fish (SF) consumption (yes/no for any consumption of sport-fish from GL or IL in the year before, as main contrast in this study), ducks/geese consumption, smoking, age, and gender. Predicted values were generated based on this model to aid understanding of the results.

2.2. AOC eaters' study

2.2.1. Population

Potential high Great Lakes fish-consuming recruits for the AOC eaters Study came via three sources: (1) contacts in the Chinese and Vietnamese communities of Metro Toronto and Hamilton (Murkin et al., 2003), which previous research had indicated might be sources of frequent sport-fish consumers (Cavan et al., 1994; Kraft, 1995); (2) referrals from the Sport Fish and Wildlife Consumption Study, hereafter referred to as the Shore Survey (Fish and Wildlife Nutrition Project, 2000); and (3) family members, friends, or acquaintances of potential recruits. Shore fishers were contacted at popular fishing spots in the Metro Toronto, Hamilton Harbour, Niagara River, Detroit River, and St. Clair River AOC. Thirty-eight percent (1762/4595) ate some or all of their catch, 27% (465) of these reported more than 26 Great Lakes meals per year, and 153 of these provided recontact information (Kraft and the Fish and Wildlife Nutrition Project, 1999). Sources 1 and 3 together provided 79 people who also reported eating

26 or more meals of GL fish in the last year (Murkin et al., 2004).

Among these 232 potential recruits, some were found to be ineligible on recontact due to too few meals or medical conditions ($n = 15$, 6.5%), a few refused ($n = 13$, 5.6%), and some could not be reached or dropped out after initial contact ($n = 25$, 10.7%), leaving 179 potential participants. In order to optimize the use of limited study resources, we gave priority to the following subgroups: women and adults younger than 45 years old (concern about reproductive outcomes); Cantonese, Mandarin, or Vietnamese speakers (reduction of translator training); and consumers of 72-plus meals of GL fish or aquatic wildlife (focus on most frequent consumers). This prioritization excluded another 88 who had consumed between 26 and 72 meals, leaving 91 participants (39% of 232), 51 recruited via the Shore Survey and 40 via sources 1 (community) and 3 (personal contacts) (Cole et al., 2002). Unfortunately, 5 of these did not provide blood samples for metals, leaving 86 participants for this report. We chose to classify by country of origin, thus broadly reflecting both historical exposures and current dietary practices, into Asian-Canadians (AC) and Euro-Canadians (EC).

2.2.2. Measures

The questions on fish, aquatic wildlife, and waterfowl consumption were adapted from the Anglers' Study in light of findings from the Hamilton Vietnamese study (Cavan et al., 1996) and a focus group with Chinese members (Kraft, 1995). The participants were shown pictures of 39 commonly consumed fish species and asked if they had consumed any of these fish during the past 12 months from the locations that they had indicated. A table containing the 39 fish species was used to record the number of fish meals of each species that was consumed, in each season, during the past 12 months. If a participant could not recall the number of fish meals eaten in each season, they were asked for the total number of fish meals consumed in the past 12 months. Total fish consumption included fish from both sport-fish and commercial sources (Murkin et al., 2003).

Procedures for blood collection, shipping, and storage were the same as for the Anglers' Study. Laboratory analyses were carried out at the CTQ laboratory, accredited by the Canadian Association for Environmental Analytical Laboratories and a participant in an Interlaboratory Comparison Program for Heavy Metals in Biological Fluids (Weber, 1988). Using the same general analytic method, CTQ achieved an LOQ of 2 ppb (2 μg/L).

2.2.3. Statistical analyses

Analyses were conducted with Stata 7.0 for Windows using an approach similar to that used for the Anglers, but with different predictor variables available in the multivariable analyses.

3. Results

3.1. Fish consumption

Angler sport-fish consumption ranged from a median of 11 meals/year in Mississauga to a median of 29 meals per year in Cornwall (Kearney et al., 1999). In Mississauga, 76% of sport-fish eaters consumed fish from inland lakes and rivers, followed by Lake Ontario (40%) and Georgian Bay (32%). The most popular species for inland lakes were small and largemouth bass, walleye, northern pike, and yellow perch. For Cornwall, 96% of eaters consumed fish from the St. Lawerence River and 28% consumed fish from other inland lakes and rivers. The most popular St. Lawerence River species were yellow perch, smallmouth bass, walleye, and largemouth bass. Total fish consumption, including sport-fish and commercial fish, ranged from a median of 26.5 meals/year among Cornwall women to 82 meals/year among Mississauga men (Kearney and Cole, 2003).

In keeping with our selection criteria, AOC eaters reported considerably more sport-fish consumption than anglers (hence the higher median splits for AOC eaters than for anglers in Table 2). They ate fish from over 81 different inland and Great Lakes locations for a total of 1103 participant–location–species combinations, with a mean of 12 and a range of 2–30 species–location combinations for each participant. The three species most frequently eaten by the AC group were rock bass, largemouth bass, and white bass, in contrast to yellow perch, walleye, and smallmouth bass among EC. Although both groups ate commercial fish, AC ate considerably more than EC, resulting in significantly greater overall fish consumption in the year prior: a median of 213 meals in the AC group versus 169 among the EC.

3.2. Mercury levels

Total mercury levels in the whole blood of anglers were above the detection limit in 87% of the samples and all were within the Health Canada normal acceptable range of less than 20 μg/L (Health Canada, 2001). Inorganic mercury was detectable in only 58 samples and ranged from <1.1 to 3.15 μg/L. The organic levels in whole blood ranged from 0 to 15.8 μg/L, accounting, on average, for 62% of the total mercury. All AOC eaters had detectable levels, with two participants having total blood mercury levels above the Health Canada normal acceptable range, including an elderly Chinese man who had the highest value of 26.0 μg/L, with a considerable inorganic contribution

(91%). An additional five male AOC Eaters had levels ranging from 15.5 to 19 μg/L, with potential of occupational exposures, i.e., metal working likely. Six AOC eater women of reproductive age (6/35 or 25%), all AC, had total mercury levels above 10 μg/L, the level at which we chose to carry out counseling on active exposure-reduction strategies, given the particular vulnerability of the fetus (Mahaffey, 1999). Only one woman was currently pregnant and had just reduced her consumption of sport-caught fish. Organic mercury was, on average, 77% of the total mercury among AOC eaters.

Comparing summary statistics across groups (see Table 1), we can see that AC AOC sport-fish eaters had the highest levels of total mercury in blood. EC AOC and angler sport-fish eaters had levels about one-third as high, followed by angler non-(sport-fish)-eaters. Angler levels are reported for both communities combined, since no significant differences were observed between them.

3.3. Associations between personal characteristics, consumption, and mercury levels

Few other personal characteristics showed associations with mercury levels (Table 1). Levels were lowest among middle-household-income AC AOC eaters and higher among EC AOC eaters with a body mass index

Table 1
Mercury levels for anglers and AOC-eaters stratified by selected characteristics

Statistical	Anglers		AOC Eaters	
	SF noneaters[a]	SF eaters[b]	Euro-Canadian	Asian-Canadian
Total mercury levels (μg/L) by fish consumption (for anglers) and country of origin (for AOC eaters)				
N	56	176	45	41
Minimum	<1.1	<1.1	0.4	1.0
Maximum	5.4	16.3	7.2	26.0
Median	1.5	2.3	2.2	8.4
Arithmetic mean	1.8	2.8	2.5	9.6
Standard deviation	1.2	2.1	1.6	5.7
Geometric mean	1.5	2.2	2.0	7.9
Geometric standard deviation	2.0	2.0	1.9	2.0

Additional stratification by sociodemographic and personal characteristics

Variable	Anglers				AOC-Eaters			
	SF noneaters[a]		SF eaters[b]		Asian-Canadian		Euro-Canadian	
	n	Geo-mean (G-SD)	*n*	Geo-mean (G-SD)	*n*	Geo-mean (G-SD)	*n*	Geo-mean (G-SD)
Age (years)								
17–30	8	1.6 (1.8)	23	1.9 (1.8)	10	7.2 (2.3)	12	1.9 (1.6)
31–43	29	1.5 (1.5)	60	2.0 (1.9)	20	8.5 (1.5)	23	1.8 (2.0)
44–64	19	1.4 (2.3)	93	2.4 (2.1)	11	7.6 (2.6)	10	3.0 (1.9)
Gender								
Male	30	1.7 (1.8)	116	2.4 (2.1)	14	7.2 (1.8)	30	2.0 (1.9)
Female	26	1.3 (2.1)	60	1.9 (1.8)	27	9.4 (2.2)	15	2.2 (1.9)
Education (years)								
1–11	18	1.3 (2.1)	56	2.2 (1.9)	19	9.1 (1.7)	7	3.2 (2.2)
11–13	12	1.4 (2.1)	50	2.0 (2.3)	15	6.0 (2.3)	23	1.7 (1.9)
14–20	25	1.6 (1.8)	70	2.3 (1.9)	6	10.2 (1.7)	15	2.2 (1.6)
Household income (1000 CDN$)								
5–29.9	9	1.2 (1.9)	30	2.2 (2.3)	31	8.7 (1.9)*	12	2.0 (1.7)
30–59.9	32	1.4 (2.1)	74	2.2 (1.8)	2	2.1 (2.9)	17	2.0 (1.9)
60–100	12	2.0 (1.6)	62	2.1 (2.2)	2	9.2 (1.1)	7	2.6 (1.8)
Body mass index (BMI)[c]								
⩽25	26	1.7 (2.0)	56	2.2 (2.0)	32	8.3 (1.9)	14	1.4 (1.7)
>25	30	1.3 (1.9)	120	2.2 (2.0)	9	6.8 (2.2)	30	2.4 (1.9)*

SF, Sport-fish; geo-mean, geometric mean; G-SD, geometric standard deviation.
*$P<0.05$, comparing across categories of household income and BMI for the designated country of origin group.
[a] Ate SF in last 12 months (from GL or inland lakes).
[b] Did not eat SF in last 12 months (from GL or inland lakes).
[c] BMI weight in kg/(height in m^2).

$>25\,kg/m^2$. Other nonsignificant trends were higher levels with increasing age among both angler and EC AOC eaters; higher levels among angler men and AOC eater women; and lower levels among those with high school education among all eater groups. More consistent bivariate relationships of increasing levels of mercury with increasing fish consumption were observed for both anglers and AOC eaters (Table 2). These relationships held in multivariable analyses (Table 3). Among anglers, levels of total mercury among men 50 years old who ate sport-fish would be almost 50% higher than those of women of the same age who did not eat sport-fish (2.54 vs 1.26 μg/L). In keeping with a negative interaction term between age and gender, younger angler women actually had higher levels than older women for the same level of sport-fish consumption. Among AOC eaters, AC, older age, and higher total fish consumption were all associated with higher levels of total mercury in blood, generating a predicted range of 1.8 μg/L among low-consuming, 30-year-old EC participants to a high of 20.1 μg/L among high-consuming, 50-year-old AC participants (model, $R^2 = 55.4\%$).

4. Discussion

Wide variations in sport-fish and total fish consumption are common among studies from different parts of the world. AOC eaters ate a median of 213.5 meals during the year before in contrast to Kosatsky et al. (2000), who considered as eaters people who consumed more than 1 meal of fish per week. Total fish consumption by Asian-Canadian women (median 213, mean 233 meals/year) was comparable to Danish women's seafood consumption (median 3 seafood meals/week, Olsen et al., 1993) and the consumption of women of reproductive age in Greenland and the Faroe Islands. Other contrasts can be seen with relevant Canadian fish eater studies (Table 4) and studies of women fish eaters of reproductive age (Table 5).

AOC eaters' total mercury levels were comparable to those in the Québec Inuit survey (geometric mean, 15.0 μg/L; Santé Québec, 1994) and a study of 179 commercial fishermen and their families along the Lower North Shore of the Gulf of the St. Lawrence River (geometric mean, 5.4 μg/L; Laliberté et al., 1992). The mean total mercury level for noneater anglers

Table 2
Blood total mercury by fish consumption categories

Consumption variable	Total	
	n	Total mercury geo-mean (G-SD) μg/L
Anglers		
Sport-fish[a] consumption (no. of meals in last 12 months)		
None	56	1.5 (2.0)
1–52	137	2.1 (1.9)
>52	39	2.7 (2.4)
Commercial-fish consumption (no. of meals in last 12 months)		
⩽36	117	1.9 (2.0)
>36	115	2.1 (2.0)
Total fish consumption (no. of meals in last 12 months)		
⩽63	118	1.8 (2.0)
>63	114	2.2 (2.1)

AOC–eaters, stratified by country of origin

Consumption variable	Asian-Canadian		Euro-Canadian		Total	
	n	Total mercury geo-mean(G-SD) μg/L	n	Total mercury geo-mean(G-SD) μg/L	n	Total mercury geo-mean(G-SD) μg/L
Sport-fish[a] consumption (no. meals in last 12 months)						
⩽186	13	8.3 (1.8)	37	1.9 (1.8)	50	2.7 (2.4)
>186	27	7.8 (2.1)	8	3.1 (1.9)	35	6.3 (2.2)**
Commercial-fish consumption (no. meals in last 12 months)						
2–52	12	7.5 (2.2)	31	2.0 (1.9)	43	2.9 (2.5)
53–116	29	8.1 (1.9)	14	2.2 (1.9)	43	5.3 (2.4)**
Total fish consumption (no. meals in last 12 months)						
⩽213.5	11	7.1 (1.7)	32	1.8 (1.8)	43	2.6 (2.2)
>213.5	30	8.2 (2.1)	13	2.6 (2.2)	43	5.8 (2.5)**

Geo-mean, geometric mean; and G-SD, geometric standard deviation.
** $P<0.05$, comparing across categories of fish consumption.
[a] Great Lakes + inland lakes fish consumption; one AC participant did not report inland-fish consumption, making calculation of overall sport-fish consumption impossible.

Table 3
Predicted blood total mercury levels based on final multivariable models

Sport-fish consumption	Age (years)	Total blood mercury geometric mean (μg/L)	
		Male	Female
(a) Anglers' estimated[a] blood total mercury levels by sport-fish consumption, age, and gender			
Yes	30	1.9	1.9
	50	2.5	1.8
No	30	1.3	1.4
	50	1.8	1.3

AOC eaters estimated[b] blood total mercury levels, by country of origin, age, and total fish consumption (interquartile range)

Country of origin group	Age (years)	Total blood mercury geometric mean (μg/L)	
		At 25% quartile total fish consumption (142 meals)	At 75% quartile total fish consumption (373 meals)
Euro-Canadian	30	1.8	2.4
	50	2.3	3.0
Asian-Canadian	30	11.9	15.5
	50	15.4	20.1

[a] Predicted blood mercury levels are based on the following equation derived from the data: Natural logarithm (Ln) blood total mercury level = −0.157 + 0.015(age in years) + 0.586(gender)−0.019(age*gender) + 0.339(sport-fish consumption). Gender classified as 0, male, 1, female, and sport-fish consumption in last 12 months as 0, no 1, yes.

[b] Predicted blood mercury levels are based on the following equation derived from the data: Ln blood total mercury level = −1.21 + 1.19 (country of origin group) + 0.013(age in years) + 0.279(natural log of total fish consumption) ($R^2 = 55\%$). Country of origin group classified as: 0, Euro-Canadian, 1, Asian-Canadian total fish consumption as meals during last 12 months; age in years, range from 17 to 64.

(1.9 μg/L) was similar to that for noneaters (2.0 μg/L) in the most widespread review to date (Brune et al., 1991). Absolute levels for AOC eaters were in the range of those who consume several meals per week (Brune et al., 1991) (Table 4). Levels were substantially lower than frequent-seafood-consuming women of reproductive age in Greenland, the Faroe Islands, the Seychelle Islands, and the Canadian North. While 31% of Inuit women of reproductive age had total mercury levels >10 μg/L (Wheatley and Paradis, 1996), one-quarter of our frequent fish consumers did, and Stern et al. (2001) estimated that only 1–3% of New Jersey pregnant women had such levels (Table 5). Higher levels among angler sport-fish consumers (since they also ate more commercial fish) and among our AOC eaters might be due to commercial fish meals including species known to have higher levels, such as white tuna (CFIA, 2002). Contributions of imported seabass with an order of magnitude higher mercury levels than local fish-farm species and sport-fish (Knobelock et al., 1995) might play a role for AC AOC eaters as well.

The multivariate models both demonstrated age effects despite the relatively short half-life of mercury of several months, although they were opposite for angler women. The generally lower levels among women AOC eaters and the interaction between age and gender among anglers may indicate some elimination of mercury by women via reproductive events over time. Yet different consumption patterns, different pharmokinetics for mercury across genders, or, in the case of AOC eaters, the role of occupational exposure among some men may all play a role. The U-shaped relationships between income and education and mercury levels, although not significant, are intriguing. Those with lower education and income did tend to eat more and perhaps also fished closer to home in more contaminated areas. Those with higher education and income may have had greater means to get to inland lakes further north in the Canadian shield with lower acid-buffering capacity and higher mercury levels (OMEE, 1995).

Unfortunately, our small sample size did not allow us to tease out relationships between species–location mixes and contaminant levels, even though we know that these and fish size may cause considerable variability in contaminant intakes via sport-fish. Imprecision and, in the case of dichotomous variables, misclassification of fish consumption (Cavan et al., 1996) may have impacted the strength of the relationships between mercury levels and fish consumption that we observed. In addition, contaminant intakes come from a wide variety of other foods, medications or products consumed, about which we did not have data. Variation in fish contaminant levels, imprecision

Table 4
Comparison of blood mercury levels

Author (date)	Population	Group	Total mercury
Canadian fish eater studies			
Cole et al. (these studies)	Lake Ontario licensed anglers	Sport-fish noneaters	Arith mean, 1.8 μg/L Geometric mean, 1.5 μg/L
		Sport-fish eaters	Arith mean, 2.8 μg/L Geometric mean, 2.2 μg/L
	Eaters from Ontario Areas of Concern	Euro-Canadian sport-fish eaters	Arith mean, 2.5 μg/L Geometric mean, 2.0 μg/L
		Asian-Canadian sport-fish eaters	Arith mean, 9.6 μg/L; geometric mean, 7.9 μg/L
Kosatsky et al. (2000)	Montreal-area fishers	<1 meal sport-fish/week	Geometric mean, 1.4 μg/L; median, 1.4 μg/L
		$\geqslant 1$ meal sport-fish/week	Geometric mean, 3.0 μg/L; median, 3.0 μg/L
Wheatley and Paradis (1998)	38571 Canadian First Nation people eating wild foods		Arith mean, 29.8 μg/L (NWT); range, 1–225.7 μg/L
Mahaffey and Mergler (1998)	South shore Upper St. Lawrence R.	Nonconsumers	Arith mean, 1.0 μg/L; median, 0.8 μg/L
		Sport-fish consumers	Arith mean, 1.3 μg/L; median, 1.0 μg/L
Laliberté et al. (1992)	North shore St. Lawrence R. commercial fishermen.	Mean 948 g seafood/week	Geometric mean; 5.4 μg/L
Reviews			
Kosatsky and Foran (1996)	13 data sets in long-term fish-eating population	Not reported for any study	From 0–5% > % 20 μg/L, except for Canada First Nations program, 1979–1984 where 22–27% > %20 μg/L
Brune et al. (1991)	33 data sets, categories of fish meals/week	None	2.0 μg/L (arith mean)
		<2	4.8 μg/L (arith mean)
		>2–4	8.4 μg/L (arith mean)
		>4	44.4 μg/L (arith mean)

Arith mean, arithmetic mean.

Table 5
Comparison of total blood mercury levels across selected studies of women of reproductive age

Author (date)	Population group	Fish consumption	Total blood mercury levels
Cole et al. (these studies) (AOC eaters)	Euro-Canadian and Asian-Canadian women, 17–49 years ($n = 38$).	Median, 213.5 total fish meals/year	Arith mean 6.5 μg/L; median, 5.8 μg/L; range, 0.6–21.5 μg/L; 15% > 10 μg/L
Muckle et al. (2001)	Pregnant Inuit women, Quebec	Marine food	Arith mean, 10.4 μg/L[a]
Stern et al. (2001) (15%)	New Jersey pregnant women	Mean of 83 fish meals/year, highly skewed	Arith mean, 1.0 μg/L
Hacon et al. (2000)	110 pregnant women, Alta Floresta, Brazil	44% ate fish once a week	Arith mean, 1.1 μg/L[b]
Mahaffey and Mergler (1998)	65 women, from upper St. Lawerence R., Quebec	25% ate fish during two seasons	Arith mean, 0.28 μg/L
Jensen et al. (1997)	Baffin region, 32 Inuit mother–baby pairs	Seal meat, seal liver, and narwhal mattak	Mothers, arith mean, 9.04 μg/L; Babies (umbilical cord), arith mean, 10.41 μg/L
Myers et al. (1997)	Seychelles Islands, 738 mothers	Consumed "large" amounts of marine fish	Arith mean, 2.9 μg/L[b]
Wheatley and Paradis (1996)	Inuit women	Consumed country foods	Range, 0.25–13.3 μg/L Arith mean, 8.6 μg/L
Grandjean et al. (1992)	Faroe Islands mothers	Most ate several fish dinners/week	Median, 12.1 μg/L; range, 2.6–50.1 μg/L
Foldspang and Hansen (1990)	Greenland mothers	Mean of 2.5 seafood meals/week	Arith mean, 14.9 μg/L

[a] 1 μg/L = 4.96 nm/L (Grandjean et al., 1992).
[b] Based on generally accepted relationship of concentrations: hair/blood = 200/1.

in measuring consumption, and other unmeasured intakes may all attenuate relationships, as was observed with the more defined population of Asian-Canadian sport fishers in Montreal (Shatenstein et al., 1999).

Studies from New Zealand (Kjellstrom et al., 1986, 1989); Canada (McKeown-Eyssen et al., 1983); Brasil (Lebel et al., 1996), and the Faroe Islands (Grandjean et al., 1997) suggest that fetal exposure across the placental barrier due to regular maternal fish consumption during pregnancy can be associated with neurological/neurobehavioral deficits in children (Aschner, 2002). Among women of reproductive age; mercury levels have been associated with both adverse pregnancy outcomes in some groups of high seafood consumers (e.g., low birth weight in Foldspang and Hansen, 1990) and better pregnancy outcomes among others (e.g., Olsen et al., 1993). Developmental outcomes among offspring of mothers with the high seafood consumption mentioned above have shown both cognitive deficits in mixed organochlorine and mercury exposures (Grandjean et al., 1997) and better neurobehavioral outcomes among those with only mercury exposures (Myers et al., 1997, 2003; Axtell et al., 2000; Davidson et al., 2001). The latter have been attributed to higher intakes of omega-3 fatty acids (e.g., mercury and omega-3 fatty acid correlation of 0.3 in Laliberté et al., 1992); although protein and iron may also contribute (Cole et al., 2002).

This combination of simultaneous risks and benefits associated with frequent fish consumption poses dilemmas for public health responses, as with First Nation Canadian fish and wild food consumers (Wheatley and Paradis, 1996). Yet in the Brazilian Amazon, concerted campaigns on species selection among frequent fish consumers have resulted in reductions of mercury levels of up to 40% with no reduction in total fish consumption (Mergler et al., 2001). Hence, we strongly support continued outreach to sport-fish eaters to support their consumption of species from locations with lower contaminant levels through advisories (Mahaffey, 1999) backed up by periodic monitoring of different kinds of fish consumption and mercury levels among frequent fish consumers (Paradis et al., 1997), in keeping with public health surveillance principles (Kosatsky and Weber, 2002). Although we recognize the resource intensiveness of such surveillance, we would argue that joint documentation of nutritional benefits and contaminant levels (Cole et al., 2002) should occur, rather than an exclusive focus on risks by environmental health-researchers and benefits by nutritionists and health promotion researchers. Surveillance should provide strong levers for reductions in the overall contaminant loadings to our environment such that human health benefits from fish consumption can be maximized and risks minimized in the coming years.

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