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Environmental exposures to polychlorinated biphenyls (PCBs) among older residents of upper Hudson River communities☆,☆☆

Edward F. Fitzgerald[a,*], Erin E. Belanger[b], Marta I. Gomez[b], Syni-an Hwang[b], Robert L. Jansing[c], Heraline E. Hicks[d]

[a]Department of Epidemiology and Biostatistics, School of Public Health, University at Albany, State University of New York, One University Place, Rensselaer, NY 12144, USA
[b]Bureau of Environmental and Occupational Epidemiology, Center for Environmental Health, New York State Department of Health, Troy, NY, USA
[c]Division of Environmental Disease Prevention, Wadsworth Center, New York State Department of Health, Albany, NY, USA
[d]Division of Toxicology and Environmental Medicine, Agency for Toxic Substances and Disease Registry, Atlanta, GA, USA

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Abstract

The upper Hudson River has been heavily contaminated with polychlorinated biphenyls (PCBs) due to discharges from former electrical capacitor plants in Hudson Falls and Fort Edward, NY. An epidemiologic study was conducted to assess the impact of dietary and residential exposure on PCB body burden among older, long-term, non-occupationally exposed adults living in the vicinity of these former capacitor plants. The study population consisted of 133 persons 55–74 years of age who had lived in Hudson Falls or Fort Edward for 25 years or more. The comparison group consisted of 120 persons from Glens Falls, which is upriver. Both groups were interviewed, and blood samples were obtained for congener-specific PCB analysis. Persons from the study area reported greater past consumption of Hudson River fish than did the comparison area, but current rates were very low in both areas. The geometric mean serum PCB concentrations for the study and comparison populations did not differ significantly (3.07 ppb wet weight and 3.23 ppb, respectively, for total PCB). Serum PCB concentrations increased with cumulative lifetime exposure to PCBs from Hudson River fish consumption ($p<0.10$). Persons who lived within 800 m of the river did not have significantly greater serum PCB concentrations than the control population, nor did persons who lived downwind and within 800 m of a PCB-contaminated site. The results indicate no detectable differences in serum PCB levels according to proximity or wind direction relative to local point sources, but lifetime consumption of Hudson River fish was positively associated with serum PCB concentrations.

Keywords: PCBs; Hazardous waste; Fish consumption; Inhalation; Superfund

1. Introduction

Polychlorinated biphenyls (PCBs) are halogenated aromatic hydrocarbons with unique physical and chemical properties such as thermal stability, resistance to acids, oxidation, hydrolysis, and low vapor pressure (ATSDR, 2000b). Production ceased in the USA in 1977, but PCBs remain a persistent environmental problem (Holoubek, 2001). Through bioaccumulation, these highly lipophilic compounds have contaminated the food chain. Ingestion is the major pathway of exposure for the general population, especially the consumption of fish caught from contaminated bodies of water (Bloom et al., 2005; Fitzgerald et al., 2004). Duarte-Davidson and Jones (1994) speculated inhalation may be the second most important pathway but relatively few studies have investigated this hypothesis directly.

Over approximately 30 years, General Electric (GE) plants in Fort Edward and Hudson Falls, New York used

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*Corresponding author. Fax: +1 518 402 0380.
E-mail address: eff02@health.state.ny.us (E.F. Fitzgerald).

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PCBs to manufacture electrical capacitors. Nearly one million pounds of PCBs were discharged from these facilities into the upper Hudson River, or about 15% of the nationwide discharge at that time (Hetling et al., 1978). In general, the extent of the PCB pollution along the upper Hudson River (Hudson Falls to Troy Dam) exceeds that of many other contaminated river systems. For example, sediment PCB concentrations exceeding 50 ppm have been identified in 40 "hot spots" along a 40-mile stretch of the upper River. In 1983, the US Environmental Protection Agency (USEPA) classified a 200-mile section of the river from Hudson Falls to New York City as a National Priority List site, making it one of the largest Superfund sites in the USA. In 2002, the USEPA issued a federal Superfund Record of Decision which called for targeted environmental dredging and removal of approximately 2.65 million cubic yards of PCB-contaminated sediment in the upper River. The USEPA and GE continue to negotiate the details of the project, which is planned to commence in 2008.

Since sampling data indicated that many species had PCB levels exceeding the US Food and Drug Administration's tolerance limit of 2 ppm, the New York State Department of Environmental Conservation (NYSDEC) banned all fishing on the upper Hudson and commercial fishing of several species on the lower Hudson (Troy Dam to New York City) in 1976. The ban for the upper River was changed to a "catch and release" policy in 1996. Numerous fish advisories have also been established for the consumption of species from the lower River (NYSDEC, 2003; NYSDOH, 2005). Two earlier surveys, however, suggest that the advisories have not been completely successful in preventing exposure to PCBs from eating Hudson River fish (Barclay, 1993; ATSDR, 2000a). Another potential source of exposure to PCBs along the upper Hudson is inhalation. Ambient air concentrations along a 2-mile path from Hudson Falls to Fort Edward ranged from 20 to 130 ng/m^3 in 1991, one–two orders of magnitude higher than background for Upstate New York (Harza Engineering Company, 1992).

Despite the high levels of PCBs in the environment along the upper Hudson River, no study to date has investigated the extent to which local residents have been exposed. Consequently, this article assesses the impact of dietary and residential exposure on PCB body burdens among older men and women living along contaminated portions of the upper River. Specifically, we hypothesize that higher serum PCB concentrations will be observed among (1) persons who have eaten Hudson River fish, and (2) persons who live near or downwind of the River and other local PCB sites. We also hypothesize that serum PCB concentrations will be greater among the residents of these upper River communities compared to a control community. The current study is part of an ongoing project designed to evaluate the neuropsychological effects of PCBs. The focus is upon older persons because PCBs may exacerbate the neurodegenerative processes associated with aging (Schantz et al., 1999, 2001).

2. Materials and methods

2.1. Study and comparison populations

The study population consisted of men and women aged 55–74 who resided in the Villages of Hudson Falls or Fort Edward, NY for at least 25 years. Restricting length of residence to 25 years or more ensured that participants resided in the study area when the capacitor facilities were still using PCBs. The comparison population consisted of men and women residing in the City of Glens Falls, NY for 25 years or more. According to the 2000 US Census, these three communities are demographically and economically similar. Glens Falls, however, is upriver from the GE facilities. Environmental sampling data indicate that it was not affected by the capacitor plants' PCB pollution, nor is there any other significant point source within the city limits. The comparison population was frequency matched to the study population for age and gender.

Several sources were used to enumerate a pool of potential participants from the study and comparison areas. Initially, we employed an on-line telephone directory search engine; later we obtained a digital database from *info*USA®. Computerized records from the New York State Department of Motor Vehicles were used to obtain the birth date and gender for each person on the lists. After excluding persons who were not aged 55–74, there remained 1281 candidates in Fort Edward and Hudson Falls and 1423 in Glens Falls.

Since telephone numbers are often listed under the name of only one spouse we asked each respondent if anyone else aged 55–74 resided in the same household. If yes, that person was also questioned about their eligibility and interest in participating in the study. Another limitation was that about 20% of the residential telephone numbers were unlisted and therefore excluded from consideration. However, it is unlikely that this problem resulted in bias since the same method was used to select both the study and comparison populations and the decision to list a telephone number is presumably unrelated to PCB exposure.

2.2. Recruitment

With source populations identified, we randomly selected persons for participation. An informational packet was initially mailed to each potential participant. A telephone call was made within 2 weeks of the mailing, which was also used to screen for length of residence, occupational exposure to PCBs, education, and medical history. To avoid confounding with occupational exposures to PCBs, anyone who had worked for 1 year or more at the capacitor plants or any other job that entailed exposure to PCBs was excluded. Each person meeting the eligibility criteria was fully informed about the study, and those who agreed to participate signed an informed consent that had been approved by the Institutional Review Board of the NYSDOH.

2.3. Interview

Interviews were conducted in the years 2000 through 2002. The interview included questions about sociodemographic characteristics, residential history, and dietary history. During the interview, each participant was asked to mark on a map their residences and locations from which they ate fish. They were planimetric maps (1:24,000 scale) obtained from the New York State Department of Transportation, and were digitally transferred into our Geographic Information System using MapInfo Professional® (Versions 7.0–8.5). Study staff visited each current residence and recorded the coordinates into a handheld GPS unit. The dietary history consisted of a detailed report of the participant's consumption of fish, including the species, frequency, and duration of consumption. Although emphasis was placed on fish obtained from the Hudson River, all fresh bodies of water in New York were assessed. The participants were asked to report their fish intake over four periods of time: the 1970s or earlier, 1980s, 1990s, and in the past year.

2.4. Serum PCB analysis

A 25 ml fasting sample of venous blood was collected in a red top evacuated glass tube without ethylenediamineetraacetic acid by nurses certified in standard phlebotomy techniques. The blood was centrifuged and the serum pipetted into a glass bottle with a Teflon-lined cap. The serum was then analyzed for PCBs and lipids, without knowledge of any study results, by the Wadsworth Center of the NYSDOH.

For the PCB analysis, the serum samples were extracted by adding a volume of methanol equivalent to the sample volume and 15 ml diethyl ether/hexane and shaking for 1 min. The supernatant was withdrawn from the aqueous layer into a Kuderna–Danish evaporator and the diethyl ether/hexane extraction was repeated twice. The extract was transferred to a deactivated Florisil column and target analytes were eluted with hexane. The first 40 ml of eluate was collected, concentrated to 0.2 ml, and analyzed by dual capillary gas chromatography with micro-electron capture detection. To determine initial and ongoing recovery and precision, newborn calf serum was spiked with a matrix solution at a final concentration of 2 ppb for each of 19 PCB congeners. The median matrix spike recovery was 81%, with a relative standard deviation of 20%. The serum samples were also spiked with a surrogate solution containing PCB-43, 246/246-hexabromobiphenyl, and heptachlor epoxide isomer A at 5 ppb to assess extraction efficiency. The median recovery for these surrogates was 83%, with a relative standard deviation of 14%.

Though 144 congeners were measured, only the 30 congeners that typically constitute over 95% of the total PCB residue in human serum were reported (Humphrey et al., 2000). The method detection limit was 0.02 ppb per congener; non-detectable concentrations were assigned a value of one-half the detection limit. The 30 congeners were summed to calculate total PCB. However, data are only presented for individual congeners if 50% or more of the samples had a detectable concentration. The data were recovery adjusted, using the results for the spiked surrogate compounds included in every analytical batch. Cholesterol and triglycerides were assayed enzymatically so that the PCB concentrations could be expressed on both a wet weight and lipid basis (Phillips et al., 1989). In addition, nine dioxin-like PCB congeners were measured in the serum of more than 90% of the study participants, and toxic equivalent quantities (TEQs) were calculated (Van den Berg et al., 1998).

2.5. Exposure to PCBs from Hudson River fish consumption

To simplify the dietary exposure assessment, we focused on fish consumed from a 25-mile stretch of the upper Hudson River that extended 12 miles above and 13 miles below Baker's Falls. Baker's Falls is a waterfall near the Hudson Falls GE facility. It was chosen as the demarcation point because fish sampled below this location have much higher PCB concentrations than those sampled above. The PCB concentrations in fish samples taken by the NYSDEC from locations above and below Baker's Falls separately were averaged by decade for each of the seven species most frequently consumed by study participants (brown bullhead, yellow perch, largemouth bass, smallmouth bass, pumpkinseed, rock bass, and walleye). These average total PCB concentrations were then multiplied by the yearly consumption rate and the number of years consumed for each of the four time periods and summed to estimate cumulative lifetime exposure to PCBs from the consumption of Hudson River fish.

2.6. Residential proximity to the Hudson River and local PCB sites

We used residential proximity to the Hudson River at the time of interview as an indicator of potential exposure to PCBs through contact with contaminated soil, sediments, water, or air for persons from the study area. The fact that these participants had lived at their current residence for a mean of 32 years minimized the possibility of misclassification due to change in residence. Distance was calculated from the geocoded addresses to the nearest point on the River. An 800 m cutpoint was used to categorize residences as being proximate to the River because it came closest to a median split. We also examined the potential impact of 19 PCB-contaminated hazardous waste sites in the study area identified by the NYSDEC as either Class 2, significant threat to public health or environment ($n = 15$), or Class 2a, needs further study ($n = 4$). In addition to proximity, we evaluated how often each residential address was downwind of one or more of these PCB sites. To assess wind direction, residences were first placed into 30° vectors stemming from each site. These vectors were then assigned a percentage of time that the wind blew in that direction over a 1-year period. The percentages were summed across sites to obtain an estimate of the relative frequency that each residence was downwind of at least one site.

2.7. Statistical analysis

Multiple linear regression analysis was used to test for association between the potential environmental exposures and serum total PCB concentrations after controlling for potential confounders. Potential confounders were first screened using bivariate analysis to evaluate 11 background variables (age, gender, education, height, weight, body mass index (BMI), marital status, cigarette smoking, alcohol consumption, and prescription drug use), some of which have been related to serum or plasma PCB levels in other studies (Rylander et al., 1997; Moysich et al., 2002). Variables significant in the bivariate analysis were then regressed on log-transformed serum total PCB concentration using stepwise procedures to add or delete the background variables one at a time. Study versus comparison area, Hudson River fish consumption, and residential proximity and wind direction were then added to the regression model to estimate their associations with serum total PCB concentrations after adjustment for all remaining background variables. Multiple regression analysis was also used to test for associations with serum PCB concentrations for congeners that had detectable levels of PCBs for 50% or more of the samples and were found in local fish or outdoor air samples. A similar analysis was conducted for TEQs based on the serum concentrations of the nine measured dioxin-like congeners. We also compared the percent of samples with detectable concentrations for six lightly chlorinated congeners that had detectable concentrations for less than 50% of the samples.

3. Results

3.1. Response rates

During the study period, 1125 candidates in the study area and 1228 in the comparison area were able to be located and contacted by telephone. Of these persons, 85% agreed to be screened for eligibility; 482 (50%) were eligible in the study area, 419 (41%) in the comparison area. The reasons for ineligibility were: (1) length of residence <25 years (20% for study area and 33% for comparison area); (2) occupational exposure to PCBs $\geqslant 1$ year (25% and 17%, respectively); and (3) medical exclusions including severe head injury and neurological diseases (17% and 16%, respectively). In addition, 11% of persons from the comparison area were ineligible because they had previously lived in the study area for 5 or more years. At recruitment, 99 persons of those eligible were lost to contact, deceased, or not recruited because the study ended. Among those who were eligible and invited to participate, the response rates were 38% in the study area and 41% in the comparison area. There were no differences in participation according to age or gender. However, participation rates were lower among persons with a high-school diploma or less compared to those with higher education (respectively 45% versus 55%, $p<0.05$). After the data collection was completed, 53 participants were excluded because they failed to have blood drawn, the laboratory was unable to analyze the serum for PCBs, or their interview indicated a reason for exclusion not previously reported. The final group for analysis included 253 participants, 133 in the study area and 120 in the comparison area. Fig. 1 shows the residential locations of the participants with a small degree of random error added to protect confidentiality.

3.2. Background characteristics

Table 1 summarizes the participant's background characteristics by study and comparison area. Reflecting the frequency matching, both groups were similar regarding their distributions by age and gender. They were also similar concerning most other background characteristics. Educational attainment, however, differed significantly with 65% of participants from the comparison area having more than a high-school education versus 50% from the study area ($p<0.05$). Ninety-seven percent of the participants were white and 99% were non-Hispanic (data not shown).

3.3. Hudson River fish consumption

Fifty-one participants (20%) reported eating at least one fish meal from the 25-mile stretch of the Hudson River that was the focus of the dietary exposure assessment. The duration of consumption ranged from 2 to 52 years, with a median of 13 years. When consumption was limited to the seven most commonly consumed species, 48 persons (19%) reported eating fish from this stretch of the River during the 1970s or earlier, 14 (8%) during the 1980s, and three (2%) during the 1990s. There were 248 participants (98%) who were aware of upper Hudson River bans and advisories.

Consumption of fish from this stretch of the Hudson River was more prevalent among persons from the study area, with 24% ever reporting eating such fish compared to only 13% of persons from Glens Falls. Rates of Hudson River fish consumption were also higher in the study area, especially in the 1970s or earlier. Persons in the study area reported consuming a mean of 13.5 Hudson River fish meals annually in the 1970s or earlier, compared to a mean of 1.6 meals for the comparison area ($p<0.05$). In addition, 95% of the reported consumption for persons from the comparison area was from relatively uncontaminated fish obtained above Bakers Falls, while 75% of the fish consumed by persons in the study area was from heavily contaminated fish caught below Bakers Falls.

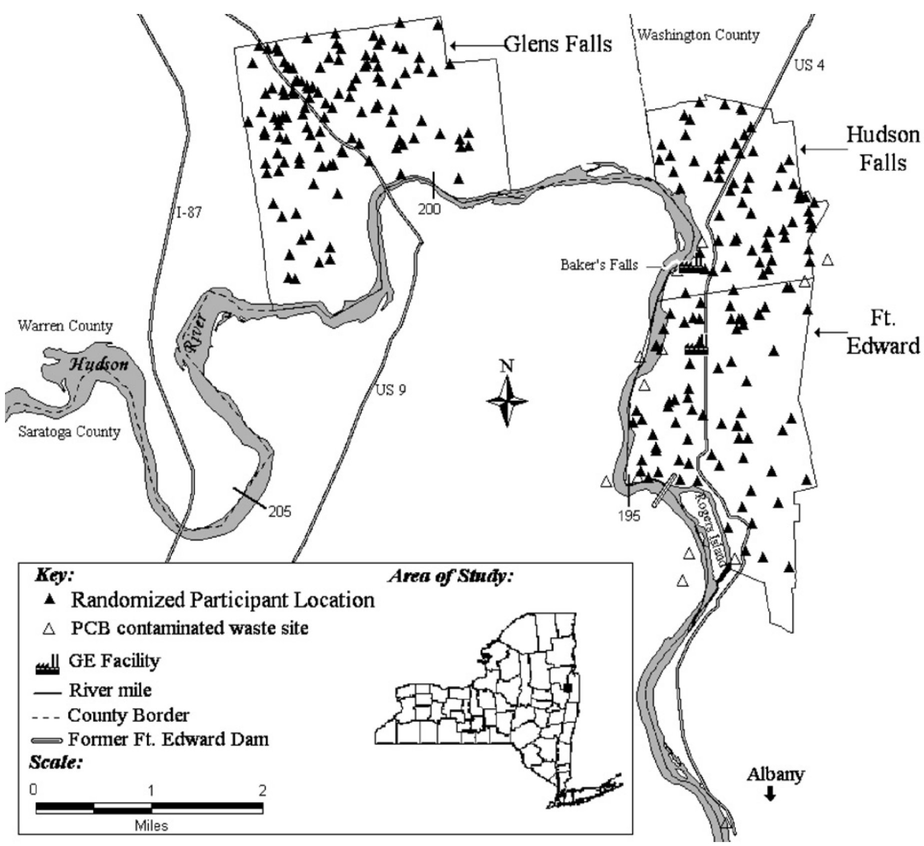

Fig. 1. Map of the Upper Hudson River: Fort Edward, Hudson Falls, and Glens Falls.

Table 1
Demographic characteristics of the participants by study and comparison area

Characteristic	Mean (SD) and range	
	Study area ($N=133$)	Comparison area ($N=120$)
Age (years)	64.1 (5.9), 55–74	63.8 (6.1), 55–74
Height (inches)	66.9 (3.8), 59–76	67.4 (4.2), 59–76
Weight (pounds)	186.7 (48.8), 95–469	182.9 (38.8), 93–350
Body Mass Index	29.3 (7.3), 18.5–71.3	28.2 (5.1), 16.7–47.5
Cigarette smoking (packs in last year)*	70.1 (159.5), 0–730	36.3 (109.9), 0–730
Alcohol consumption (drinks per week)	3.8 (6.5), 0–42	5.1 (6.7), 0–42
Length of current residence (years)	32.8 (11.1), 1–75	31.5 (11.4), 3–75
	Number (%)[a]	
Gender (male)	67 (50%)	60 (50%)
Education**		
Less than high-school diploma	11 (8.3%)	9 (7.5%)
High-school diploma	55 (41.4%)	33 (27.5%)
Some college	35 (26.3%)	30 (25.0%)
4-year college or more	32 (24.1%)	48 (40.0%)
Income		
<\$45,000	77 (58.8%)	57 (49.6%)
⩾\$45,000	54 (41.2%)	58 (50.4%)
Marital status		
Never married	4 (3.0%)	3 (2.5%)
Married/live-in partner	102 (76.7%)	93 (77.5%)
Divorced/separated	10 (7.5%)	13 (10.8%)
Widowed	17 (12.8%)	11 (9.2%)
Medication use (past 2 years)		
Diuretics	22 (16.5%)	24 (20.0%)
Antibiotics**	15 (11.3%)	26 (21.7%)
Acetaminophen	28 (21.1%)	27 (22.5%)
Hyperlipoproteinemia drugs*	46 (34.6%)	29 (24.2%)
Potassium supplements	34 (25.6%)	40 (33.3%)
Vitamin and mineral supplements	77 (57.9%)	67 (55.8%)
NSAIDS	90 (67.7%)	76 (63.3%)

NSAIDS = non-steroidal anti-inflammatory drugs.
*$p<0.10$ for study versus comparison area.
**$p<0.05$ for study versus comparison area.
[a]The total number of responses varies due to missing data.

3.4. PCB concentrations in serum

The mean total PCB concentration was 3.6 ppb (wet weight), with a standard deviation of 2.0 ppb. Thirty-nine participants (15%) had a total PCB level ⩾5.0 ppb and four participants (2%) had a level ⩾10 ppb. The median total PCB level was 3.2 ppb, with a maximum of 19.3 ppb. The six leading PCB congeners, based on the highest mean concentrations, were PCB-74, 118, 153, 138, 170, and 180. On average, these congeners accounted for approximately two-thirds of the total PCB in serum. Nine dioxin-like PCB congeners were measured in the serum of 232 participants. The mean TEQ concentration was 34.2 ppt (lipid basis), and the median was 14.9 ppt.

Age, BMI, and cigarette smoking were the only background variables associated with serum total PCB concentration in the multiple regression analysis. Specifically, log serum PCB concentrations (lipid basis) increased with age ($\beta = 0.021$, $p<0.001$) and BMI ($\beta = 0.010$, $p = 0.031$) and decreased with packs of cigarettes smoked in the past year ($\beta = 0.014$, $p = 0.105$). Consequently, these variables were included in the final regression models.

Table 2 displays the geometric means for serum PCB concentration (wet weight and lipid basis) by study and comparison area, adjusted for age, BMI, and smoking. Results are shown for total PCB and 12 congeners that had detectable levels for 50% or more of the samples and were found in local samples of fish or outdoor air. The concentrations for total PCB did not differ significantly between the two groups; only PCB-99 and 118 showed a difference at $p<0.10$, and both were higher in the comparison area. There was no significant difference between the areas in geometric mean TEQ concentration (data not shown).

The 48 persons who reported eating the seven species of Hudson River fish were divided into low and high groups according to their median estimated cumulative lifetime exposure to PCBs. Their geometric mean serum PCB concentrations (lipid basis) after adjustment for age, BMI, and cigarette smoking are given in Table 3, together with the results for the 197 persons who did not eat Hudson River fish. The group with the greatest cumulative lifetime exposure to PCBs from Hudson River fish had a geometric

Table 2
Adjusted[a] geometric mean serum PCB concentrations (ppb) by study and comparison area (wet-weight and lipid basis)

Congener	Wet weight		Lipid basis[b]	
	Study area ($N=133$)	Comparison area ($N=120$)	Study area ($N=128$)	Comparison area ($N=117$)
PCB-28	0.04	0.04	5.5	5.3
PCB-74	0.20	0.19	29.9	28.4
PCB-99	0.07	0.09	11.4	13.8*
PCB-105	0.03	0.04	5.2	5.9
PCB-118	0.15	0.18	22.6	27.4*
PCB-138	0.39	0.43	60.1	64.4
PCB-153	0.51	0.53	78.7	79.4
PCB-170	0.16	0.15	23.9	22.5
PCB-180	0.44	0.43	67.3	64.8
PCB-183	0.04	0.05	6.2	6.8
PCB-187	0.09	0.10	14.0	15.2
PCB-194	0.09	0.10	14.1	14.8
Total PCB	3.07	3.23	473.4	485.0

*$p<0.10$ for study versus comparison area.
[a]Adjusted for age, BMI, and cigarette smoking.
[b]Five persons from the study area and three persons from the comparison area were missing lipid determinations.

Table 3
Adjusted[a] geometric mean serum PCB concentrations (ppb—lipid basis) by cumulative lifetime exposure to PCBs from Hudson River fish consumption

Congener	No fish exposure ($N = 197$)	Low fish exposure ($N = 23$)	High fish exposure ($N = 25$)
PCB-28	5.4	5.4	5.7
PCB-74	29.5	25.9	29.8
PCB-99	12.5	12.6	12.4
PCB-105	5.5	5.4	5.7
PCB-118	25.0	24.9	23.2
PCB-138	60.9	63.2	70.8
PCB-153	77.1	82.6	92.4
PCB-170	22.5	24.0	29.6**
PCB-180	63.3	67.7	90.9**
PCB-183	6.5	6.4	6.5
PCB-187	14.4	14.9	15.2
PCB-194	14.2	14.9	15.9
Total PCB	469.9	481.9	553.6*

*$p<0.10$ for high versus no fish consumption.
**$p<0.01$ for high versus no fish consumption.
[a]Adjusted for age, BMI, and cigarette smoking.

Table 4
Adjusted[a] geometric mean serum PCB concentrations (ppb—lipid basis) by distance to the Hudson River, with comparison area[b]

Congener	$\leqslant$800 m ($N = 59$)	>800 m ($N = 69$)	Comparison area ($N = 117$)
PCB-28	5.8	5.3	5.3
PCB-74	29.9	29.7	28.5
PCB-99	11.8	10.9	13.9
PCB-118	23.5	21.9	27.5
PCB-153	75.8	79.1	80.7
PCB-105	5.0	5.3	6.0
PCB-138	56.0	61.7	65.6
PCB-187	14.7	13.2	15.3
PCB-183	6.2	6.1	6.9
PCB-180	64.3	66.3	66.9
PCB-170	23.0	23.8	23.0
PCB-194	14.1	13.9	15.0
Total PCB	461.4	470.1	493.3

[a]Adjusted for age, BMI, cigarette smoking, and Hudson River fish consumption.
[b]$p>0.10$ for overall F-test and for pairwise contrast of $\leqslant$800 m versus comparison area for each congener and for total PCB.

Table 5
Adjusted[a] geometric mean serum PCB concentrations (ppb—lipid basis), by wind direction and distance to PCB contaminated waste sites, with comparison area[b,c]

Congener	Downwind more often, <800 m ($N = 36$)	Downwind more often, >800 m ($N = 35$)	Downwind less often ($N = 57$)	Comparison area ($N = 117$)
PCB-28	6.2	5.3	5.2	5.3
PCB-74	29.4	33.9	27.6	28.6
PCB-99	11.3	11.9	10.9	13.9
PCB-118	21.9	26.1	21.0	27.6
PCB-153	76.2	78.8	77.8	80.6
PCB-105	4.7	5.6	5.3	5.9
PCB-138	56.1	60.0	60.7	65.3
PCB-187	14.0	12.9	14.4	15.3
PCB-183	5.6	5.7	6.9	6.8
PCB-180	62.7	61.4	70.4	66.6
PCB-170	23.4	21.8	24.7	23.0
PCB-194	14.1	13.0	14.6	15.0
Total PCB	448.2	465.7	479.8	492.3

[a]Adjusted for age, BMI, cigarette smoking, and Hudson River fish consumption.
[b]PCB contaminated waste sites defined as NYSDEC Class 2, significant threat to public health or environment ($n = 15$), or 2a, needs further study ($n = 4$).
[c]$p>0.10$ for overall F-test and for pairwise contrast of downwind more often, <800 m versus comparison area for each congener and for total PCB.

mean of 553.6 ppb (lipid basis), compared with 469.9 ppb (lipid basis) for those who never ate Hudson River fish ($p<0.10$). The high-exposure group also tended to have higher serum concentrations for many congeners, with significant differences for PCB-170 and 180. In contrast, few differences were evident for persons with low cumulative exposure to PCBs from Hudson River fish consumption relative to the unexposed. Some participants also reported eating fish from Lakes Ontario and Champlain, but controlling for the consumption of fish from these lakes did not materially change the results in Table 3 (data not shown). There were also no significant differences in mean TEQ concentration according to Hudson River fish consumption (data not shown).

Regarding residential PCB exposure, Table 4 displays geometric mean serum PCB concentrations (lipid basis) by proximity to the Hudson River for persons from the study area, with persons from the comparison area included as the referent. The results are adjusted for Hudson River fish consumption, age, BMI, and smoking. There were no significant differences according to residence within 800 m of the River, either for total serum or individual congeners. The data by wind direction and residential proximity to PCB sites in the study area are shown in Table 5. Once again, we did not observe significant differences in adjusted geometric mean serum concentrations of total or congener-specific PCB. There were also no differences by proximity or wind direction in geometric mean TEQ concentrations or in the percentage of samples with detectable concentrations for the six lightly chlorinated congeners not displayed in Tables 4 and 5 (data not shown). The results for serum PCB concentrations expressed on a wet weight basis were similar to those presented in Tables 3–5 (data not shown).

4. Discussion

The finding that Hudson River fish consumption was most prevalent in the 1970s or earlier and then declined dramatically is most likely the result of the fishing ban and health advisories that were imposed on the Hudson River in 1976. In fact, 98% of the study participants stated that they were aware of the ban and advisories. This result suggests that the ban and advisories have been effective in reducing consumption, at least among older residents. They also may indicate that awareness has increased over time, since in earlier surveys only 55% (1991–92) and 75% (1996) of interviewees along the upper Hudson River reported knowledge of the ban and health advisories (Barclay, 1993; ATSDR, 2000a). However, these earlier surveys may not be comparable to the current investigation. The earlier surveys interviewed anglers while they fished the River, a group that may be more knowledgeable than the general population about the ban and advisories. On the other hand, they also included minorities and low-income persons, groups that are generally less aware (Imm et al., 2005).

Serum total PCB concentrations increased significantly with age and BMI. Other studies have also found that age is an important correlate (Fitzgerald et al., 2004), probably reflecting the greater cumulative exposure of older persons to PCBs and the long biological half-lives of these compounds. The findings of other studies in regard to BMI are mixed, with some investigations also reporting positive correlations (Falk et al., 1999) whereas others have found inverse associations (Wolff et al., 2000) or no association (Hanrahan et al., 1999). BMI is a crude indicator of adiposity, and its relationship to circulating levels of PCBs and other organochlorine compounds is complex, depending on the timing of exposure, pharmacokinetics, age, and serum lipids (Wolff et al., 2005). There was also a tendency for serum total PCB concentration to decrease with smoking in the past year. Lifetime history of smoking was not associated with serum PCB concentrations among New York City women (Wolff et al., 2005), but a recent investigation of women and infants living near the PCB-contaminated New Bedford, MA harbor found that maternal smoking during pregnancy was associated with lower fetal cord serum PCB concentrations (Choi et al., 2006). Decreases in PCB body burden may reflect the impact of cytochrome *P*-450 enzymes such as CYP1A1 and CYP1A2, since they are induced by smoking (Kalow and Tang, 1991) and are involved in the metabolism of PCBs (Safe, 1994).

After adjusting for age, BMI, and cigarette smoking, there was no significant difference in geometric mean total serum PCB concentration between residents of the study and comparison areas. There was also no statistically significant difference in their adjusted geometric means for individual congeners. The three leading congeners in the serum of residents from both areas were PCB-138, 153, and 180. These three congeners are also present in the greatest concentrations in the serum of the general US population (CDC, 2005), and they typically are the most dominant congeners in human tissue worldwide (Hansen, 1998).

Given the similarity in total and congener-specific serum PCB concentrations between the study and comparison areas, the results do not support the hypothesis that current body burdens of PCBs among older, long-term residents of Fort Edward or Hudson Falls are greater than Glens Falls residents. Caution must be exercised in comparing serum PCB levels across studies given differences in analytical methods, time periods, and populations (Longnecker et al., 2003). In general, however, the serum total PCB levels of both the study and comparison populations are similar to those of other populations with no unusual exposure to PCBs (ATSDR, 2000b). In one of the few studies that focused specifically on older men and women, Schantz et al. (2001) reported median total PCB concentrations of about 6.0 ppb for Michigan residents aged 60–69 who consumed little or no Great Lakes fish, compared to 3.2 ppb for each gender in the current investigation.

Despite the low current consumption rate, the findings are generally consistent with the hypothesis that body burdens are greater among relatively more frequent lifetime consumers of Hudson River fish. These results are consistent with other studies indicating that the ingestion of contaminated fish is a major source of exposure to PCBs (Bloom et al., 2005; Fitzgerald et al., 2004). When relatively heavy consumers were compared to non-consumers, statistically significant differences in adjusted geometric mean serum concentrations were observed for PCB-170 and 180, both found in Hudson River fish. Consistent with their degree of chlorination and substitution pattern, these congeners resist metabolism (Matthews and Dedrick, 1984), and would be expected to have biological half-lives of 10–20 years (Wolff and Schecter, 1992). Consequently, their elevated serum concentrations may reflect the continued impact on body burden of Hudson River fish consumption decades earlier.

In contrast to the findings for Hudson River fish consumption, the results do not support the hypothesis that persons who live near the River or one of 19 PCB-contaminated waste sites in the study area have elevated serum PCB concentrations. The lack of significant differences by proximity and wind direction is consistent with the results of other studies suggesting persons living near potential point sources such as hazardous waste sites do not have elevated PCB body burdens independent of other exposures such as diet and occupation (Orloff et al., 2003; Choi et al., 2006).

Several German studies (Gabrio et al., 2000; Liebl et al., 2004; Schwenk et al., 2002) have found increased mean serum concentrations for some lower chlorinated PCB congeners among teachers and pupils in schools with indoor air contaminated with PCBs from the use of sealants. Despite the very high concentrations of total PCBs in indoor air (from 690 to 20,800 ng/m^3), all three investigations concluded that the excess body burden was very small compared to that attributable to dietary intake. In one study, the authors concluded that differences were not discernible below indoor air levels of 1000 ng/m^3 (Gabrio et al., 2000). The lack of an observed difference in serum PCB concentrations according to outdoor air exposure for this and other studies may be due in part to the fact that PCB levels in outdoor air are much lower than this 1000 ng/m^3 threshold, even in the vicinity of PCB-containing waste sites (Vorhees et al., 1997).

4.1. Strengths and limitations

The restriction of the study population to older, long-term residents strengthened this study as it maximizes the potential for exposure since everyone from the study area lived there when the capacitor facilities were using PCBs. The use of congener-specific serum PCB measurements provided an accurate and objective measure of absorbed dose adjusted for lipids. A concurrent comparison group matched on age and gender from another community upriver from the pollution is also a strength.

Although the short-term test–retest reliability of fish consumption data collected with food frequency methods has been shown to be acceptable (Li et al., 2005), recall accuracy is a possible limitation, especially as it pertains to consumption 10 or more years ago (Rylander et al., 1998). The positive correlation between fish consumption and serum PCB levels, including two persistent congeners found in Hudson River fish, however, helps to validate the dietary histories. In addition, it is possible that some participants who ate Hudson River fish in the past may have denied more recent consumption since it continues to be illegal to possess fish from Hudson Falls to the Troy Dam. If that were the case, elevated levels of more lightly chlorinated congeners such as PCB-28 and 74 would be expected since they reflect more recent impact and are found in Hudson River fish. No such elevations were found, suggesting that the low reported levels of current consumption are likely accurate.

We used residential proximity as a surrogate for exposure rather than direct air, soil, sediment, or soil PCB measurements. Although previous studies indicate that air levels are inversely related to distance from the Hudson River (Buckley and Tofflemire, 1983), this approach is ecologic and may not accurately measure exposure. Both indoor and outdoor air samples were collected from the homes of participants as part of the project and are currently being analyzed for PCBs. When the results are available, they will be correlated with the serum PCB data to identify any associations. It is also possible that the lack of statistically significant differences in geometric mean serum PCB concentrations reflects statistical power, although with a sample size of 253 persons and an alpha error of 5% (one-sided) we had 80% power to detect differences on a lipid basis between the study and comparison areas as small as 16% for serum total PCB, 20% for heavily chlorinated congeners such as PCB 180, and 26% for more lightly chlorinated congeners such as PCB 74.

Finally, it is important to note that the results of this study pertain only to the years 2000–2002. It is possible that differences in serum PCB concentrations between the study and comparison areas existed in the past, when levels of PCBs in the local environment were higher. This is particularly relevant for the lightly chlorinated congeners, since they are more easily metabolized and excreted (Hansen, 1999). It is also likely that differences in serum PCB concentrations by Hudson River fish consumption were greater in the past than they are currently, since most of the consumption occurred in the 1970s or earlier.

5. Conclusion

The results suggest that, although some older long-term residents of Fort Edward and Hudson Falls ate fish from the upper Hudson River in the past, their current rates of consumption are low. The ban and advisories issued by state environmental and health agencies appear to be responsible for this change. After adjustment for age, BMI, and smoking, geometric mean concentrations of PCBs in the serum of Fort Edward and Hudson Falls residents did not differ significantly from those for Glens Falls residents. In general, the serum PCB levels for both groups were similar to those reported in other studies of persons with no unusual PCB exposures. Despite low current consumption rates, serum PCB levels tended to increase with estimated cumulative lifetime exposure to PCBs from Hudson River fish consumption, attesting to the long biological half life of congeners such as PCB-170 and 180. No significant differences were detected in geometric mean serum PCB concentrations according to residential proximity or wind direction relative to local point sources.

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