Baseline Concentrations of Polychlorinated Biphenyls and DDT in Lake Michigan Fish, 1971 [1]

Gilman D. Veith [2]

ABSTRACT

Responding to the recommendations of the Lake Michigan Interstate Pesticide Committee, the author aimed to establish baseline data on polychlorinated biphenyls (PCB's) and DDT in Lake Michigan fish in 1971. Because the past 2 years had witnessed unprecedented legislative action to protect food resources and other aquatic species near the top of the food chain from persistent hazardous chemicals, the author also attempted to gauge the impact of cooperative legislative action on the quality of large lakes.

Thirteen species of fish taken from 14 regions of Lake Michigan in the fall of 1971 were analyzed for PCB's and DDT analogs. Mean wet-weight concentrations of PCB's similar to Aroclor 1254 ranged from 2.7 ppm in rainbow smelt to 15 ppm in lake trout. Most trout and salmon longer than 12 inches contained PCB's at concentrations greater than the tolerance level of 5 ppm established by the Food and Drug Administration, U.S. Department of Health, Education, and Welfare. Mean concentrations of total DDT ranged from less than 1 ppm in suckers to approximately 16 ppm in large lake trout. The presence of the major chlorinated hydrocarbons was confirmed by gas-liquid chromatography/mass spectrometry; additional PCB confirmations were obtained through perchlorination. The most abundant PCB's were tetra-, penta-, hexa-, and heptachlorobiphenyls which are similar to commercially prepared Aroclor 1254; lesser chlorinated PCB's were present in fish from nearshore waters.

[1] Supported by U.S. Environmental Protection Agency Project 16020 PRH, University Engineering Experiment Station, and University of Wisconsin Department of Civil and Environmental Engineering, Madison, Wis.

[2] National Water Quality Laboratory, U.S. Environmental Protection Agency, 6201 Congdon Boulevard, Duluth, Minn. 55804.

Introduction

This paper identifies and quantifies the most abundant organochlorine compounds, particularly polychlorinated biphenyls (PCB's) and DDT, in Lake Michigan fish in 1971. By establishing data on PCB's and DDT in Lake Michigan fish as recommended by the Lake Michigan Interstate Pesticide Committee, the author of the present study aimed to develop a 1971 baseline to predict trends of these chemicals in the lake. Lake Michigan contains much higher concentrations of potentially hazardous and persistent organic chemicals than the other Great Lakes, in part because of their widespread usage in the watershed and their disproportionally brief flushing period and low biomass density. Previous studies have shown that fish from Lake Michigan approach the action levels for dieldrin set by the Food and Drug Administration (FDA), U.S. Department of Health, Education, and Welfare (*1*); a major percentage of Lake Michigan fish exceeded the 5 ppm action level for DDT in 1969 (*2*). Similarly, Veith (*3*) has shown that PCB concentrations similar to Aroclor 1254 were greater than 15 ppm or three times the FDA action level in large fish captured from Lake Michigan in 1969.

Despite the comparatively high levels of DDT, dieldrin, and PCB's in Lake Michigan, there is no unequivocal evidence that they are endangering aquatic life. Concentrations of these chemicals appear to be below 10 parts per trillion (ppt) in the pelagic water and less than 100 ppt in nearshore waters. However, considerable indirect evidence suggests that the buildup of organochlorine compounds may threaten biological resources of the lake. Other reports have reviewed the chronic toxicity of pesticides and PCB's (*4-7*).

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States surrounding Lake Michigan have made a major effort to restock the lake with brown, lake, and rainbow trout and coho and chinook salmon. Between 1963 and 1970, over 600,000 rainbow trout were released by Wisconsin alone (*8,9*). However, Reinert (*2*) previously noted that DDT and dieldrin levels in eggs of these fish are similar to concentrations which inhibited reproduction in the studies of Burdick et al. (*10*) and Macek (*11*). Johansson et al. (*12*) have shown that 15 ppm PCB's (lipid basis) in salmon eggs produced mortality in 50 percent of the samples tested. Death can be expected in all eggs when the PCB lipid content reaches 25 ppm.

Although continued stocking of fish may maintain a food resource, many fish contain residue body burdens which make them unfit for consumption. The effect of these fish on mink production in the North Central States has been studied in detail: before DDT and dieldrin concentrations in these fish had been well documented, Hartsough (*13*) indicated that the fish were suspected to inhibit mink reproduction; Aulerich et al. (*14*) clearly demonstrated that the fish had been the cause of the minks' reproductive failure; and Aulerich and Ringer (*15*) reported that DDT and DDD did not have significant adverse effects on mink. Furthermore, dieldrin was lethal to mink at 2.5 ppm in the food when fed for extended periods, but did not appear to affect reproduction at twice this concentration during the gestation period. Aulerich et al. concluded that feeding coho salmon to mink did not cause reproduction problems, but that the disorder is associated with other species of fish and ". . . appears to be dependent upon the species of fish and its environment" (*16*). Finally, after the earlier reports that PCB's were present in Lake Michigan fish, Ringer et al. (*17*) demonstrated that 10 ppm Aroclor 1254 in coho salmon produced 71 percent mortality in mink and that a mixture of 10 ppm PCB's and 0.5 ppm dieldrin in coho feed produced 100 percent mortality. No kits were born alive when the diet contained 5 ppm or more Aroclor 1254 alone. This clearly indicates that biological resources of Lake Michigan may seriously endanger other species even though concentrations of toxicants are not severe enough to produce readily discernible effects within the aquatic communities.

Equally important is the coincidence of high chlorinated hydrocarbon levels in herring gull and other bird populations coupled with reproductive failures and subsequent population decline (*18*). Anderson (*19*) found that the eggs of the Great Lakes herring gull contained the highest chlorinated hydrocarbon levels ever reported for that species. He also found that the degree of eggshell thinning in the Lake Michigan gull, whose population declined dramatically in the early 1960's, varied from 9 percent in 1953-56 to 18 percent in 1965. In comparison, eggs of gulls on Lake Huron and Lake Superior have exhibited shell thinning of 7 percent and 8 percent, respectively, and those from gulls on the East Coast have remained essentially unchanged. Double-crested cormorants from Wisconsin had eggshells 20 percent thinner than those of gulls, and their eggs had the highest DDE concentrations of any cormorant eggs sampled from interior North America. Golden eagles, which feed primarily on mammals, do not show eggshell thinning as dramatic as that of bald eagles, which feed on fish (*19*).

Lake Michigan is the only Great Lakes watershed where major persistent chemicals have been curtailed. Although use of chlorinated pesticides in agriculture was probably diminishing in the late 1960's, the Lake Michigan Enforcement Conference recommended regulatory actions on many uses in 1968. This recommendation led to restrictions on DDT including its sale in Illinois, Michigan, and Wisconsin. A more detailed summary is presented by Lueschow (*20*). Monsanto Company, the sole producer of PCB's in the United States, restricted PCB sales in 1970; by April 1971 they were sold only to close-system users.

To measure the impact of the unprecedented cooperative legislative action regarding these chemicals, and to establish baseline data, the Lake Michigan Interstate Pesticide Committee recommended that this study be funded.

Sampling Procedures

Fish were collected in September and October 1971 with gill nets and pond nets from the four regions of Lake Michigan outlined in Figure 1. Whole fish were stored frozen (−20° C) in aluminum foil or polyethylene bags for 60 days or less and homogenized while frozen by repeatedly passing them through a meat grinder. All metal surfaces were rinsed with acetone, polyethylene bags were examined for interferences, and the grinder bearing and seal were checked periodically to assure that the sample was not contaminated during storage or preparation.

Analytical Procedures

REAGENTS

Sodium sulfate (Fisher Scientific Co.) was washed with three volumes of 1:1 hexane-acetone and dried at 130° C. To prevent further contamination from cap liners or containers, the Na_2SO_4 was stored in large glass bottles with aluminum foil liners in the cap.

The florisil (Kensington Chemical, Fisher Scientific Co.) was extracted in an all-glass Soxhlet extractor for 24 hours with the azeotrope of hexane and acetone to remove traces of organic impurities. The solvent was evaporated from the florisil at 100° C, and the solid was heated at 650° C for 2.5 hours for activation. If not used immediately after heating, the florisil was heated to 105° C before use.

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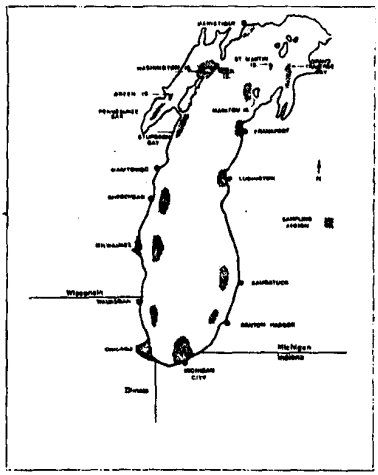


FIGURE 1. *Sampling regions for collecting fish, Lake Michigan—1971*

Other analytical components included:

Silicic acid:	Mallinckrodt Chemical, AR grade, Ramsey and Patterson. Used directly from reagent bottle.
Hexane:	Skelly B. Redistilled in glass from Dri-Sodium, Fisher Scientific Co.
Acetone:	Fisher Scientific Co., MCB. Redistilled in glass from Dri-Sodium, Fisher Scientific Co.
Ethyl ether and methylene chloride:	Mallinckrodt Chemical. Pesticide-quality solvents. Used directly from reagent bottle after periodic checks showed no interferences.
Glass wool:	Soaked in acetone, rinsed with 1:1 acetone:hexane mixture.
Glassware:	Washed thoroughly with hot detergent; rinsed once with hot water, twice with distilled water, again with 1:1 mixture of redistilled acetone:hexane.

PREPARATION OF SAMPLES

Procedures to extract and remove the bulk of the lipids have been described previously (*21*). Because of the high relative concentration of *p,p'*-DDE in Lake Michigan fish, DDE was quantitated directly by diluting 10 percent of the nonpolar florisil eluate to the appropriate volume for gas-liquid chromatographic (GLC) analysis. PCB's were separated from TDE and DDT isomers with a modified Armour and Burke procedure which omitted Celite 545 (*22*).

Quantitative gas chromatographic analyses were conducted on an Aerograph 1745-20 gas chromatograph equipped with dual concentric-tube electron-capture detectors (3H, 250 mc). Columns were 2.0-m-by-1.8-mm-ID glass coils packed with 3 percent OV-101 on 120/140-mesh Gas-Chrom Q. The carrier gas, purified N_2, was maintained at 20 ml/min; the injector, column, and detector temperatures were 240°, 180°, and 220° C, respectively. Chromatograms were recorded on a Varian model A-25 dual pen recorder.

Previous work (*21*) showed that fish from Lake Michigan contain mixtures of PCB's that closely resemble the Aroclor 1254 produced by Monsanto Company, although PCB's both heavier and lighter than those most abundant in Aroclor 1254 were also present. The fish extracts contain predominantly those PCB's which elute at 70, 84, a doublet of 98 and 104, 125, 146, and 176; peak height of *p,p'*-DDE is represented here as 100 (Fig. 2). The presence of DDE precluded the use of the 98 and 104 PCB components in the quantitation, and PCB's based on Aroclor 1254 were determined by summing the heights of the 70, 84, 125, 146, and 174 PCB components when peak height of DDE is 100. This method also decreased the effect of minor compositional variations on the analytical result.

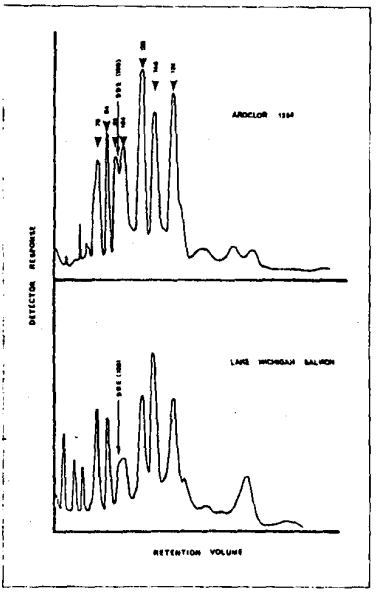


FIGURE 2. *Chromatograms of PCB mixtures in Aroclor 1254 and fish from Lake Michigan*

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Recovery of PCB's from fish tissue averaged 85.1 ± 4.3 percent, whereas recovery of DDE was greater than 90 percent. The precision of the method outlined above is summarized in Table 1, which lists means and standard deviations of the analyses of six replicates of several fish species for PCB's, DDT, and lipids. The standard deviation for PCB analyses ranged from 5 percent in smaller fish to 14 percent in large coho salmon. The decrease in precision in analyses of large coho resulted from the difficulty of homogenizing larger fish. Precision was poorest in DDT analyses, where the standard deviation ranged from 8 to 23 percent with a mean of approximately 14 percent. This reduced precision results from losses during silicic acid chromatography which is used to quantitate the TDE and DDT isomers. The precision of DDE analyses was greater than those for DDT analyses, which was anticipated because of the fewer manipulations of the extracts. The standard deviation ranged from 7 to 18 percent, but the average deviation was approximately 10 percent. Because of the relatively simple procedure, lipid analyses were most precise, exhibiting standard deviations from 5 to 7 percent.

TABLE 1. *Precision of chlorinated hydrocarbon determinations for PCB's, DDE, DDT, and lipids in selected fish, Lake Michigan—1971*

Species	No. Replicates	Aroclor 1254	*p,p'*-DDE	*p,p'*-DDT	Lipid, %
Coho salmon (23 in.)	6	15.2±2.2	7.5±0.6	3.2±0.6	4.2±0.2
Coho salmon (27 in.)	6	13.1±1.3	5.5±0.4	1.8±0.4	10.0±0.6
Whitefish (13 in.)	6	4.1±0.2	0.35±0.04	0.56±0.04	16.2±0.9
Bloater (10 in.)	6	5.7±0.4	3.4±0.3	2.2±0.3	18.2±1.3
Alewife (8 in., composite)	6	4.0±0.2	1.1±0.2	1.0±0.2	5.7±0.3

NOTE. In columns 3-6, first number represents mean, second represents standard deviation.
Residues are ppm wet weight.

The determinable limit for PCB analysis was approximately 0.1 ppm; limits for *p,p'*-DDT, *o,p'*-DDT, *p,p'*-TDE, and *p,p'*-DDE were approximately 0.05 ppm.

CONFIRMATION OF MAJOR COMPONENTS

Major components of Lake Michigan fish extracts were characterized for a limited number of composite samples by standard gas-liquid chromatography/mass spectrometry techniques. In addition, the presence of PCB's in samples from each collection area was confirmed by perchlorination of PCB's to decachlorobiphenyl and subsequent analysis of the product by GLC (*23*). Aliquots of the hexane fraction of silicic acid columns were evaporated to dryness in a 5-ml vial fitted with a teflon-lined screw cap. Antimony pentachloride (0.2 ml) was added to the residue, and the vial was sealed and held at 180° C for 6 hours. Approximately 1 ml 6N HCl was added to the products to remove the $SbCl_5$, and the solution was extracted with five 1-ml hexane portions. The hexane was passed through a disposable pipette containing anhydrous Na_2SO_4 to remove traces of the aqueous solution. The sample was collected in a graduated centrifuge tube and diluted to the proper volume for GLC analysis. This technique also provided semiquantitative information for PCB's to supplement direct GLC analysis of the extracts. For those samples which contained PCB's similar to Aroclor 1254, estimates of total PCB's by perchlorination were within 15 percent of direct GLC analysis.

Results and Discussion

Approximately 850 fish were analyzed for PCB mixtures most closely resembling Aroclor 1254; a summary is presented in Table 2. Mean concentrations ranged from 2.7 ppm in smelt to 15.5 ppm in lake trout. Larger fish, such as brown, lake, and rainbow trout and chinook and coho salmon, contained PCB's at mean concentrations two to three times the 5 ppm action level established by FDA (*1*). Mean PCB concentrations in redhorse suckers, smelt, and whitefish were considerably less than 5 ppm. Mean concentrations in the alewife, carp, chub, and yellow perch were approximately 5 ppm; the range was 4.2-6.0 ppm. As expected, PCB levels increased with the percentage of fat and size of fish.

In Lake Michigan fish the mean concentration of total DDT, the sum of *p,p'*-DDT, *o,p'*-DDT, *p,p'*-TDE, and *p,p'*-DDE, ranged from 0.9 ppm in carp to 7.1 ppm in lake trout (Table 2). As with PCB's, fish with higher lipid concentrations contained greater concentrations of DDT.

The ratio of PCB's to total DDT ranged from 1.3 in redhorse suckers caught primarily in the northern waters to 7.6 in carp. The ratio of PCB's to DDT in the majority of the fish was between 1.7 and 2.8, and only in the carp, redhorse, yellow perch, and white sucker did the ratios fall outside this range. This ratio may become important in future studies to determine the rates at which the chemicals are eliminated from the Lake Michigan system.

Mean ratios of *o,p'*-DDT to *p,p'*-DDT ranged from 0.1 to 0.3; this ratio in the majority of the fish was 0.2. Since technical DDT generally contains about 30 percent of the *o,p'*-DDT isomer (ratio, 0.4), data from Lake Michigan fish suggest that degradation, other removal mechanisms, or both in the lake are slightly greater for the *o,p'* isomer than for the *p,p'* isomer. More than 80 percent of the total DDT residue is accounted for by *p,p'*-DDE and *p,p'*-DDT.

Not only did PCB concentrations vary considerably among the 13 species captured, but the range of PCB concentrations in a single lake species was generally

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greater than 100 percent. The concentration range in red suckers was less, but all were captured in the same region of the lake. Although some variation in concentrations is expected because of the normal analytical error, the much larger ranges in Table 2 are undoubtedly due to other factors that limit usefulness of the mean concentrations presented. Previous research has shown that the lipid content, size of fish, season of capture, and concentration in the water may affect considerably the observed concentration of chlorinated hydrocarbons in tissue (*2*).

CHLOROBIPHENYLS

Regional variation in PCB concentrations and variations due to lipid content for each species are shown in Table 3. The wet-weight concentration of PCB's in ale-

TABLE 2. *Major chlorocarbons in fish, Lake Michigan—1971*

Species[1]	No. Fish Analyzed	Mean Fish Weight, g	Mean Lipid, %	Mean PCB's	Mean DDE	Mean ΣDDT	Mean PCB/ ΣDDT	Mean DDE/ ΣDDT	Mean o,p'-DDT/ p,p'-DDT
Alewife	83	100	6.5[3.9]	4.6[2.1]	1.7[0.8]	2.2[1.1]	2.4	0.8	0.2
Bloater	287	249	10.0[5.9]	6.0[2.2]	2.5[1.1]	3.8[2.8]	2.2	0.7	0.2
Brown trout	17	3,650	15.5[4.1]	7.3[2.8]	2.7[1.0]	4.2[1.6]	1.8	0.6	0.1
Carp	42	2,160	10.0[7.0]	4.2[3.6]	0.7[0.9]	0.9[1.2]	7.6	0.8	0.3
Chinook salmon	21	3,100	5.0[3.9]	11.4[4.0]	5.2[1.5]	6.8[2.5]	1.7	0.8	0.2
Coho salmon	56	2,720	6.5[2.1]	11.5[5.7]	4.8[2.3]	6.3[2.8]	2.1	0.7	0.2
Lake trout	134	1,620	16.6[4.3]	15.5[3.3]	5.0[2.8]	7.1[3.7]	2.5	0.7	0.2
Yellow perch	44	148	6.1[1.7]	3.8[3.5]	1.0[0.6]	1.6[1.1]	4.8	0.9	0.1
Rainbow trout	11	4,190	18.4[3.3]	9.3[4.1]	3.4[1.3]	4.2[1.8]	2.3	0.8	0.2
Redhorse sucker	16	902	8.6[1.2]	3.0[0.7]	1.6[0.5]	2.6[0.7]	1.3	0.6	0.2
Smelt	38	51	5.8[1.8]	2.7[1.3]	0.8[0.4]	1.2[0.6]	2.6	0.7	0.1
White sucker	51	1,130	5.9[2.8]	3.9[3.6]	1.0[0.5]	1.6[1.2]	3.4	0.7	0.1
Whitefish	43	1,170	17.6[4.4]	3.0[1.9]	0.8[0.3]	1.4[0.6]	2.8	0.7	0.2

NOTE: Expressions in brackets represent standard deviations.
Residues are ppm wet weight.
[1] Scientific names appear in Table 3.

TABLE 3. *Mean concentrations of PCB's and DDT in fish, Lake Michigan—1971*

Location	Capture Date	No. Fish Analyzed	PCB's	Percentage Fish Above 5 ppm PCB's	PCB's, Lipid Weight	p,p'-DDE	p,p'-TDE	p,p'-DDT	o,p'-DDT	Total DDT	Percentage Fish Above 5 ppm DDT
Alewife (*Alosa pseudoharengus*)											
Michigan City	10/15	10	4.4[2.0]	40	164	1.4	0.19	0.5	0.08	2.2	10
Benton Harbor	9/2	10	4.8[1.1]	40	60	1.8	0.23	0.5	0.08	2.7	0
Waukegan	8/23	2	2.5[0.1]	0	47	1.0	0.18	0.5	0.07	1.6	0
Saugatuck	4/11	12	5.3[3.2]	41	51	1.8	0.22	0.8	0.10	2.7	11
Sheboygan	10/15	4	5.5[1.4]	50	79	2.2	0.20	0.7	0.07	3.2	0
Ludington	7/3	16	4.4[1.4]	18	207	ND	ND	ND	ND	ND	ND
Frankfort	10/5	10	3.7[1.2]	20	62	1.3	0.16	0.4	0.06	1.9	0
Manitou Island	9/10	3	3.8[2.2]	33	51	3.2	0.33	1.3	0.16	5.0	30
Rock Island	9/11	3	8.9[12.0]	66	182	1.1	0.11	0.3	0.04	1.5	0
St. Martin Island	9/11	6	3.5[1.3]	16	82	1.0	0.14	0.3	0.05	1.5	0
Brown trout (*Salmo trutta*)											
Michigan City	10/15	1	11.9[0.0]	100	51	3.7	0.70	1.7	0.22	6.4	100
Sheboygan	7/13	5	7.9[3.0]	100	42	2.6	0.46	1.2	0.18	4.4	25
Gills Rock	9/16	10	6.7[2.5]	70	54	2.8	0.48	1.0	0.14	4.4	40
Carp (*Cyprinus carpio*)											
Michigan City	11/29	2	11.0[0.2]	100	72	3.3	0.81	0.3	0.14	4.6	50
Saugatuck	10/15	15	4.6[4.8]	26	71	0.6	0.20	0.1	0.02	0.9	0
Sheboygan	7/23	11	1.7[0.8]	0	30	0.2	0.07	0.0	0.01	0.3	0
Pensaukee Bar	11/1	9	4.2[1.4]	33	30	0.8	0.19	0.0	0.01	1.0	0
Manitou Island	9/16	5	5.8[0.8]	80	30	ND	ND	ND	ND	ND	ND
Bloater (*Coregonus hoyi*)											
Benton Harbor	9/2	10	5.0[1.2]	60	24	2.5	0.31	1.3	0.19	4.3	30
Saugatuck	6/16	18	8.1[1.9]	88	46	1.9	0.47	1.8	0.19	4.3	37
Saugatuck	6/18	24	7.8[2.2]	95	43	2.4	0.63	2.4	0.25	5.7	64
Saugatuck	6/19	15	6.9[1.8]	86	34	1.8	0.47	2.3	0.31	5.1	66
Milwaukee	9/19	11	4.6[1.2]	36	28	3.4	0.36	2.0	0.26	6.0	88
Sheboygan	7/13	13	5.1[3.5]	61	31	1.3	0.40	2.2	0.24	4.1	50
Sheboygan	7/22	13	6.1[1.8]	76	21	3.4	0.34	2.0	0.24	5.9	81

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TABLE 3 (cont'd.). *Mean concentrations of PCB's and DDT in fish, Lake Michigan—1971*

Location	Capture Date	No. Fish Analyzed	PCB's	Percentage Fish Above 5 ppm PCB's	PCB's, Lipid Weight	p,p'-DDE	p,p'-TDE	p,p'-DDT	o,p'-DDT	Total DDT	Percentage Fish Above 5 ppm DDT
Sheboygan	8/19	6	3.8[0.6]	0	15	2.6	0.35	1.3	0.16	4.4	20
Sheboygan	8/27	7	5.0[1.3]	57	23	3.2	0.47	2.3	0.28	6.3	80
Sheboygan	10/15	6	3.7[0.8]	0	21	2.4	0.24	1.7	0.17	4.5	42
Ludington	7/3	43	7.4[1.8]	93	41	2.0	0.55	2.2	0.28	5.0	46
Frankfort	10/5	8	4.7[0.7]	12	28	2.2	0.33	1.2	0.16	3.8	0
Manitou Island	9/10	10	4.6[1.1]	30	24	3.1	0.50	1.8	0.26	5.6	50
Washington Island	9/9	6	4.1[0.6]	0	16	3.2	0.54	1.9	0.18	5.6	60
Rock Island	9/11	6	5.8[2.5]	66	97	2.8	0.36	1.1	0.08	4.4	20
Rock Island	9/14	7	5.6[1.6]	57	23	2.7	0.42	2.0	0.22	5.4	50
Rock Island	9/16	8	4.0[0.7]	12	18	2.8	0.29	1.3	0.14	4.5	40
St. Martin Island	7/19	9	3.4[0.6]	0	16	2.2	0.34	1.1	0.17	3.8	0
Manistique	5/27	9	4.8[0.7]	33	26	2.9	0.42	1.8	0.14	5.2	80
CHINOOK SALMON (*Oncorhynchus tschawytscha*)											
Milwaukee	10/15	1	24.0[0.0]	100	117	6.6	1.67	4.7	0.53	13.4	100
Manitowoc	10/21	8	11.3[3.1]	100	209	6.3	0.62	1.2	0.23	8.5	100
Strawberry Creek	10/21	10	9.9[2.8]	100	373	4.5	0.39	1.0	0.17	8.0	88
Gills Rock	9/16	2	12.7[0.7]	100	278	5.5	0.44	1.2	0.20	7.3	100
COHO SALMON (*Oncorhynchus kisutch*)											
Michigan City	4/17	8	3.6[1.7]	12	51	0.8	0.17	0.6	0.08	1.6	0
Michigan City	9/27	8	17.3[8.4]	87	255	5.3	0.46	1.2	0.20	7.2	85
Michigan City	10/7	6	13.0[4.0]	100	349	4.5	0.41	1.4	0.18	6.5	66
Sheboygan	10/21	9	12.1[2.8]	100	276	6.6	0.57	1.4	0.27	8.8	100
Ludington	8/28	4	11.2[3.3]	100	108	6.8	0.59	0.9	0.19	8.3	100
Platte River	10/7	10	12.9[3.3]	100	226	5.5	0.48	1.4	0.24	7.6	100
Gills Rock	9/16	11	12.6[4.1]	90	166	4.9	0.45	1.2	0.20	6.7	87
LAKE TROUT (*Salvelinus namaycush*)											
Michigan City	10/15	4	24.9[2.0]	100	89	2.9	0.88	3.1	0.35	7.3	100
Michigan City	9/8	3	21.2[6.8]	100	121	9.5	1.12	3.9	0.45	14.9	100
Saugatuck	6/21	14	11.9[3.8]	100	70	4.7	0.64	2.1	0.27	7.6	88
Saugatuck	7/10	7	15.5[2.4]	100	78	6.9	0.70	2.0	0.24	9.8	100
Saugatuck	10/1	9	18.7[4.7]	100	133	6.7	0.84	2.8	0.27	10.6	100
Milwaukee	9/14	1	21.2[0.0]	100	90	10.1	0.96	3.0	0.47	14.5	100
Milwaukee	9/19	7	21.1[6.0]	100	114	10.6	1.06	3.3	0.45	15.4	100
Milwaukee	10/15	15	10.4[3.6]	100	127	2.3	0.44	1.3	0.15	4.2	20
Sheboygan	7/1	1	1.4[0.0]	100	58	ND	ND	ND	ND	ND	ND
Sheboygan	7/15	56	12.5[3.2]	100	82	4.3	0.51	1.7	0.24	6.8	66
Ludington	7/1	10	8.1[1.8]	100	51	3.3	0.52	1.6	0.22	5.6	60
Ludington	7/4	8	8.5[1.7]	100	58	3.2	0.63	2.0	0.30	6.1	66
Grand Traverse Bay	10/19	8	11.3[5.3]	75	56	6.0	0.73	2.0	0.30	9.0	77
Green Island	7/21	19	9.0[1.7]	100	48	3.8	0.50	1.5	0.21	6.0	72
Gills Rock	9/16	10	13.7[6.4]	100	83	5.5	0.62	1.9	0.24	8.3	82
YELLOW PERCH (*Perca flavescens*)											
Michigan City	10/15	14	4.2[0.7]	14	72	0.8	0.15	0.4	0.04	1.3	0
Waukegan	8/28	9	6.1[1.5]	88	78	ND	ND	ND	ND	ND	ND
Milwaukee	10/15	10	10.9[3.1]	90	203	1.1	0.30	0.7	0.08	2.1	0
Ludington	7/6	3	6.2[1.3]	100	139	2.2	0.39	0.9	0.13	3.6	0
Frankfort	10/12	2	5.4[1.8]	50	69	1.7	0.43	2.2	0.14	4.5	0
Pensaukee Bar	8/25	10	2.7[2.1]	10	49	0.4	0.10	0.0	0.01	0.5	0
RAINBOW TROUT (*Salmo gairdneri*)											
Michigan City	10/15	1	12.0[0.0]	100	66	ND	ND	ND	ND	ND	ND
Gills Rock	9/16	9	8.8[4.3]	77	47	3.1	0.34	0.9	0.16	4.5	40
REDHORSE (*Moxostoma* sp.)											
Rock Island	9/11	7	2.8[0.9]	0	33	1.7	0.30	0.6	0.09	2.7	0
St. Martin Island	9/11	9	3.2[0.5]	0	37	1.5	0.35	0.8	0.09	2.7	0
RAINBOW SMELT (*Osmerus eperlanus mordax*)											
Michigan City	10/15	15	3.2[0.9]	0	45	0.9	0.11	0.4	0.04	1.4	0
Sheboygan	10/15	3	0.7[0.2]	0	18	0.6	0.12	0.3	0.03	1.0	0
Green Island	7/21	5	2.6[1.1]	0	57	0.7	0.12	0.2	0.02	1.0	0
Rock Island	9/11	8	2.9[1.7]	25	49	1.0	0.34	0.5	0.05	1.6	0
St. Martin Island	7/19	4	1.3[0.3]	0	31	0.7	0.09	0.2	0.04	1.0	0
WHITE SUCKER (*Catostomus commersoni*)											
Michigan City	10/15	6	10.6[4.0]	100	100	1.9	0.32	1.8	0.08	4.6	66
Saugatuck	10/15	3	6.0[2.9]	66	149	0.7	0.14	0.2	0.03	1.0	0
Saugatuck	10/18	5	2.3[0.4]	0	40	ND	ND	ND	ND	ND	ND
Pensaukee Bar	8/6	7	3.2[3.1]	14	57	0.3	0.15	0.2	0.04	0.7	0
Grand Traverse Bay	10/19	14	2.3[0.7]	0	68	0.4	0.31	0.4	0.03	2.1	0
Green Island	7/21	1	2.1[0.0]	0	20	0.7	0.19	0.4	0.08	1.3	0
Rock Island	9/11	14	2.5[0.9]	0	46	0.9	0.38	0.3	0.04	1.4	0

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TABLE 3 (cont'd.). *Mean concentrations of PCB's and DDT in fish, Lake Michigan—1971*

Location	Capture Date	No. Fish Analyzed	PCB's	Percentage Fish Above 5 ppm PCB's	PCB's, Lipid Weight	*p,p'*-DDE	*p,p'*-TDE	*p,p'*-DDT	*o,p'*-DDT	Total DDT	Percentage Fish Above 5 ppm DDT
					Lake whitefish (*Coregonus clupeaformis*)						
Michigan City	10/15	4	6.1[0.9]	100	25	0.5	0.32	0.5	0.06	1.4	0
Saugatuck	6/19	7	2.7[0.5]	0	15	0.6	0.21	0.4	0.08	1.3	0
Saugatuck	6/21	2	3.1[1.3]	0	18	ND	ND	ND	ND	ND	ND
Grand Haven	9/6	7	5.8[0.9]	71	25	0.7	0.38	0.8	0.10	1.9	0
Grand Traverse Bay	10/19	13	1.8[0.3]	0	13	1.2	0.25	0.4	0.08	2.0	0
Rock Island	9/11	10	1.5[0.2]	0	9	0.7	0.16	0.4	0.05	1.4	0

NOTE: Expressions in brackets represent standard deviations.
ND = not determined.
Residues are ppm wet weight.

wives was greater in southern Lake Michigan than in the northern regions, although anomalies are apparent. Most alewives captured south of a line between Saugatuck and Sheboygan contained between 4.4 and 5.5 ppm PCB's, whereas those caught north of the line contained between 3.5 and 4.4 ppm. An interesting exception occurred in alewives from Rock Island just off the Door County Peninsula in Wisconsin; mean PCB concentration was 8.9 ppm.

Analysis of brown trout suggested similar trends: those from Michigan City at the southern end of the lake contained 11.9 ppm PCB's, whereas those from Sheboygan and Gills Rock contained 7.9 and 6.7 ppm PCB's, respectively.

Carp from Michigan City also had higher levels of PCB's than had those from the northern region. In contrast to the 11.0 ppm found in the Michigan City carp, those from Saugatuck and Sheboygan contained 4.6 and 1.7 ppm, respectively.

PCB's in bloaters in southern Lake Michigan ranged from 4.6 ppm near Milwaukee to 8.1 ppm near Saugatuck. In general, bloaters from the northern regions had concentrations below 5 ppm. The concentration of PCB's in the five groups of bloaters collected near Sheboygan during a 3-month period varied from 3.7 to 6.1 ppm, although the mean was below 5 ppm; no trend was indicated. The variation is somewhat less when data are expressed on a lipid basis; for example, PCB concentrations in the August 27 and October 15 bloaters were 5.0 and 3.7 ppm wet weight, respectively. In contrast, the concentration of PCB's in lipids was 23 ppm and 21 ppm, respectively. Thus much of the observed variation is caused by the variation in lipid content of fish.

All chinook salmon captured in Wisconsin contained more than 5 ppm PCB's; mean concentrations ranged from 9.9 ppm in Strawberry Creek (Sturgeon Bay) to 24 ppm at Milwaukee.

In concentrations of PCB's among coho salmon, authors observed little evidence of a trend dependent upon sampling region. Except for coho caught early in 1971 near Michigan City, mean concentrations of PCB's ranged from 11.2 ppm in salmon near Ludington to 17.3 ppm in those near Michigan City.

Among lake trout PCB concentrations were greatest in those from Michigan City, Saugatuck, and Milwaukee, where mean concentrations were generally between 15 and 21 ppm. Trout from the northern areas such as Sheboygan, Ludington, Grand Traverse Bay, and Gills Rock contained considerably less, and mean concentrations ranged between 8 and 15 ppm.

Mean concentration of PCB's was unexpectedly high, 10.9 ppm, in the 10 yellow perch caught near Milwaukee. Perch from other regions averaged less by a factor of two, and those from lower Green Bay contained 2.7 ppm.

In seven Rock Island redhorse, PCB residues averaged 2.8 ppm. In nine specimens from St. Martin Island, mean concentration was 3.2 ppm.

Rainbow trout were caught only near Michigan City and Gills Rock. The Michigan City rainbow trout had 12.0 ppm PCB's, whereas those from Gills Rock averaged only 8.8 ppm.

Concentrations of PCB's in white suckers and smelt were generally between 2 and 4 ppm, although the average concentration was 6.0 ppm in the three white suckers from Saugatuck on October 15 and 10.6 ppm in the six from Michigan City the same day. Except for whitefish caught at Grand Haven and Michigan City, the PCB concentration in whitefish was less than 3.1 ppm.

DDT AND ANALOGS

Concentrations of *p,p'*-DDT, *o,p'*-DDT, *p,p'*-TDE, and *p,p'*-DDE are presented in Table 3 along with the total DDT and percentage of fish that contained residues above the 5ppm action level established by FDA (*1*). Total DDT in alewives ranged from 1.6 ppm near Waukegan to 5.0 ppm near the Manitou Islands. There was no trend in the variations according to region. A brown trout from Michigan City contained 8.4 ppm total DDT, whereas those from Sheboygan and Gills Rock averaged 4.4 ppm. Except for the carp from Michigan City, which averaged 4.6 ppm total DDT, average concentrations in Lake Michigan carp were 1.0 ppm or less.

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Total DDT in bloaters ranged from 3.8 ppm at Frankfort and St. Martin Island to 6.2 ppm at Sheboygan. There are no trends for DDT in chubs (Table 3). Except for eight coho salmon caught near Michigan City in the spring, which averaged 1.6 ppm total DDT, total DDT in this species varied little throughout the lake. Mean concentrations ranged between 6.5 and 8.8 ppm.

Lake trout from Michigan City averaged 14.9 ppm total DDT on September 8, 1971; those caught October 15, 1971, averaged only 7.3 ppm. The discrepancy is likely due to size differences. For example, the lake trout caught near Milwaukee in September also contained a mean concentration of approximately 15 ppm; however, the smaller trout caught near Milwaukee in October averaged only 4.2 ppm total DDT. DDT concentrations in lake trout from northern areas of the lake were less than 8 ppm; approximately 60-70 percent of the lake trout contained over 5 ppm total DDT.

Yellow perch from Pensaukee Bar in lower Green Bay had the lowest DDT content, 0.5 ppm; perch from other areas contained between 1.3 and 4.5 ppm total DDT. None of the perch contained more than 5 ppm total DDT.

Concentration of DDT in smelt, whitefish, and white suckers averaged approximately 1-2 ppm, although white suckers from Michigan City averaged 4.6 ppm total DDT.

Summary

Concentration of PCB's ranged from less than 2 ppm in small fish with low lipid content to over 20 ppm in larger fish with higher lipid content. The concentration of PCB's in Lake Michigan coho salmon is two to three times greater than in coho from Lake Huron, approximately 1.5 times greater than in Lake Ontario coho salmon, and approximately 10 times greater than in coho from Lakes Erie and Superior. Essentially 100 percent of large salmon and trout, both popular food sources, and 50-80 percent of bloaters from Lake Michigan contain PCB concentrations greater than the 5 ppm tolerance level set by FDA. Additional monitoring of this watershed is needed to determine whether tissue concentrations will reflect restrictions in domestic PCB sales and possible decreases in PCB usage in the watershed even though U.S. production of Aroclor 1254 has remained essentially the same as in 1969 (*24*).

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