RESIDUES OF PCB's AND DDT IN THE WESTERN LAKE SUPERIOR ECOSYSTEM

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Fish from western Lake Superior (1972–73) contained DDT and PCB residues at concentrations greater than 0.1 ppm. The most predominant PCB's were those containing 3 to 6 chlorine atoms per molecule, and GLC data indicated that the mixtures were most like the commercial product Aroclor® 1254[2]. Other chlorinated contaminants identified by GC/MS analyses and occurring at concentrations less than 0.1 ppm were hexachlorobenzene (C_6C1_6), chlordane, nonaclor, and dieldrin. Lindane, which has been previously reported in Lake Superior, was below the detection limit of approximately 0.01 ppm.

The relationship between the size of lake trout and the concentration of total DDT in the fish was compared to measurements reported in previous studies. The comparison suggests that DDT residues have declined since 1968. The concentration of PCBs was estimated to be 0.8 ng/L in Lake Superior water and 0.1 ppm in large zooplankton. The apparent bioconcentration factor for PCBs in Lake Superior fish ranged from 10^5 to 10^6. The concentration of total DDT and PCBs in the larger Lake Superior fish exceeded the 5 ppm tolerance level established by the U.S. Food and Drug Administration for these chemicals in fish to be used for human consumption.

Lake Superior is one of the largest oligotrophic bodies of fresh water in the world. Approximately 60% of the watershed is the lake itself, and the population density around the lake is low. Concentrations of trace elements have remained relatively small compared to those in the other Great Lakes and are indicative of a high quality of water. It has recently been shown, however, that activities in the watershed can significantly alter the composition of interstitial and lake water in the western area of Lake Superior (Glass and Poldoski 1974) and that these changes may be gradual enough to be indiscernible over short time spans with conventional techniques.

Until recently, DDT and dieldrin were the only chlorinated organic contaminants measured in the Lake Superior ecosystem. Reinert (1970) showed that mean concentrations of

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[2]The U.S. Environmental Protection Agency neither recommends nor endorses any commercial product; trade names are used only for identification.

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DDT in fish caught in Lake Superior between 1965 and 1968 ranged from 0.32 ppm in smelt to 1.44 ppm in herring. Although lake trout shorter than 16 inches averaged only 0.97 ppm of DDT, the concentration increased with length to a mean of 7.44 ppm in the 27- to 33-inch trout. Dieldrin was observed at concentrations less than 0.05 ppm.

Henderson *et al.* (1969) reported mean concentrations of "total" DDT in whitefish and lake trout captured from the Apostle Island region of Lake Superior in 1967 to be 1.40±0.46 ppm and 0.82±0.13 ppm, respectively. Later, Henderson *et al*, (1971) reported that the mean concentrations of total DDT in bloaters, whitefish, and lake trout captured in 1969 were 1.81, 0.74, and 1.58 ppm, respectively. Also reported was the presence of approximately 0.03 ppm of hexachlorocyclohexane (BHC including lindane) and chlorobiphenyl analogs (PCBs) at mean concentrations of 3.47, 1.96, and 2.84 ppm in the bloater, whitefish, and trout, respectively. However, confirmations of the presence of BHC and PCBs were not included.

Poff and Degurse (1970) reported "total" DDT concentrations in lake trout from the Apostle Islands area ranging from 0.48 to 11.54 ppm depending on the length of the fish and type of tissue.

This paper presents the results of a study to characterize the major chlorinated organic contaminants that have been found as residues in western Lake Superior.

Methods

Sampling. The sampling sites selected in western Lake Superior are illustrated by the crosshatched areas in Figure 1. Fourhorn sculpins, *Myoxocephalus quadricornis* (Linnaeus), slimy sculpins, *Cottus cognatus* Richardson, and zooplankton, *Mysis relicta*, were sampled by trawling along the north shore sites in the fall of 1972 (Eaton 1973). Other fish from the north shore were collected with gill nets. The fish from the Apostle Island sampling site were collected with gill nets by the Wisconsin Department of Natural Resources during the fall of 1973. All samples were preserved by freezing in aluminum foil or glass jars rinsed with acetone.

Samples of Lake Superior sediment were collected with a Shipek dredge from the 270-m depth approximately 5 miles off Silver Bay, Minnesota. This sediment was primarily taconite tailings, which cover approximately 1,000 square miles of natural sediment. The sediment was sectioned with a stainless steel spatula to remove any sediment that contacted the dredge. The sample was deposited in a glass jar, previously rinsed with acetone, and stored frozen until analysis.

Samples of Lake Superior water were collected from the Environmental Research Laboratory-Duluth water supply inlet and control water from a PCB bioassay. The water (20 L) was passed through glass columns packed with polyurethane foam which had been exhaustively extracted with solvent to remove impurities. These samples were analyzed immediately after collection.

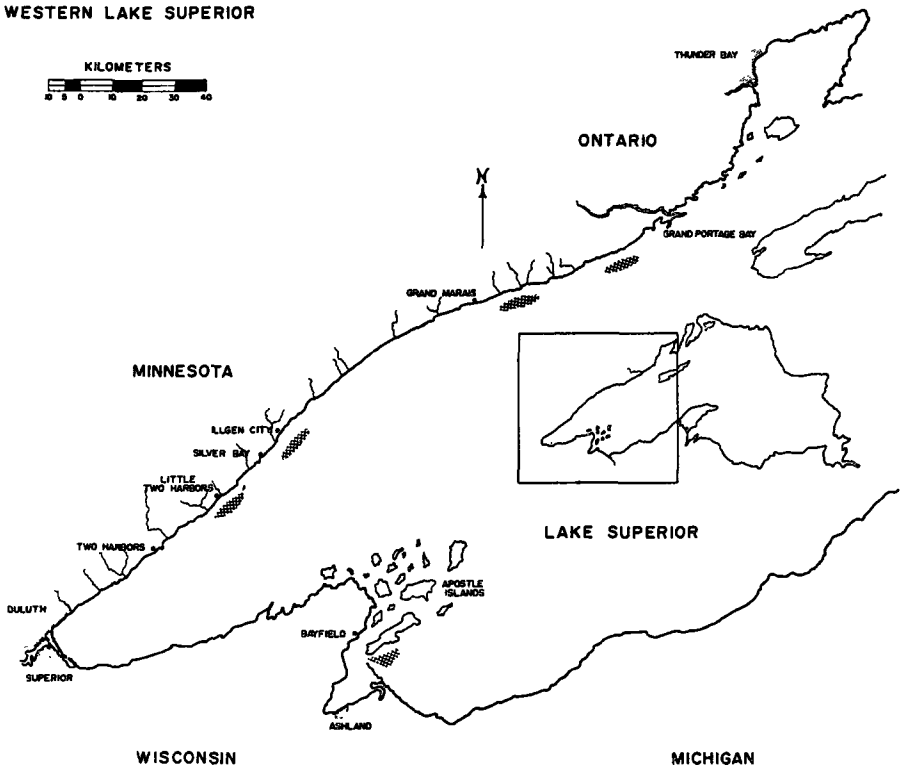

Fig. 1. Major sampling regions (crosshatched) in the study of western Lake Superior.

Sample Preparation. *Fish.* The fish samples intended for DDT and PCB analysis were blended with anhydrous Na_2SO_4 and extracted with hexane and ethyl ether (3:1 v/v). Lipids were removed by Florisil chromatography. An aliquot was removed for the determination of *p,p'*-DDE, and the remainder of the extract was fractionated by silicic acid chromatography as described by Armour and Burke (1970). Details of the analysis of PCB's and chlorinated pesticides are presented elsewhere (Veith and Lee 1971, Veith 1975).

Zooplankton. Although conventional methodology for the measurement of PCBs and DDT is adequate for the analysis of Lake Superior fish, these trace chemicals cannot be measured routinely in zooplankton and water samples because of the small concentrations present and the limited sample size generally available. Consequently, the extracts of zooplankton were separated into fractions containing PCBs and DDT on micro-Florisil columns described by Veith (1975). The PCBs were measured as decachlorobiphenyl ($C_{12}Cl_{10}$) after perchlorination with $SbCl_5$ and corrected to an equivalent weight of the Aroclor 1254 reference mixture which most resembles the PCB mixtures in Lake Superior fish.

Sediment. The sediment was air-dried and transferred in triplicate to glass Soxhlet extraction thimbles. A small subsample was placed in a tared weighing pan and heated over-night at 105° C to determine the moisture content. The sediment was extracted for 36 hr with the azeotrope of hexane/acetone, and the extract was evaporated to near dryness. Because of the small amounts of organic matter in the sediment, the extract was perchlorinated directly without cleanup.

Water. The PCBs extracted from water were removed from the polyurethane foam columns with acetone (50 ml) and hexane (225 ml). The extracts were dried over anhydrous Na_2SO_4 and concentrated to 5 ml in a Kuderna-Danish evaporative concentrator. The concentrates were transformed to 1-g Florisil columns (prewashed with hexane), and the PCBs were eluted with 75 ml of hexane. The eluant was collected in a Kuderna-Danish concentrator and reduced to about 1 ml for transfer into the perchlorination vials.

Perchlorination. To perchlorinate the PCBs to decachlorobiphenyl ($C_{12}Cl_{10}$), the extract was slowly evaporated to dryness in a 5-ml test tube fitted with a Teflon-lined screw cap. Approximately 0.2 ml of $SbCl_5$ was added, and the tube was capped and then heated to 170° C for 4 hr. After the tube was cool, 1 ml of 6N HCl was added to destroy the excess $SbCl_5$. The aqueous phase was extracted with five 1-ml volumes of hexane by jetting the hexane into the lower phase with a disposable pipet. Each 1 ml of extract was transferred to a disposable pipet containing a 4-cm column of anhydrous Na_2SO_4. The column was washed into a graduated centrifuge tube with 5 ml hexane and analyzed by gas-liquid chromatography (GLC). Commercially available $SbCl_5$ produces a blank in this analysis, and both the $SbCl_5$ and reagent blanks limit the determinable limit in these analyses.

Instrumental. *Gas chromatography*. The fish extracts were analyzed on a 2-m × 2-mm id glass column packed with 3% OV-101 on 80/100 mesh Gas Chrom Q using an electron capture detector. The $C_{12}Cl_{10}$ formed from the PCBs in the zooplankton and water extracts was analyzed on a 1-m × 2-mm id glass column coated with 3% Dexsil 300 on 80/100 mesh Gas Chrom Q using an electron capture detector. The detector response was linear up to approximately 0.2 mg of $C_{12}Cl_{10}$, and the detection limit was approximately 0.02 ng.

GC/MS analyses. Gas chromatographic/mass spectral (GC/MS) analyses were conducted to confirm the presence of the major chlorinated contaminants in Lake Superior fish. The cleanup of tissue for GC/MS analysis was accomplished as described by Veith *et al*. (1975). The mass spectra were obtained at 7-sec intervals with a Varian Mat CH-5 mass spectrometer equipped with a Spectro-System 100 data system described by Kuehl *et al*. (1974). The mixtures of chemicals in the extract were separated by a gas chromatograph fitted with a 2-m × 2-mm id glass column packed with 3% OV-101 on 80/100 mesh Gas Chrom Q. The temperature was held initially at 125° C for 3 min and was then increased 4° C/min to 235° C.

Results and Discussion

Major chlorinated contaminants. A typical gas chromatogram of the extract of aquatic organisms from Lake Superior is illustrated in Figure 2. On the basis of weight,

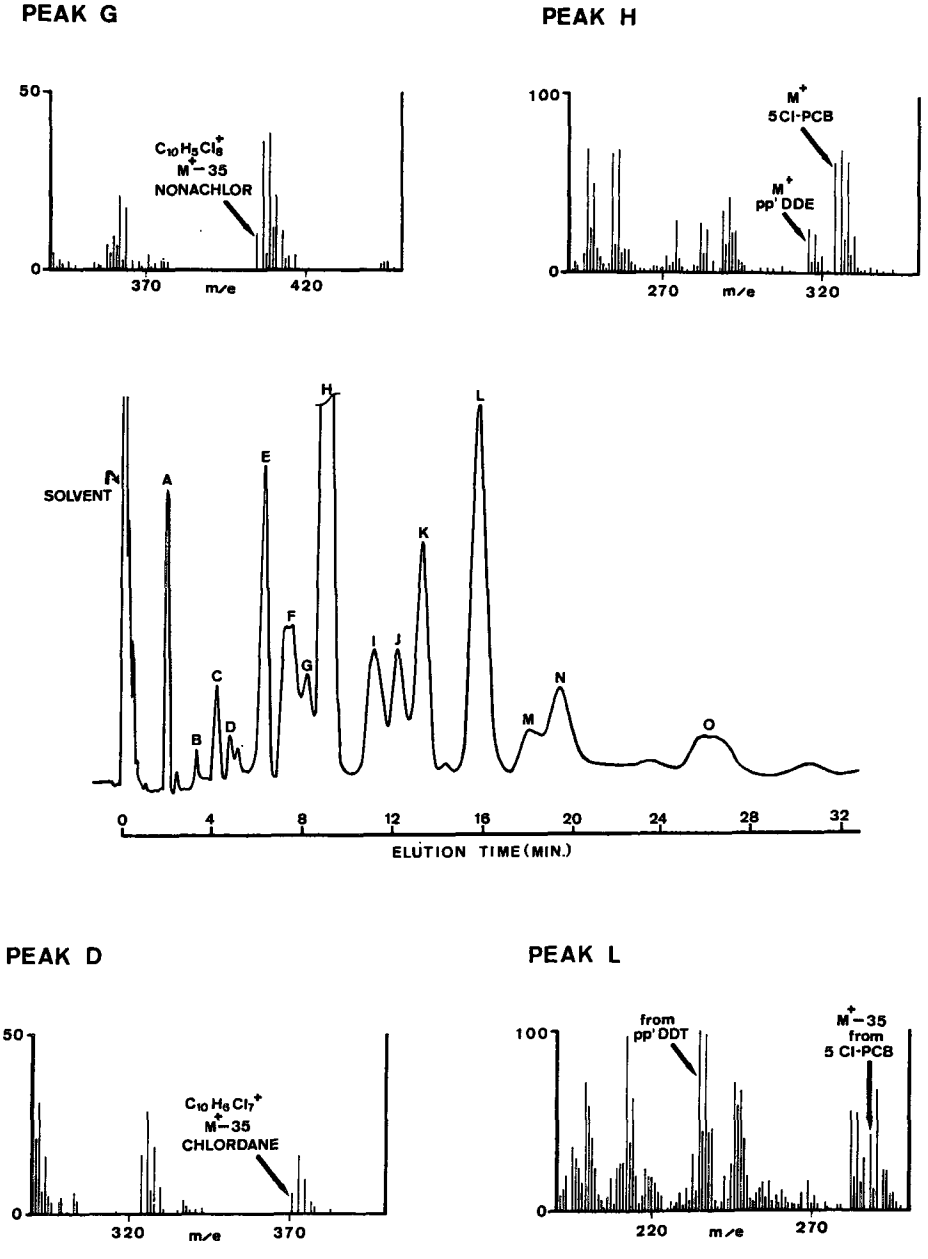

Fig. 2. Gas chromatogram of a Lake Superior trout extract and mass spectra of selected peaks of the chromatogram. On the basis of GLC retention time and GC/MS analysis, peak A is hexachlorobenzene (C_6Cl_6), peak D contains chlordane, peaks F and G contain nonachlor isomers, peak H is *p,p'*-DDE, peak J contains *o,p*-DDT, peak K contains *p,p'*-DDE, peak L contains *p,p'*-DDT, and peaks B–I and J–O contain PCB analogs

the major chlorinated contaminants (greater than 50 ppb in fish) are PCBs containing 3, 4, 5, and 6 chlorine atoms per molecule, *p,p'*-DDE, *p,p'*-TDE, and *p,p'*-DDT, as indicated in the chromatogram. Hexachlorobenzene (C_6Cl_6, peak A) was identified by GC/MS and, although the concentration in large trout was approximately 30 ppb, determinations could not be made with the smaller fish. Likewise, the *cis*- and *trans*-isomers of chlordane ($C_{10}H_6C1_8$, peak D) and nonachlor ($C_{10}H_5Cl_9$, peak G) were identified, but were present at concentrations below 30 ppb. In addition, chlorinated chemicals with major mass fragments at m/e 339, 341, and 343 were observed in the GC/MS analyses. The compounds are most likely the C_8Cl_7 moiety arising from chlorinated norbornes such as that found in mixtures of technical grade toxaphene. Because of the small concentration present in even the larger lake trout, dieldrin was not confirmed by GC/MS analysis in this study.

Lake Superior water. The use of polyurethane foam plugs in the analyses of PCBs in Lake Superior water at total concentrations below 0.01 μg/L has been successful for several years at the Environmental Research Laboratory-Duluth (Snarski and Puglisi, in preparation). More than 160 spiked samples were analyzed to determine the recovery of PCBs at 0.01 μg/L, 0.1 μg/L, and 1.0 μg/L concentrations. The 57 samples spiked with 0.01 μg/L indicated a recovery of 79% at this concentration, the standard deviation of the analyses was ±59%.

The experiment to measure the PCBs in Lake Superior water consisted of 2 perchlorination blanks, 3 reagent blanks (extraction through perchlorination), 3 replicate samples of Lake Superior water, and 3 replicate samples from the control tanks in the PCB bioassay system. The results of these analyses are summarized in Table 1. Since the perchlorination blanks were essentially the same as the overall reagent blank, the major source of PCBs is assumed to be the perchlorination step and all blanks were grouped together. The Lake Superior water samples contained approximately 0.8 ng/L of PCBs as Aroclor 1254. However, the standard error of the measurements at this concentration was 50% of the mean. The estimated concentration of PCBs in the bioassay control tanks was approximately 3 ng/L. These measured concentrations were statistically greater than those in the Lake Superior water and indicate a minor contamination of the bioassay water supply system by the water-distribution system, fish food, or an inadvertent carry-over from the PCB bioassay experimental tanks from which the samples were taken.

Lake Superior sediments. Because of the small quantities of PCBs in the sediments of Lake Superior and the unavoidable contamination of the samples by traces of PCBs in reagents, reliable estimates of the reagent blanks were necessary. Four replicate reagent blanks were examined by operating the Soxhlet extractors without sediment and perchlorinating the extract with $SbCl_5$. The blanks were 183±18 ng of $C_{12}Cl_{10}$ for the sediment methods. The total quantity of $C_{12}Cl_{10}$ in the sediment extracts was approximately 350 ng, or approximately twice the reagent blanks. The concentration of PCBs (as Aroclor 1254) in the sediment on an oven-dried basis was 7.0±0.5 ppb.

Lake Superior zooplankton. The results of the analyses of 4 composite samples of *Mysis relicta* are presented in Table 2. The concentrations of dieldrin and DDT analogs except *p,p'*-DDE were at or near the determinable limit of 0.001 and 0.005 ppm, respec-

Table 1. *PCBs in Lake Superior water and control bioassay tanks*

Origin	Sample Number	Sample Volume (L)	Total ng $C_{12}Cl_{10}$ Mean		Standard error	Estimated PCB concentration (ng/L as Aroclor 1254)
Reagent blanks	5	–	44	±	12	–
Lake Superior	3	20.3 ± 0.02	62	±	6	0.8 ± 0.4
Bioassay control tanks	3	21.1 ± 0.05	132	±	11	3.2 ± 0.5

Table 2. *Concentration of major chlorinated hydrocarbons in Mysis relicta from Lake Superior near Illgen City, Minnesota*[a]

Dieldrin[b] (ppm)	Total DDT[c] (ppm)	PCBs (as Aroclor 1254)	
		Direct GLC (ppm)	Perchlorination (ppm)
0.001	0.050	0.08	0.11
0.002	0.053	0.12	0.14
0.002	0.041	0.09	0.11
0.002	0.040	0.05	0.08

[a] Collected by trawl, July 10-14, 1972 – see Eaton (1973)
[b] Determinable limit for dieldrin for zooplankton ≃ 0.001 ppm
[c] *p,p'*-DDT and DDD was generally below the determinable limit of 0.005 ppm. Consequently total DDT is essentially *p,p'*-DDE

tively. Consequently, the total DDT concentrations ranging from 0.04 ppm to 0.053 ppm are essentially the concentration of *p,p'*-DDE.

The concentrations of PCBs were estimated by direct GLC comparison with Aroclor 1254 standards, and by perchlorination to decachlorobiphenyl followed by a weight correction to an average chlorine content of 54%. The measured PCB concentrations from the direct analysis ranged from 0.05 to 0.12 ppm. The PCB concentrations from the perchlorination analysis ranged from 0.08 to 0.14 ppm. The PCB concentrations measured by perchlorination were consistently 20 to 30% greater than those measured by direct GLC. These results reflect the presence of di- and trichlorobiphenyls which are not measured in the Aroclor 1254 comparison.

Lake Superior fish. Sculpins were sampled only along the north shore of Lake Superior. Table 3 summarizes the concentrations of PCBs (as Aroclor 1254), *p,p'*-DDE, and *p,p'*-DDT in composite samples of the sculpins. The concentration of PCBs in slimy sculpins ranged from 0.18 ppm in those captured near Grand Marais to 0.34 ppm in those from the Split Rock area. In general, the concentrations of PCBs in slimy sculpins were greater in fish from the Little Two Harbors and Illgen City sampling areas than in those from the Grand Marais and Grand Portage areas. The mean concentration measured in the composites of 60- to 100-mm fourhorn sculpins in the Illgen City area was 0.28 ppm whereas the mean in the area near Grand Marais was 0.25 ppm. Similarly, the mean for the fourhorn sculpins greater than 100 mm in the Illgen City area was 0.32 ppm and the mean for those near Grand Marais was 0.23 ppm.

The results of the analyses of larger fish from Grand Marais, Illgen City, Little Two Harbors, and Apostle Island regions are presented in Table 4. The mean concentration of PCBs in fish from the Apostle Island region ranged from 0.4 ppm in smelt to 1.8 ppm in lake trout. The largest lake trout analyzed weighed 5.6 kg and contained 5.6 ppm of

Table 3. *Concentration of major chlorinated hydrocarbons in Lake Superior sculpins*

Area	Number[a] of fish	Length (mm)	Fat (%)	PCBs (ppm)	DDE (ppm)	DDT (ppm)	Total DDT[b] (ppm)
			Slimy sculpin				
Little Two Harbors	6	60-100	4.9	0.34	0.13	0.12	0.25
Illgen City	15	60-100	2.9	0.19	0.18	0.08	0.26
Illgen City	12	60-100	2.5	0.23	0.10	0.06	0.16
Grand Marais	18	60-100	1.8	0.18	0.18	0.09	0.27
			Fourhorn sculpin				
Illgen City	7	60-100	4.5	0.24	0.20	0.09	0.29
"	3	>100	5.7	0.31	0.32	0.12	0.44
"	4	60-100	4.8	0.27	0.22	0.11	0.33
"	11	>100	6.9	0.45	0.46	0.18	0.64
"	7	60-100	6.9	0.32	0.30	0.13	0.43
"	7	>100	5.8	0.20	0.36	0.08	0.44
Grand Marais	21	60-100	4.0	0.31	0.26	0.14	0.40
"	11	>100	3.7	0.24	0.27	0.24	0.51
"	18	60-100	2.2	0.19	0.19	0.08	0.27
"	2	>100	3.0	0.21	0.16	0.08	0.24
Grand Portage	6	60-100	4.3	0.12	0.14	0.06	0.20
"	6	>100	5.2	0.39	0.40	0.23	0.63

[a] Fish were composited into single analysis

[b] Total DDT = *p,p'*-DDE+*p,p'*-DDT; *p,p'*-DDD and *o,p'*-DDT were not measurable in sculpins.

PCBs; all of the smaller trout contained less than 5 ppm of PCBs. The mean total DDT in the fish from the Apostle Island region ranged from 0.3 ppm in smelt to 3.7 ppm in lake trout. Only in the large lake trout were the concentrations of PCBs and DDT greater than the U.S. Food and Drug Administration's guideline of 5 ppm. The concentration of dieldrin was generally at or below the determinable limit of 0.03 ppm. In the large trout and long-nose suckers, dieldrin concentrations as great as 0.09 ppm were observed.

Similar results were observed in the fish from the north shore of Lake Superior. The mean concentration of PCBs ranged from 0.3 ppm in smelt to 2.0 ppm in herring. The mean concentrations of PCBs in lake trout were 0.8 ppm and 0.7 ppm at Little Two Harbors and Illgen City, respectively. The lake trout from Grand Marais contained 1.9 ppm of PCBs and the siscowet contained 3.3 ppm. Although the concentrations appear to be

Table 4. *Concentration of major chlorinated hydrocarbons in fish from western Lake Superior*[a]

Species	Number of fish	Mean weight[b] (g)	Mean lipid (%)	Dieldrin (ppm)	*p,p'*-DDE (ppm)	Total DDT analogues[c] (ppm)	PCBs (ppm) Aroclor 1254
			Apostle Island Region (Wisconsin) (November 1973)				
Burbot (*Lota lota* (Linnaeus))	3	1,290 ± 200 (1,057 – 1,474)	6.2 ± 1.4 (4.8 – 7.7)	0.03 (0.03)	0.7 ± 0.3 (0.4 – 0.9)	0.4 ± 0.2 (0.2 – 0.6)	1.4 ± 0.4 (1.0 – 1.7)
Lake trout (*Salvelinus namaycush* (Walbaum))	9	2,600 ± 1,700 (257 – 5,652)	8.9 ± 3.6 (1.4 – 13.0)	0.03 ± 0.02 (<0.03 – 0.05)	2.2 ± 2.3 (0.05 – 6.9)	3.7 ± 4.2 (0.1 – 12.8)	1.8 ± 1.6 (0.3 – 5.6)
Long-nose sucker (*Catostomus catostomus* (Forster))	8	970 ± 160 (569 – 1073)	6.1 ± 3.7 (1.9 – 12)	0.03 ± 0.03 (<0.03 – 0.09)	0.8 ± 0.9 (0.16 – 2.60)	1.5 ± 1.6 (0.03 – 3.3)	0.9 ± 0.8 (0.3 – 2.7)
Rainbow smelt (*Osmerus mordax* (Mitchell))	5	64 ± 6 (57 –72)	8.2 ± 2.2 (6.7 – 12)	<0.03	0.17 ± 0.04 (0.11 – 0.20)	0.28 ± 0.06 (0.18 – 0.33)	0.4 ± 0.1 (0.4 – 0.5)
Lake whitefish (*Coregonus clupeaformis* (Mitchill))	10	708 ± 168 (338 – 204)	6.2 ± 3.2 (1.3 – 13.7)	<0.03	0.43 ± 0.21 (0.11 – 0.74)	1.0 ± 0.6 (0.16 – 1.94)	0.7 ± 0.4 (0.1 – 1.4)
			Little Two Harbors Region (Minnesota) (July 1972)				
Burbot	4	410 ± 80 (320 – 502)	3.3 ± 0.8 (2.3 – 4.2)	<0.03	0.2 ± 0.2 (0.05 – 0.46)	0.4 ± 0.3 (0.08 – 0.77)	0.5 ± 0.5 (<0.9 – 1.0)
Bloater (*Coregonus hoyi* (Gill))	14	172 ± 75 (77 – 390)	172 ± 8.2 (1.2 – 26.0)	<0.03	0.8 ± 0.4 (0.08 – 1.65)	1.3 ± 0.7 (0.69 – 3.01)	1.0 ± 0.3 (0.40 – 1.60)

Lake herring (*Coregonus artedii* (Lesueur))	3	305 ± 70 (231 – 370)	5.3 ± 3.0 (1.9 – 7.8)	<0.03	0.6 ± 0.2 (0.44 – 0.86)	1.3 ± 0.6 (0.89 – 1.93)	2.0 ± 1.0 (1.2 – 3.1)
Lake trout	12	400 ± 100 (202 – 552)	6.1 ± 2.8 (2.6 – 13.0)	<0.03	0.5 ± 0.2 (0.11 – 0.84)	0.9 ± 0.4 (0.21 – 1.45)	0.8 ± 0.4 (<0.3 – 1.5)
Rainbow smelt	8	40 ± 10 (27 – 52)	2.1 ± 2.9 (0.6 – 6.5)	<0.03	0.2 ± 0.1 (0.06 – 0.41)	0.3 ± 0.2 (0.10 – 0.68)	0.4 ± 0.5 (<0.4 – 1.2)
			Illgen City Region (Minnesota) (July 1972)				
Burbot	6	430 ± 300 (158 – 1006)	7.1 ± 2.4 (4.0 – 10.2)	<0.03	0.5 ± 0.2 (0.31 – 0.74)	0.8 ± 0.3 (0.54 – 1.28)	0.9 ± 0.3 (0.5 – 1.2)
Bloater	6	320 ± 90 (245 – 484)	9.1 ± 3.4 (5.2 – 12.8)	<0.03	0.5 ± 0.2 (0.35 – 0.76)	1.3 ± 0.4 (0.85 – 1.92)	0.7 ± 0.2 (0.4 – 0.9)
Lake trout	10	390 ± 210 (106 – 733)	4.6 ± 1.1 (2.8 – 6.9)	<0.03	0.6 ± 0.4 (0.20 – 1.40)	0.9 ± 0.5 (0.28 – 1.68)	0.7 ± 0.3 (0.3 – 1.2)
Rainbow smelt	10	45 ± 10 (39 – 66)	2.8 ± 1.2 (1.4 – 4.6)	<0.03	0.2 ± 0.1 (0.12 – 0.30)	0.3 ± 0.1 (0.21 – 0.49	0.3 ± 0.1 (0.2 – 0.5)
			Grand Marais (Minnesota)				
Lake trout	1	1820	18	–	0.6	0.8	1.9
Siscowet[d] (*Salvelinus namaycush siscowet* (Agassiz))	1	3180	34	–	1.8	2.2	3.3

[a] Determinable limit for lindane, heptachlor, chlordane, and aldrin was 0.01 ppm

[b] Data expressed as mean ± standard deviation; the range is presented in parentheses

[c] Total DDT = $\Sigma(p,p'\text{-DDE} + o,p'\text{ DDT} + p,p'\text{-DDD} + p,p'\text{-DDT})$

[d] The siscowet is a subspecies of lake trout found in Lake Superior and is characterized by high lipid content

Table 5. *Mean concentration of total DDT (ppm) in western Lake Superior lake trout of various sizes as reported in three studies 1965-73*

Length of fish (inches)	1965-68 Reinert (1970)	1968-69 Poff and Degurse (1970)	1972-73 This study
2 - 5.9	0.21	-	-
6.0 - 9.9	0.63	-	0.63
10.0 - 15.9	0.97	-	0.83
16.0 - 21.9	2.84	-	1.03
22.0 - 26.9	3.99	3.28	2.15
27.0 - 32.9	7.44	5.08	4.72

lower in trout captured along the north shore than in trout from the Apostle Islands, the mean weight of the north shore trout was approximately 400 g in contrast to the 2,600 g for trout from the Apostle Islands, and direct comparisons of concentrations cannot be made.

Although the data in the literature concerning PCBs are insufficient to relate the results of this study to the quality of Lake Superior at an earlier time, the DDT variations in various-sized lake trout reported in this paper can be compared to those reported by Reinert (1970) and Poff and Degurse (1970) (Table 5). Apparently DDT residues in trout greater than 16 inches have declined by a factor of two since 1965–68. This trend cannot be statistically analyzed because of the limited number of samples and changing analytical methodology; however, it is consistent with that observed for DDT in the rigorously studied Lake Michigan ecosystem where a decline of 30% each year has been observed since the ban of DDT in 1970 (Wilford 1974).

The concentration of PCBs in the water of western Lake Superior is estimated to be about 0.8 ng/L. If we use typical concentrations of 0.1 ppm for large zooplankton such as *Mysis*, 0.3 ppm for bottom fish such as sculpins, and 1.0 ppm for pelagic fish, the apparent bioconcentration factors (concentration in organism divided by the concentration in water) for the respective organisms are approximately 1.2×10^5, 3.7×10^5, and 1.2×10^6. The apparent bioconcentration factors for fish are slightly greater than the 2×10^5 measured for Aroclor 1254 in the laboratory (Nebeker *et al.* 1974, Defoe *et al.* in preparation). However, the fish in laboratory experiments were exposed to PCBs in water only, and Jarvinen *et al.* (in preparation) and Reinert *et al.* (1974) have demonstrated that fish acquire greater residues when the chemical is accumulated from water and food. In addition, the apparent bioconcentration factors for fish in large lakes may reflect short periods of time spent in harbor areas where the concentration in the water is greater than in the nearshore area or open lake.

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