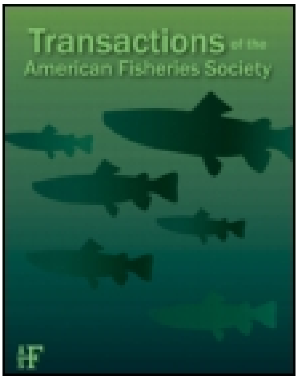

Transactions of the American Fisheries Society

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/utaf20

Contamination of Stream Fishes with Chlorinated Hydrocarbons from Eggs of Great Lakes Salmon

James W. Merna [a]

[a] Michigan Department of Natural Resources, Institute for Fisheries Research, Ann Arbor, Michigan, 48109, USA

Available online: 09 Jan 2011

Transactions of the American Fisheries Society 115:69–74, 1986

Contamination of Stream Fishes with Chlorinated Hydrocarbons from Eggs of Great Lakes Salmon[1]

JAMES W. MERNA

Michigan Department of Natural Resources, Institute for Fisheries Research
Ann Arbor, Michigan 48109, USA

Abstract.—Pacific salmon *Oncorhynchus* spp. have been stocked in the Great Lakes where they accumulate body burdens of chlorinated hydrocarbons. The transport of these contaminants to resident communities in spawning streams was studied in two tributaries of Lake Michigan accessible to anadromous spawners and one control tributary blocked to them. No polychlorinated biphenyls (PCBs), DDT, or dieldrin were detected in the sediments or biota of the control stream, or in sediments of the test streams. However, trout *Salmo* spp. and, to a lesser extent, sculpins *Cottus* spp. accumulated PCBs and DDT as a result of eating contaminated salmon eggs. Eggs constituted as much as 87% (by weight) of the total stomach contents of trout collected during the salmon spawning season early October to early January. Salmon eggs contained 0.46–9.50 mg PCBs/kg, and 0.14–1.80 mg DDT/kg. Consumption of eggs varied greatly among individual trout, and there was a strong correlation between numbers of eggs in the stomachs and PCB and DDT concentrations in the fillets.

The purpose of this study was to assess the extent to which spawning salmon from Lake Michigan contaminated stream communities with chlorinated hydrocarbons. Coho salmon *Oncorhynchus kisutch* and chinook salmon *O. tshawytscha,* stocked in Lake Michigan (and other Great Lakes), accumulate body burdens of contaminants. They ascend tributary streams of the Great Lakes to spawn, after which they die and become buried in silt beds. Many of these streams support important trout fisheries.

Body tissues of salmonid fishes in Lake Michigan contain several environmental contaminants including PCBs,[2] dieldrin,[3] and DDT[4]. Fillets taken (in 1977) from salmon larger than 4.5 kg contained PCB concentrations ranging from 1.46 to 26.18 mg/kg and DDT concentrations of 0.75 to 13.10 mg/kg (Anonymous 1977). Salmon potentially release contaminants by metabolism, egg deposition, and decay of their carcasses. Chlorinated hydrocarbons released into streams tend to be bound to organic sediments in the silt beds (Odum et al. 1969), from which they can enter the water or food chain. Invertebrate scavengers such as crayfish and amphipods can ingest pesticides bound to organic debris or salmon flesh. Salmon eggs are eaten at several levels of the food chain; those that are not will release contaminants as they decay. Resident fish thus are subject to uptake of contaminants directly from the water and from their diet.

Since the significance of chlorinated hydrocarbons in the aquatic environment was first realized, scientists have attempted to assess the importance of diverse routes of entry into aquatic organisms. Early researchers were divided as to the relative importance of direct uptake and dietary contributions. Harrison et al. (1970), Macek and Korn (1970), and Johnson et al. (1971) emphasized food chain contributions, whereas Reinert (1967), Chadwick and Brocksen (1969), Grzenda et al. (1970), and Hamelink et al. (1971) emphasized direct uptake from the water. Jarvinen et al. (1976) exposed fathead minnows *Pimphales promelas* to DDT in the water and in the diet. Mean bioconcentration factors were 1.2 times from the diet and 100,000 times from the water.

Recent research is in agreement that the chlorinated hydrocarbon body burden of top predators is mostly dietary in origin. Sullivan et al. (1983) found direct uptake of PCBs through the gills of lake trout *Salvelinus namaycush* accounted for only 2 to 3% of the total accumulation. Jensen et al. (1982) demonstrated that 7.5% of PCBs in lake trout and salmon was by direct uptake. Spigarelli et al. (1983) credited direct uptake for 10% of the total PCB accumulation in brown trout *Salmo trutta,* and concluded that body burdens of the predators would equilibrate with the concentration in their food supply in 70–155 d depending on temperature. Thomann (1981) and Thomann

---

[1] Contribution from Federal Aid in Fish Restoration Project F-35-R, Michigan.

[2] Polychlorinated biphenyls.

[3] 1,2,3,4,10,10-hexachloro-6-7,-epoxy-1,4,4a,5,6,7,8a-octahydro-1,4-5,8-dimethanonaphthalene.

[4] Dichlorodiphenyltrichlorethane.

and Connolly (1981) observed that the total tissue concentrations in aquatic organisms were controlled by the water column concentrations even though as much as 99% of the body burden was attributable to food intake.

I have studied the role of spawning salmon in introducing chlorinated hydrocarbons into two small Michigan trout streams. The extent of contamination of stream sediments and biota by decaying salmon was assessed. In addition, the contribution of PCBs and DDT to trout, through consumption of salmon eggs and through decaying salmon, was evaluated.

Methods

Field Collections

Three Michigan trout streams were selected for this study. Bigelow Creek, Newaygo County (a tributary of the Muskegon River), and Pine Creek, Manistee County (a tributary of the Manistee River), have large spawning runs of both coho and chinook salmon. The third stream, Hersey Creek, Osceola County (a tributary of the Muskegon River), is not accessible to anadromous fish and served as a control. Migrating fish are blocked from this creek by Croton Dam on the Muskegon River. The three streams are in similar land-use areas, are similar in size and flow, and are isolated from industrial and urban contamination.

The streams were sampled periodically between October 13, 1977, and December 7, 1978, a period that included two salmon spawning runs. Salmon start entering the streams in late September, and spawning continues through December. As nearly as possible, all levels of the food chain were sampled. Stream sediments, sculpins, and brown trout were collected in Pine and Bigelow creeks each time the streams were visited. All samples were taken within a 400-m stretch of stream that was extensively used by spawning salmon. Mottled sculpins *Cottus bairdi* were collected in Bigelow Creek, and slimy sculpins *Cottus cognatus* were found in Pine Creek. Rainbow trout *Salmo gairdneri* were collected in Pine and Bigelow creeks, but were not present in Hersey Creek.

All trout were measured, stomachs were removed, and scale samples were taken at the streams. Stomachs were immediately preserved in 10% formalin solution to stop digestion. Sculpins were preserved intact in formalin.

An age–size distribution was determined from trout collected the first time the streams were sampled. On subsequent sampling trips, an attempt was made to collect six each of age-I and age-II brown trout and age-I rainbow trout. Because of variability of sizes within the age groups, this was not always accomplished. Brown trout were not abundant in either Pine Creek or Bigelow Creek, and I attempted to minimize the number of trout killed.

Adult coho and chinook salmon were collected periodically during spawning runs. Edible fillets and eggs were retained for contaminant analysis.

All samples, except the preserved stomachs and sculpins, were kept on ice until returned to the laboratory where they were frozen until they could be prepared for analysis.

An attempt was made to sample a benthic invertebrate species, but no single species was sufficiently abundant in each stream for tissue analysis. Crayfish *Orconectes* sp., which are susceptible to electrofishing, were found only in Bigelow Creek and were never abundant.

Two areas were selected as sediment sampling stations in each stream, one station having a high organic silt content, and the other with sediment of almost pure sand. Altogether, 28 sediment samples were collected in Pine and Bigelow creeks during the study. These were divided equally between samples of high organic silt content and those of almost pure sand. Salmon spawned in the areas sampled and their carcasses were numerous there during and after the spawning season. Hersey Creek was only sampled twice throughout the study. A sediment sample consisted of five cores taken at each sample station. Each core was 3 cm in diameter and recovered the top 10 cm of substrate. The five subsamples were thoroughly mixed in a plastic bag, kept on ice until returned to the laboratory, and frozen until analyzed.

Laboratory Methods

Food items in trout and sculpin stomachs were counted in the laboratory. During the 1977 salmon spawning period, it became obvious that salmon eggs constituted a high percentage of the diet of the stream fish. Because of the large size of salmon eggs relative to most other food items, numerical analysis of stomach contents did not represent the importance of the various items in the diet. Consequently, during the 1978 spawning run, the weight of salmon eggs was separated from the total weight of the remaining stomach contents.

Wet weights were determined on an electric balance after the samples were brought to a uniform state of moisture. Excess moisture was removed from the items by placing them in a fine-mesh

TABLE 1.—Mean concentrations (with 95% confidence limits) per wet weight of PCBs and DDT in crayfish, sculpins, brown trout, rainbow trout, salmon, and salmon eggs in Bigelow and Pine creeks.

Species	Sample[a]	Number of samples	PCBs (mg/kg)	DDT (mg/kg)
		Bigelow Creek		
Crayfish	Whole	4	0.21±0.19	0.05±0.06
Sculpins	Whole	7	0.32±0.12	0.10
Brown trout				
Age I	Composite fillets	11	0.54±0.20	0.36±0.29
Age II	Composite fillets	7	0.39±0.07	0.17±0.07
Age I	Individual fillet	6	0.49±0.13	0.23±0.03
Rainbow trout				
Age I	Composite fillets	11	1.05±0.51	0.37±0.18
Age II	Composite fillets	4	1.66±2.59	0.84±1.81
Age I	Individual fillet	14	0.75±0.19	0.25±0.04
Age II	Individual fillet	4	0.59±0.16	0.19±0.06
		Pine Creek		
Sculpins	Whole	7	1.17±0.56	0.23±0.12
Brown trout				
Age I	Composite fillets	8	0.72±0.28	0.35±0.14
Age II	Composite fillets	5	1.11±0.75	0.47±0.44
Age II	Individual fillet	15	1.42±0.82	0.47±0.26
Rainbow trout				
Age I	Composite fillets	12	1.47±0.64	0.45±0.13
Age II	Composite fillets	3	2.27±1.94	0.67±0.43
Age I	Individual fillet	11	0.36±0.09	0.18±0.07
		Bigelow and Pine creeks, combined data		
Coho salmon	Individual fillet	5	2.59±2.14	0.66±0.61
Coho salmon	Eggs	5	1.92±1.25	0.64±0.42
Chinook salmon	Individual fillet	6	1.59±0.85	0.34±0.18
Chinook salmon	Eggs	4	4.02±6.20	1.07±1.30

[a] Each "whole" sample was a composite of three to five whole individuals. Each "composite fillet" sample contained fillets from 2 to 10 trout. Each "individual fillet" sample came from one trout. Each "egg" sample comprised many eggs from one female.

wire basket made to fit in the sleeve of a centrifuge, and spinning them at 1,000 revolutions per minute for 30 s. The basket was placed in a weighing bottle to prevent further weight loss by evaporation while items were weighed. All PCB, DDT, and dieldrin analyses were conducted on a wet-weight basis by the Environmental Services Laboratory of Michigan Department of Natural Resources. The analytical methods have been described by Bedford and Zabik (1973). The PCBs were all Aroclor 1254 (Aroclors 1242 and 1260 were never detected), and the DDT complex was mostly DDE. Other laboratory commitments limited the number of samples that could be analyzed for this study, so most were composites of several fish of one age group (established from scale samples) of one species. Analyses of individual fish were conducted for the last three sampling periods of the study and these data were used to estimate variability. The only trout tissues analyzed for contaminants were edible fillets. Sculpin samples were ground whole fish, and they were always composite samples.

In addition to the routine samples that were taken each sampling period, additional organisms were collected as available throughout the study. These included adult salmon and eggs taken from females prior to spawning.

Results and Discussion

All samples were analyzed for dieldrin, PCBs, and DDT. Dieldrin was never detected in any of the stream communities, nor were PCBs or DDT detectable in any samples from the control stream. Sediment samples from the study streams also failed to yield measurable quantities of any contaminants. Decay of salmon carcasses is relatively slow in the cold water prevalent during spawning season. Once a carcass became embedded in a silt bed, it could usually be found undisturbed for several months. One sediment sampling station in an area of organic silt was intentionally located close

TABLE 2.—Mean number of salmon eggs, and the percent eggs formed of entire ration (with 95% confidence limits) in stomachs of trout from Pine and Bigelow creeks during salmon spawning, 1978.

Species and age of trout	Collection date, 1978	N	Number of eggs		Average % eggs of total ration (weight)
			Average	Range	
			Pine Creek		
Brown trout					
Age I	Oct 12	3	30.3±24.9	20–40	85.3±7.8
Age II	Oct 12	2	45.0±190.6	30–60	87.5±95.3
Age II	Dec 6	5	17.6±38.0	0–72	32.6±41.6
Rainbow trout					
Age I	Oct 12	7	9.0±6.6	0–23	59.1±25.5
Age I	Dec 6	6	3.8±3.9	0–9	44.2±38.3
			Bigelow Creek		
Brown trout					
Age I	Oct 12	3	18.3±44.8	0–36	31.2±73.6
Age I	Dec 6	9	2.1±2.8	0–7	3.5±8.1
Rainbow trout					
Age I	Oct 12	5	16.8±2.8	14–20	39.6±25.3
Age I	Dec 6	8	2.8±3.6	0–12	34.1±30.3

to a buried, decomposing carcass. This silt bed was sampled several times during the decay process, but chlorinated hydrocarbons were never detected. I found no evidence that chlorinated hydrocarbons transported into spawning streams in salmon tissues are retained in the streams by adsorption to organic sediments.

Salmon

Fillets and eggs of coho and chinook salmon were contaminated with PCBs and DDT in both Pine and Bigelow creeks (Table 1). The mean fillet concentrations in the two streams—coho salmon, 2.59 mg PCB/kg and 0.66 mg DDT/kg; chinook salmon 1.59 mg PCB/kg and 0.34 mg DDT/kg—were fairly similar to those in Lake Michigan fish (>2.3 kg) measured during the Great Lakes Environmental Contaminants Survey (Anonymous 1977)—2.51 mg PCB/kg, and 1.86 mg DDT/kg. The concentration of contaminants in salmon eggs was higher than in fillets from the same salmon.

Crayfish

Crayfish from Bigelow Creek were the only invertebrates sampled in sufficient quantity for contaminant analysis. Composite samples of crayfish contained relatively low concentrations of chlorinated hydrocarbons (Table 1). It was reasoned that crayfish would feed directly on salmon carcasses and accumulate more contaminants. However, concentrations in my limited number of composite samples do not implicate crayfish as likely sources of contamination of the higher trophic levels.

Sculpins

Concentrations of PCBs and DDT measured in whole sculpins from Pine and Bigelow creeks were mostly quite low; however, the mean of PCB concentration in the sculpins of Pine Creek was considerably higher than in those sampled from Bigelow Creek (Table 1).

The Office of Toxic Materials Control, Michigan Department of Natural Resources, has analyzed water from trout streams during salmon spawning runs and has never been able to detect PCBs or DDT (John Hesse, personal communication). Consequently, uptake by stream fish must be dietary. Although salmon eggs are a logical source of contaminants in the diet of sculpins, no eggs were found in 73 sculpin stomachs from Bigelow Creek, and only nine eggs were found in 58 sculpin stomachs from Pine Creek. All samples were taken during the spawning season when eggs were found in trout stomachs. The few eggs found in Pine Creek sculpins indicate that eggs were sometimes eaten, and Pine Creek sculpins had the greater PCB contamination. The low consumption of salmon eggs by sculpins is almost certainly due to habitat choice; sculpins were always collected in quiet backwater pools with organic silt sediments. Salmon eggs would be most abundant in the thread of the stream. The redds are located in fast riffle areas, and the eggs are most apt to be dislodged and carried in high-velocity sections.

None of the major food items in the diet of sculpins could be collected in sufficient quantity for analysis. Sculpin diets consisted primarily of

Gammarus, Oligochaeta, and insect larvae, including several species of Trichoptera, Ephemeroptera, and Diptera.

Trout

Most of the trout samples from Pine and Bigelow creeks were treated as composites of 2 to 10 fish due to the limited number of analyses that could be completed by the laboratory. Only the trout collected during the last three sampling trips of 1978 were analyzed individually.

Contaminant levels in all fish from Pine Creek tended to be higher than in fish of the same species from Bigelow Creek (Table 1). This was especially true of the brown trout, which had rather low concentrations of PCBs in Bigelow Creek. Rainbow trout from Pine Creek had the highest PCB concentrations, which exceeded 2 mg/kg in several composites of five or more fish.

The PCB concentration in most trout samples was two to three times the concentration of DDT. This is approximately the same ratio measured in the adult salmon in the streams.

The stomach contents of trout from Pine and Bigelow creeks indicated the most likely dietary source of contaminants was salmon eggs. The major salmon-spawning period in both streams extends from early October through December, and some salmon are in the streams from September to February. Trout fed extensively on salmon eggs throughout the spawning period. The occurrence of 20 or more eggs per trout stomach was common, and numbers ranged to a high of 72 eggs found in one age-II brown trout (Table 2). Many trout were so gorged with eggs that their presence could be visually detected externally when the trout were captured. It is thus obvious that a major portion of the diet of some trout, over a period of at least 90 d, was contaminated with chlorinated hydrocarbons. The percent (weight) contribution of salmon eggs to the diet ranged from 3.5 to 87.5%. The large confidence limits for many of the collections indicate the extreme variability in consumption of eggs by trout. Some stomachs in the collection contained no eggs. The greater number of eggs in stomachs in October coincided with the peak of the spawning season. Salmon eggs were more important in the diet of trout in Pine Creek (62% by weight overall) than in Bigelow Creek (27%). Pine Creek also supports a larger spawning population of salmon (Carl 1980). The number of eggs deposited was estimated to be 809/m^2 in Pine Creek and 421/m^2 in Bigelow Creek.

If some trout consume more eggs than others, it is reasonable that the rate of consumption would affect the uptake of chlorinated hydrocarbons. Contaminant concentrations in 25 individual trout collected during the 1978 salmon-spawning season were correlated with the number of eggs in their stomachs (Figure 1: PCB, $r = 0.96$; DDT, $r = 0.97$), indicating that some individuals become habitual salmon egg eaters, and thus subject to higher levels of dietary contamination. These were probably trout that resided immediately downstream from preferred spawning areas. Some redds are used repeatedly throughout the spawning season, resulting in continual disruption and dislodging of eggs. Even though all trout were collected within approximately 400 m of stream, the availability of eggs within the sampling area was probably quite variable. It is also possible that individual trout learn to locate areas where drifting eggs are abundant. The average contribution of eggs to the total ration of all trout sampled in both study streams during October was 66% by number of items and 74% by weight.

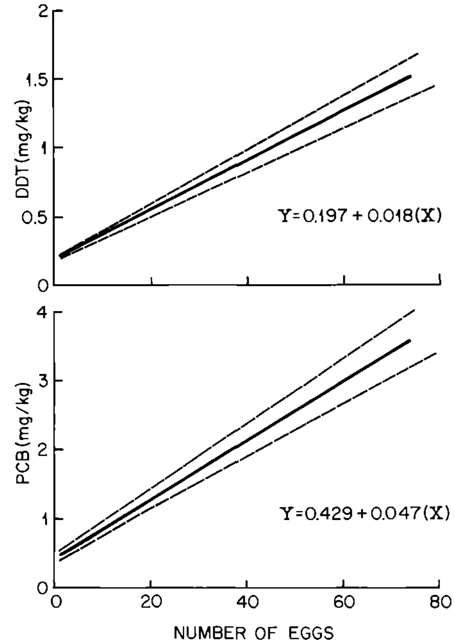

FIGURE 1.—Concentrations of PCBs and DDT (Y) in trout fillets from Bigelow and Pine creeks as a function of number of eggs (X) in their stomachs. Dashed lines represent the 95% confidence limits about the regression line.

In summary, my study provides reasonably strong evidence for chlorinated hydrocarbon contamination of resident stream trout by spawning salmon in Great Lakes tributaries. The study failed to demonstrate retention of contaminants in stream sediments and indicated relatively low contamination of crayfish and sculpins. The observed food habits of the trout indicate that the most likely source of contamination is salmon eggs. Concentrations of PCBs and DDT in fish tissue appear to be decreasing in Lake Michigan. If they continue to decline, contamination will probably not constitute a hazard to either the trout population or to human health. At the time the samples were collected, however, some trout fillets contained more than the allowable limit of 2 mg/kg of PCBs.

References

Anonymous. 1977. Great Lakes environmental contaminants survey—1976–1977. Michigan Department of Agriculture in cooperation with Michigan Department of Natural Resources and United States Food and Drug Administration. Michigan Department of Natural Resources, Lansing.

Bedford, J. W., and M. J. Zabik. 1973. Bioactive compounds in the aquatic environment: uptake and loss of DDT and dieldrin by freshwater mussels. Archives of Environmental Contamination and Toxicology 1:97–111.

Carl, L. M. 1980. Aspects of the population ecology of chinook salmon in Lake Michigan tributaries. Doctoral dissertation. University of Michigan, Ann Arbor.

Chadwick, G. G. , and R. W. Brocksen. 1969. Accumulation of dieldrin by fish and selected fish food organisms. Journal of Wildlife Management 33:693–700.

Grzenda, A. R., D. F. Paris, and W. J. Taylor. 1970. The uptake, metabolism and elimination of chlorinated residues by goldfish (*Carassius auratus*) fed a ^{14}C-DDT contaminated diet. Transactions of the American Fisheries Society 99:385–395.

Hamelink, J. L., R. C. Waybrant, and R. C. Ball. 1971. A proposal: exchange equilibria control the degree chlorinated hydrocarbons are biologically magnified in lentic environments. Transactions of the American Fisheries Society 100:207–214.

Harrison, H. L., and six coauthors. 1970. Systems studies of DDT transport. Science (Washington, D.C.) 170:503–508.

Jarvinen, A. W., M. J. Hoffman, and T. W. Thorslund. 1976. Toxicity of DDT food and water exposure to fathead minnows. U.S. Environmental Protection Agency, Ecological Research Series EPA-600/3-76-114.

Jensen, A. L., S. A. Spigarelli, and M. M. Thommes. 1982. PCB uptake by five species of fish in Lake Michigan, Green Bay of Lake Michigan, and Cayuga Lake, New York. Canadian Journal of Fisheries and Aquatic Sciences 39:700–709.

Johnson, T. B., R. C. Saunders, H. O. Sanders, and R. S. Campbell. 1971. Biological magnification and degradation of DDT and aldrin by freshwater invertebrates. Journal of the Fisheries Research Board of Canada 28:705–709.

Macek, K. J., and S. Korn. 1970. Significance of the food chain in DDT accumulation by fish. Journal of the Fisheries Research Board of Canada 27:1496–1498.

Odum, W. E., G. M. Woodwell, and C. F. Wurster. 1969. DDT residues absorbed from organic detritus by fiddler crabs. Science (Washington, D.C.) 164:576–577.

Reinert, R. E. 1967. The accumulation of dieldrin in an alga (*Scenedesmus obliquus*), daphnia (*Daphnia magna*), guppy (*Lebistes reticulatus*) food chain. Doctoral dissertation. University of Michigan, Ann Arbor.

Spigarelli, S. A., M. M. Thommes, and W. Prepejchal. 1983. Thermal and metabolic factors affecting PCB uptake by adult brown trout. Environmental Science and Technology 17:88–94.

Sullivan, J. R., J. B. Delfina, C. R. Buelow, and T. B. Sheffy. 1983. Polychlorinated biphenyls in the fish and sediment of the Lower Fox River, Wisconsin. Bulletin of Environmental Contamination and Toxicology 30:58–64.

Thomann, R. V. 1981. Equilibrium model of fate of microcontaminants in diverse aquatic food chains. Canadian Journal of Fisheries and Aquatic Sciences 38:280–296.

Thomann, R. V., and J. P. Connolly. 1981. An age dependent model of PCB in a Lake Michigan food chain. Manhattan College Environmental Engineering and Science Program, Final Report to the U.S. Environmental Protection Agency in Cooperative Agreement CR805916010, Duluth.

Received April 17, 1984
Accepted August 6, 1985