Insecticides, Polychlorinated Biphenyls and Metals in African Lake Ecosystems. II. Lake McIlwaine, Rhodesia

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Although there are numerous studies on concentrations and biological magnification of pesticides and polychlorinated biphenyls (PCB's) in American lake ecosystems, (HUNT and BISCHOFF 1960, HICKEY *et al.* 1966, HANNON *et al.* 1970), there are very few on African lakes. Africa is of special interest because many insecticides which have been limited in usage in the United States such as DDT, aldrin and dieldrin are still commonly used in many African countries. Therefore, during 1974-1975 four African lakes were examined for the concentration and distribution of insecticides, PCB's and metals. The results of these studies on two of these lakes, Hartbeespoort Dam and Voëlvlei Dam in the Republic of South Africa have been reported by GREICHUS *et al.* (1977). This paper deals with Lake McIlwaine in Rhodesia. A later paper will report the results on Lake Nakuru, Kenya.

STUDY AREA

Lake McIlwaine is situated approximately 35 km southwest of Salisbury, the capital of Rhodesia, (Fig. 1). It was formed by an earth dam built in 1952 on the Hunyani river. The capacity of the dam is 2,504,000,000 cubic meters, and the catchment area covers 2,230 km^2 most of which is agricultural land or natural woodland. The main inflow of water is provided by the Hunyani river in the southeast and from two smaller rivers, the Makabusi and Marimba. The city of Salisbury with a population of about 500,000 is located in the northern portion of Lake McIlwaine's catchment area. All the sewage effluent produced by the city is discharged into the lake via the Makabusi and Marimba rivers.

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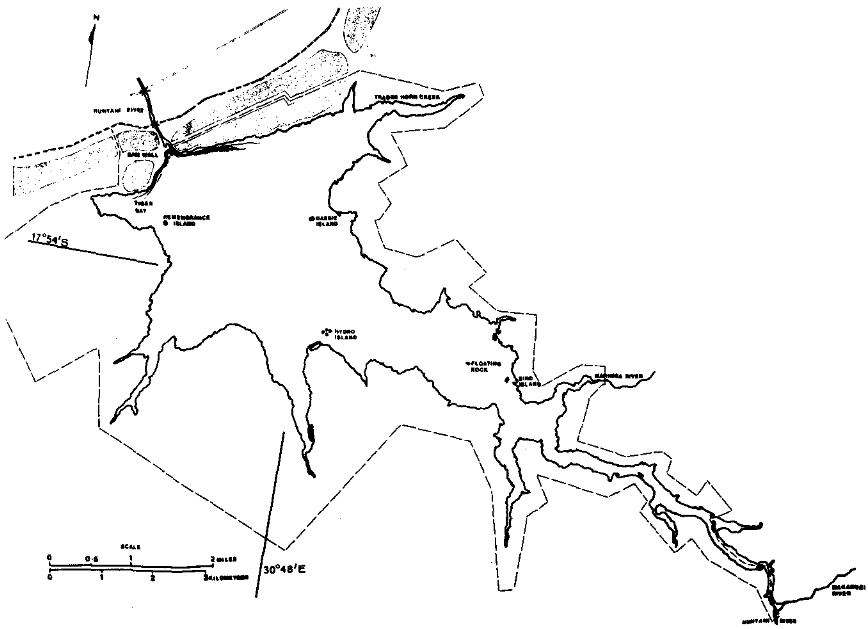

Figure 1. Lake McIlwaine and catchment area.

Lake McIlwaine's primary purpose is to supply water for Salisbury, but it is also heavily used for recreation. There are yachting, power boat and angling clubs, camping and caravan sites, a hotel, and a commerical fishery located on the lake. Lake McIlwaine's entire area is in the Robert McIlwaine National Park, and the southern portion is maintained as a game park, supporting a variety of game species which are no longer found in the surrounding farm land.

Treated sewage effluent discharged into the Makabusi and Marimba rivers flows into Lake McIlwaine making the lake highly eutrophic (MARSHALL and FALCONER 1973). A serious aspect of the eutrophication is the high population of blue-green algae, which has made water purification expensive and difficult (MCKENDRIC and WILLIAMS 1968). Water from the rivers has been diverted for crop irrigation to reduce the effluent flowing into the lake. The benthic fauna, of which the oligochaete (*Branchiura sowerbyi*) are the most abundant, has been affected by eutrophication of the lake

(MARSHALL 1971).

Twenty-three species of fish have been reported in Lake McIlwaine. The most important of these is the green-headed bream (*Sarotherodon macrochir*) which comprises approximately 60 percent of the commerical catch. Also there are numerous fish-eating birds that live around the lake, the most common being the white-breasted cormorant (*Phalacrocorax carbo lucidus*), the reed cormorant (*Phalacrocorax africanus*) and the darter (*Anhinga rufa*). These birds feed primarily on two species of small fish, the dwarf bream (*Haplochrimis darlingi*) and the spot tail (*Alestes imberi*).

MATERIALS AND METHODS

Lake McIlwaine was chosen as the lake to be studied in Rhodesia by scientists from the University of Salisbury and from the Department of National Parks and Wildlife Management. The decision was based on the economic and recreational value of the lake.

Samples were collected from October 24 to November 3, 1974 and included water, bottom sediments, plankton, oligochaetes, benthic insects, three species of fish (green-headed bream, dwarf bream and spot tail), and a fish-eating bird (the white-breasted cormorant).

Samples were collected by the same methods employed for the two lakes in the Repbulic of South Africa (GREICHUS *et al.* 1977). All samples were preserved in 10 percent formalin except water samples (200 ml) for metal analysis which were adjusted to a pH of <2.0 with HNO_3. Water samples were filtered before analysis through columns with sealed-in coarse porosity glass fritted discs. Studies conducted in this laboratory (GREICHUS *et al.* 1977) and by others (FRENCH and JEFFERIES 1971) have shown that insecticide and PCB residues in formalin preserved samples do not differ appreciably from those preserved by freezing. With both freezing and formalin preservation, p,p'-DDT and p,p'-DDD are slowly converted to p,p'-DDE. Formalin was analyzed for the presence of insecticides, PCB's and metals and found not to significantly contribute to the concentration of these materials in the samples. In the tables 1 and 3 carcass refers to a subsample of the entire bird minus intestinal contents, brain and a 10 g sample of feathers. Samples were flown as soon as possible to the Chemistry Department of South Dakota State University for analysis.

All samples were analyzed for PCB's and the following organochlorine insecticide residues: lindane, heptachlor, aldrin, endrin, heptachlor epoxide, dieldrin, chlordane, endosulfan, methoxychlor, bayluseide, toxaphene, DDE, DDD and DDT. Methods of analysis, instrumentation and recovery efficiencies for the insecticides, PCB's and metals were the same as described by GREICHUS *et al.* (1977). Insecticide and PCB residue values were corrected for percent recovery but values for metals were not. PCB's were analyzed on the basis of those resembling Aroclor 1254 and having six or less chlorines and those resembling Aroclor 1260 and having six or more chlorines (GREICHUS *et al.* 1974). Those peaks on the chromatogram with a relative retention time of 2.05 or less in comparison to p,p'-DDE under the gas chromatographic conditions employed in this study (GREICHUS *et al.* 1977) were calculated as 1254 and those with greater retention times as 1260. No major peaks of 1254 occur after the relative retention time of 2.05.

All types of samples were analyzed for the following metals: mercury, zinc, lead, arsenic, cadmium, copper and manganese. Arsenic was included in this group and referred to as a metal although it is a metalloid.

Analysis on a fresh wet weight basis could not be precisely determined because samples were preserved in 10 percent formalin. Samples for insecticide and PCB analysis were analyzed directly from their containers simultaneously with a dry weight determination ("Official Methods of Analysis" 1965). The sample used for the dry weight was also used for the metal analysis. In calculations of averages and totals, less than (<) values were included and given onehalf the stated value, that is, a value of less than 0.1 would become 0.05.

RESULTS AND DISCUSSION

Insecticides and PCB's

Concentrations of insecticide and PCB residues for the Lake McIlwaine ecosystem are given in Table 1. The insecticide residues detected most commonly were DDT, DDD, DDE and dieldrin. Those not found in concentrations above the minimum values for this laboratory included lindane, heptachlor, heptachlor epoxide, aldrin, chlordane, endrin, methoxychlor, toxaphene, endosulfan and bayluseide. Minimum values in ppm for insecticides and PCB's, respectively were as follows: water, 0.0001 and 0.001;

TABLE 1

Average Concentrations of Polychlorinated Biphenyls and Insecticides in the Lake McIlwaine Ecosystem

ppm (ug/g)[a]

Description	No	PCB's 1254[b]	PCB's 1260[b]	PCB's Total	DDE	Dieldrin	DDD	DDT	Insecticides Total
Water	10	<.001	<.001	<.001	0.0001	<.0001	<.0001	<.0001	<.0002
Bottom Sediment	10	0.05	0.07	0.12	0.015	0.004	0.040	0.002	0.061
Plankton	5[c]	0.13	0.05	0.18	0.01	<.01	0.02	0.02	0.06
Oligochaetes	1[c]	0.77	<.5	1.0	0.18	0.08	0.33	0.14	0.73
Benthic Insects	1[c]	1.3	<.5	1.6	0.13	<.01	0.12	0.11	0.36
Fish									
Dwarf Bream	5[d]	1.8	0.51	2.3	0.12	0.07	0.16	0.04	0.39
Spot Tail	5[e]	1.7	<.5	1.9	0.24	0.04	0.10	<.01	0.38
Greenheaded Bream	5[d]	0.98	<.5	1.2	0.08	0.03	0.10	<.01	0.22
Greenheaded Bream	5[f]	0.92	<.5	1.2	0.13	0.12	0.18	0.14	0.57
Cormorant									
Carcass	10	9.8	3.7	13.	11.	0.92	0.81	0.27	13.
Brains	10	1.8	2.0	3.8	2.5	1.4	0.06	0.15	4.1
Feathers	10	0.77	<.5	1.0	0.41	0.09	<.01	0.06	0.57

a. All samples analyzed on a dry weight basis except water.
b. The designation 1254 indicated those compounds having six or less chlorines and 1260 with six or more chlorines. See text for further explanation.
c. Each sample consists of a composite collected from all over the lake.
d. Each sample consists of a composite of 10 fish ranging from 23 to 40 g.
e. Each sample consists of a composite of 20 fish ranging from 6 to 9 g.
f. Individual fish ranging from 578 to 824 g.

bottom sediments, 0.001 and 0.02; and plankton, oligochaetes, benthic insects, fish and birds, 0.01 and 0.5.

Levels of total insecticides for all types of samples from Lake McIlwaine were higher than those of Voëlvlei Dam and lower than those of Hartbeespoort Dam, except bottom sediments which had higher levels of insecticides than either of the two dams. Because the samples were preserved in formalin, it was not possible to calculate wet weights. However, an estimation of wet weights revealed that both fish and birds from Lake McIlwaine had higher concentrations of insecticide residues than those reported by KOEMAN *et al.* (1972) for Lake Nakuru, Kenya.

There were greater amounts of PCB's than insecticides in all types of samples except carcass and brain of cormorants (Table 1). This was also true for Hartbeespoort and Voëlvlei Dams except that brain of birds also had higher concentrations of PCB's than total insecticides (GREICHUS *et al.* 1977). PCB levels in brains of cormorants (*Phalacrocorax auritus*) and pelicans (*Pelecanus erythrorhynchos*) collected from Lake Poinsett, South Dakota, were also higher than total insecticide levels although carcasses had higher levels of insecticides (GREICHUS *et al.* 1973).

In general concentrations of insecticides and PCB's in the Lake McIlwaine ecosystem were higher than those in Voëlvlei Dam and lower than those in Hartbeespoort Dam. The explanation may be that the catchment area of Hartbeespoort Dam encompasses a higher population with much more industrialization than does the catchment area of Lake McIlwaine, whereas, Voëlvlei Dam is remote from any large city or industrial area.

Bird carcass had higher average levels of PCB's with a greater percent of the PCB's having six or more chlorines than did fish carcass. Lower chlorinated PCB's were found by KOEMAN *et al.* (1969) to occur more frequently in the tissues of fish than sea birds.

Both insecticide and PCB levels increased with trophic level in Lake McIlwaine. It is interesting that the increased concentration of insecticides and PCB's in bird carcass compared to fish was similar for Lake McIlwaine (37 and 8 fold), Hartbeespoort Dam (30 and 7 fold) and Voëlvlei Dam (30 and 5 fold). This was not due simply to an increase in the amount of lipid in the cormorant carcass compared to the fish as the percent of lipid in dried samples of carcass of cormorant, spot tail and dwarf bream were respectively, 21, 20 and 22.

Metals

Average concentrations of metals in the Lake McIlwaine ecosystem are given in Table 2. Level of metals were within ranges reported for some American lakes and rivers for water (BUHLER 1972, PROCTOR and LANCE 1973), bottom sediments (MATHIS and KEVERN 1973, PERHAC 1974, LELAND and SHIMP 1974) and plankton (MATHIS and KEVERN 1973, FUNK *et al.* 1973). Concentrations of metals in bottom sediments of Lake McIlwaine for all types of samples were greater than those in Voëlvlei Dam and less than those in Hartbeespoort Dam (GREICHUS *et al.* 1977). Of the three areas of the dam sampled for metals, the mouth of the Hunyani River had the highest concentrations except for arsenic and copper. This may be due to sewage effluent from the city of Salisbury which is discharged into the Makabusi River which in turn empties into the Hunyani River at its entrance into the lake.

FUNK *et al.* (1973) reported higher levels of metals in aquatic worms and insects in the Spokane River than those found in Lake McIlwaine. Concentration of metals in fish from Lake Nakuru (KOEMAN *et al.* 1972) were similar to those in Lake McIlwaine. Levels of arsenic, copper, zinc, cadmium and mercury were, respectively, 0.086, 1.6, 19, not detected and 0.016 (ppm/wet weight) for Lake Nakuru fish while Lake McIlwaine fish had, respectively, 0.3, 1.45, 13, 0.03 and 0.06 (ppm/estimated wet weight). In general Lake McIlwaine fish had levels of metals somewhat higher or similar to those of Voëlvlei and Hartbeespoort Dams.

Concentrations of metals in cormorant carcasses from Lake McIlwaine (Table 3) did not appear to be unusual. Levels of arsenic and mercury in the cormorant carcasses were higher than levels in kidney and liver of white pelicans (*Pelecanus onocrotalus*) from Lake Nakuru (KOEMAN *et al.* 1972). Mercury levels were higher in muscle, brain and feathers of white pelicans collected in Idaho than levels in birds from Lake McIlwaine, Voëlvlei Dam or Hartbeespoort Dam. Birds from the three African lakes had considerably lower levels of mercury than ducks collected from Clay Lake, Ontario (VERMEER *et al.* 1973).

TABLE 2

Average Concentrations of Metals in Lake McIlwaine

	ppm (ug/g)[a]					
Description	Water[b]	Bottom Sediment[b]	Plankton[c]	Oligo-chaete[c]	Benthic Insects[c]	Fish[d]
Arsenic	0.003	37.	2.9	6.0	1.3	1.4
Cadmium	0.001	0.39	1.5	0.05	0.08	0.12
Copper	0.010	38.	N.A.[e]	7.2	10.	5.4
Manganese	0.032	350.	220.	28.	8.8	27.
Lead	0.010	41.	78.	1.3	0.91	0.84
Zinc	0.012	100.	190.	130.	78.	48.
Mercury	<.001	0.28	0.26	0.08	N.A.[e]	0.23

a. All samples analyzed on a dry weight basis except water.
b. Three samples taken from three areas of the lake.
c. One composite sample collected from all over the lake.
d. Three individual fish weighing 661, 824, and 763 g.
e. Not analyzed.

TABLE 3

Average Concentration of Metals in Cormorants Collected from Lake McIlwaine

Description	ppm (ug/g)[a] Carcass	Brain	Feather
Arsenic	1.4	0.94	1.2
Cadmium	0.04	0.10	0.38
Copper	3.1	9.0	8.7
Manganese	4.9	1.6	21.
Lead	2.7	1.3	2.4
Zinc	77.	33.	180.
Mercury	2.8	1.3	0.65

a. Values represent an average of three samples. Dry weight basis.

STICKEL (1975) has discussed the accumulation of lead and mercury in various food chains. The average concentration of lead and mercury in the small fish which constitute the major part of the diet of the Lake McIlwaine cormorant was 0.39 and 0.11 ppm, respectively. Bodies of cormorants contained 7 and 25 times as much as these two metals than bodies of fish.

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