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Mercury and Other Contaminants in Fish from Lake Chad, Africa

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Mercury and persistent organic pollutants (POPs) are widespread contaminants in freshwater food webs and their presence in abiotic and biotic compartments is influenced by numerous natural processes and human activities (Wiener et al. 2003; Larsson et al. 1998). In addition to localized inputs to lakes and rivers, both mercury and POPs can be transported long distances via the atmosphere and subsequently deposited in systems far-removed from source regions (Wiener et al. 2003; Mackay and Wania 1995). It is the organic form of mercury, methylmercury, which accumulates and concentrates through food chains and can be found at high concentrations in fish (Wiener et al. 2003). Similarly, POPs such as DDT and PCBs also bioaccumulate to significant concentrations in the top predators of lakes (e.g. Rasmussen et al. 1990) due to their recalcitrance in the environment, their lipophilic nature and the slow excretion rates in biota (e.g. Fisk et al. 1998). Considerable concern exists over the presence of these contaminants in fish, particularly in systems used for subsistence fisheries, due to the potential for human health impacts (e.g. World Health Organization 1990). Because much of the previous work has been done on mid- or high-latitude systems, little is known about pollutants in fish from tropical lakes.

Lake Chad, the largest lake in Central Africa, is facing numerous pressures from the riparian countries of Cameroon, Chad, Niger and Nigeria. There have been decreases in rainfall in the region (Olivry et al. 1996), resulting in more people moving to the Lake Chad basin and an increased usage of the lake to support agriculture and fisheries (Sarch 2001). The objectives of this study were to determine the concentrations of mercury and POPs in fish from Lake Chad, and to understand the factors that affect the concentrations of these pollutants in the fish. There is no noticeable industry in the basin that would contribute contaminants to the lake. In addition, information on recent pesticide usage in the basin was not possible to obtain.

MATERIALS AND METHODS

In December of 2000, fish, oysters and macrophytes were collected from the southern end of Lake Chad near the Chari Delta. Fish were obtained from local

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fisherman the same day they were caught while oysters and macrophytes (roots excluded) were collected by hand in the nearshore areas of the lake. Length of the fish was determined on site, and muscle samples were taken from the large fish. Whole fish, oysters and macrophytes, and muscle samples were placed in plastic bags, frozen and shipped for analyses. The fish collected had a range of dietary habits. *Oreochromis niloticus, Sarotherodon galileus, Distichodus* sp. and *Citharinus citharus* feed upon phytoplankton or periphyton. *Alestes baremoze* feed upon zooplankton. *Synodontis schall, Auchenoglanis occidentalis tchadensis, Heterotis* sp. and *Brycynus nurse* feed upon a variety of insects, crustaceans and plant materials. *Clarias gariepinus, Hydrocynus forskalii,* and *Bagrus* sp. are mainly fish eaters but also consume some invertebrates. *Lates niloticus* and *Polypterus bichir* feed upon other fish (Blache 1964; Lauzanne, 1983). In addition, the oyster *Etheria elliptica* was also collected to examine mercury concentrations and dietary habits of an invertebrate. Several nearshore plants were also collected to examine the isotopic composition of some of the primary producers.

Fish muscle tissue and whole oysters were analyzed for total mercury using the methods given in Hendzel and Jamieson (1976). Tissues were digested in nitric and sulfuric acid at 180 ^{o}C, and the extracts analyzed on an atomic absorption spectrophotometer. For quality control purposes, certified reference materials were analyzed concurrently and mean measured mercury concentrations in these materials were 0.30 ± 0.01 (n=4; certified value 0.27 ± 0.06 ug/g wet weight for Tort-2) and 2.0 ± 0.2 (n=3; certified value 2.1 ± 0.3 ug/g wet weight for Dolt-2). Concentrations of mercury in fish at or below 10 ng/g wet weight were not detectable using these methods. When some (but not all) of the values were below the detection limit for a given species, random numbers between 1 and 10 were assigned to samples to calculate means and standard deviations. All contaminant concentrations were reported on a wet weight basis.

For POP analyses, muscle samples from three or four individuals from each of two species of fish (*Synodontis schall* and *Oreochromis niloticus*) were composited based on length. These species were chosen because these genera had been analyzed for POPs in studies of other African lakes. Samples were Soxhlet extracted using 1:1 hexane:dichloromethane, cleaned up and fractionated on Florisil, and then analyzed for a number of chlorinated organic contaminants using the methods detailed in Kidd et al. 2001. Percent lipid in these tissues was determined gravimetrically using 1/11th of the extract. Florisil eluates were analyzed by capillary gas chromatography with ^{63}Ni electron capture detection using a Varian 3400 GC (Varian Instruments Palo Alto CA) equipped with a 60 m x 0.25 mm DB-5 column. Individual compounds were calibrated using external standards. Recoveries of the internal standard octachloronaphthalene ranged from 61 to 90%; data were not adjusted for recoveries. Reagent blanks were run and showed only background levels of organochlorines; results were not blank corrected. ΣPCB represents the sum of 100 individual PCB congeners. ΣDDT is the sum of the parent compounds (*p,p'*- and *o,p'*-DDT) and metabolites (*p,p'*- and *o,p'*-DDD, *p,p'*- and *o,p'*-DDE). ΣHCH was quantified as the sum of αHCH, βHCH, and γHCH. The chlorobenzenes (ΣCBz), microcontaminants in pesticide formulations, detected in these fishes included 1,2,3,4-tetrachlorobenzene, hexachlorobenzene and pentachlorobenzene. Total chlordane (ΣCHL) was the sum of all chlordane-related compounds including heptachlor epoxide. Instrument detection limits range from 0.029-0.097 pg for ΣHCH, 0.022-0.027 pg for ΣCHL, 0.039-0.063 pg for ΣDDT, 0.043-0.354 pg for ΣPCB and 0.027-0.335 pg for ΣCBz.

Dietary habits of these organisms were determined using stable carbon (C) and nitrogen (N) isotope analyses to quantify source of carbon and trophic position of the individuals, respectively (Kidd et al. 2001). Little or no fractionation of $^{13}C/^{12}C$ ratios occurs from prey to predator providing a means to trace carbon flow from primary producers to tertiary consumers (Hecky and Hesslein 1995). In contrast, the heavier isotope of nitrogen (^{15}N) is preferentially enriched in the consumer relative to its food by about 3 parts per thousand (per mil), providing a continuous measure of trophic positioning (Kidd et al. 2001). Stable C and N isotope analyses were conducted on dried and ground tissues from all individual fish (muscle only), oysters or plants. One mg samples were analyzed for C and N isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) using an automated mass spectrometer. All carbon and nitrogen isotope samples were standardized against carbon in V-PeeDee limestone and nitrogen in air, respectively, and expressed on a per mil (‰) basis. Triplicates of every tenth sample were analyzed and precision for $\delta^{13}C$ and $\delta^{15}N$ was 0.2 and 0.3 ‰, respectively.

Statistical analyses were conducted to determine the relationships between mercury concentrations and fish size or trophic positioning in the Lake Chad food web. Mercury concentrations were $\log_{10}$-transformed because standard deviations tended to be proportional to the means. All statistical analyses were conducted using the General Linear Model (GLM) in SAS (SAS, 1985).

RESULTS AND DISCUSSION

Diet was an important determinant of mercury concentrations in fish from Lake Chad; concentrations of mercury were highest in the fish-eating species *L niloticus* and *H. forskalii*, with means of 60 and 74 ng/g, respectively. Fish that feed upon insects and other invertebrates had mercury concentrations that were 3-4 times lower (e.g. *S. schall,* 17 ng/g) than the piscivorous species. Lowest concentrations of mercury concentrations were measured or often not detected (<10 ng/g) in fish such as *O. niloticus* and *Distichodus* spp that feed upon plants and algae (Table 1).

No relationships between fish size and mercury concentrations were found for each species of fish from Lake Chad (p=0.15 to 0.67). This may be due to a limited size range of fish sampled. Size has been shown to be important for several species from Lake Malawi (Kidd et al. 2003) as well as for fish from cold-water lakes (Bodaly et al. 1993; Wiener et al. 2003), with highest mercury concentrations in the largest (and presumably oldest) fish.

In general, fish from Lake Chad had similar or lower concentrations of Hg when compared to fish from other Africa lakes. Fish from Lake Chad had comparable concentrations to what has been found recently in Lake Malawi (Kidd et al. 2003), and consistently lower mercury levels than was found in Lake Victoria (Ramlal et al. 2003; Campbell et al. 2003; Table 2). As one exception, *Clarias* from Lake Chad had higher concentrations of mercury than the same genus from Lake Malawi, although only one fish was analyzed from the latter system. Primary consumers (*Tilapia* spp.) from lakes in Egypt (El Nabawi et al. 1987) and Kenya (Greichus et al. 1978) also had similar or higher concentrations of mercury, 8 and 44 ng/g wet weight, respectively, (assuming 80% water) to what we found in *O. niloticus* from Lake Chad.

Table 1. Mean (± SD) mercury (Hg) concentrations (ng/g wet weight) in fish muscle and whole oysters, and length (mm) of fish from Lake Chad, Africa.

Species	# Samples (# < detection limit)	Hg	Length
Etheria elliptica (oyster)	5	19 ± 9	-
Oreochromis niloticus	15 (14)	7 ± 4	191 ± 34
Distichodus spp.	5 (5)	< 10	344 ± 62
Citharinus citharus	6 (6)	< 10	150 ± 65
Sarotherodon galileus	4 (4)	< 10	131 ± 34
Alestes baremoze	21 (8)	13 ± 7	153 ± 43
Synodontis schall	13 (2)	17 ± 8	137 ± 12
Heterotis sp.	1 (1)	< 10	490
Auchenoglanis occidentalis tchadensis	12 (4)	19 ± 14	298 ± 41
Brycynus nurse	1 (1)	< 10	170
Hydrocynus forskalii	5	74 ± 45	344 ± 133
Polypterus bichir	13 (4)	15 ± 9	307 ± 36
Lates niloticus	12	60 ± 23	497 ± 145
Clarias gariepinus	4	33 ± 5	590 ± 107
Bagrus sp.	1	58	-

Concentrations of the POPs in fish from Lake Chad were low in both species analyzed (Table 3). The multi-purpose pesticides chlordane, HCH and DDT, and the PCBs were the most common POPs found, and they were 2 to 3 times higher in *S. schall*, a fattier secondary consumer, than in the primary consumer *O. niloticus*. In addition, concentrations of these chlorinated compounds were highest in the composite samples of larger *O. niloticus*; however, this trend was not observed for *S. schall*. Results from Lake Chad concur with studies of other tropical systems. Highest concentrations of these pesticides and PCBs tend to be found in fattier and larger individuals (e.g. Kidd et al. 2001).

Table 2. Mean (± SD) mercury (Hg) concentrations (ng/g wet weight) in fish from Lakes Chad, Victoria and Malawi.

Lake	Species	Sample #	Hg
Chad	*Lates niloticus*	12	60 ± 23
Victoria 1995	*Lates niloticus*[1]	21	137 ± 46
Victoria 1998	*Lates niloticus*[2]	9	83 ± 16
Chad	*Synodontis schall*	13	17 ± 8
Malawi 1996	*Synodontis njassael*[3]	4	23 ± 13
Chad	*Oreochromis niloticus*	15	7 ± 4
Victoria 1995	*Oreochromis niloticus*[1]	3	20 ± 12
Victoria 1998	*Oreochromis niloticus*[2]	7	19 ± 6
Malawi 1996	*Oreochromis* spp. [3, 4]	17	5 ± 2
Chad	*Clarias gariepinus*	4	33 ± 5
Malawi 1996	*Clarias* sp[3]	1	10

[1]Ramlal et al, 2003; [2]Campbell et al, 2003; [3]Kidd et al, 2003; [4]*O. squamipinnis, lidole & karongae*

Results from Lake Chad were contrasted to findings from a study in East Africa on the Lake Malawi food web (Kidd et al. 2001 and unpublished data). *Oreochromis* from Lake Chad had comparable mean concentrations of ΣDDT and 2-9 fold higher concentrations of ΣCBz, ΣPCBs, ΣCHL and ΣHCH than the same genus from Lake Malawi. *Synodontis* from Lake Chad had lower concentrations of all of the more lipophilic POPs whereas mean ΣHCH concentrations were 10-fold higher. These individuals from Lake Chad were lower in lipid and smaller than the same genus from Lake Malawi which would contribute to the lower concentrations in the former system. Given the limited number of fish analyzed, it is difficult to determine whether POP concentrations in the Lake Chad food web are similar to those in other tropical lakes.

The $\delta^{15}N$ results (Table 4) confirmed what is known of the dietary habits of the fish from Lake Chad (Lauzanne 1983) or for inland African fishes (Paugy and Lévêque 1999). Fish which are known primary consumers (*O. niloticus, S. galileus, C. citharus, Distichodus* spp.) had the lowest $\delta^{15}N$ signatures (5.4 to 6.1 ‰) of all species analyzed. Species that consume zooplankton (*A. baremoze*), or benthic invetebrates, crustaceans and plant material (*A occidentalis*, *S. schall, B. nurse, Heterotis* sp.) have a higher range of $\delta^{15}N$ values from 5.9 to 7.0 ‰ than was observed for the primary consumers. The piscivorous species in Lake Chad, including *P. bichir, H. forskalii, L. niloticus* and *C. gariepinus,* had the highest mean $\delta^{15}N$ (7.6, 8.8, 9.2 and 10.2 ‰, respectively).

As in a previous study (Kidd et al. 2001), dietary habits of fish from Lake Chad are important in determining their pollutant concentrations. Mercury concentrations were highest in the piscivorous fish (with high $\delta^{15}N$ values) and lowest in primary consumers. Similarly, concentrations of POPs were higher in the invertebrate-eating *Synodontis* sp. (mean $\delta^{15}N$ of 7.0 ‰) than the algae-eating *Oreochromis* sp. (mean $\delta^{15}N$ of 5.7 ‰). Log-transformed mercury concentrations were significantly related to $\delta^{15}N$ ($\log Hg = 0.21 \pm 0.01\ \delta^{15}N - 0.37 \pm 0.13$, $r^2=0.55$, $p<0.001$) and the slope of this relationship was similar to what was observed in Lake Malawi (slope of 0.20; Kidd et al. 2003) and lower than was found in Lake Victoria (slope of 0.29; Campbell et al. 2003).

Table 3. Percent lipid, mean length (mm) and total concentrations (ng/g weight wet ± SD) of the pesticides ΣDDT, hexachlorocyclohexane (ΣHCH) and chlordane (ΣCHL), and chlorobenzenes (ΣCBz) and ΣPCBs in muscle of pooled fish (n=3-4/sample) from Lake Chad and similar species from Lake Malawi (DDT data is from Kidd et al. 2001, other POPs are Kidd's unpublished data).

Species	% Lipid	Mean Length (mm)	DDT	PCB	CHL	CBz	HCH
Lake Chad							
O. niloticus	0.9	226	0.471	1.831	0.089	0.026	0.469
O. niloticus	1.2	196	0.473	1.614	0.112	0.026	0.279
O. niloticus	0.5	175	0.280	1.400	0.114	0.032	0.073
O. niloticus	0.4	143	0.175	0.977	0.075	0.014	0.064
S. schall	2.2	137	0.931	1.887	0.166	0.035	1.017
S. schall	1.2	123	1.053	2.714	0.191	0.032	0.700
S. schall	1.1	130	0.381	3.289	0.227	0.028	0.347
Lake Malawi							
O. lidole & squamipinnis[1]	1.0 ± 1.0	313 ± 41	0.58 ± 0.38	0.37 ± 0.24	0.01 ± 0.01	0.01 ± 0.01	0.05 ± 0.03
S. njassae	13 ± 3.6	197 ± 23	58 ± 38	5.9 ± 2.8	0.36 ± 0.10	0.16 ± 0.1	0.06 ± 0.03

In conclusion, the results presented above constitute to our knowledge the first data on the concentrations of pollutants in fish from Lake Chad. Both mercury and POPs concentrations in fish from this lake are low and similar to what has been observed in biota from other African lakes. As was observed in other tropical and temperate studies, dietary habits of the fish determined their contaminant concentrations with the highest pollutant levels found in the species from the upper trophic levels. This suggests that at least some of the processes controlling the fate of persistent, bioaccumulating pollutants are common across systems differing in species composition and climatic regimes.

Table 4. Mean stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$; ‰) isotope ratios in fish muscle, oyster and macrophytes from Lake Chad.

Species	#	$\delta^{13}C$	$\delta^{15}N$
Fish			
Citharinus citharus	6	-25.0 ± 1.1	5.6 ± 0.6
Sarotherodon galileus	4	-21.9 ± 1.8	5.6 ± 0.5
Oreochromis niloticus	15	-22.8 ± 2.9	5.7 ± 1.1
Distichodus spp.	2	-23.7, -27.1	6.1, 5.4
Brycinus nurse	1	-25.9	5.9
Heterotis sp.	1	-22.8	6.5
Auchenoglanis occidentalis tchadensis	12	-23.4 ± 2.6	6.6 ± 1.5
Alestes baremoze	21	-22.1 ± 3.0	6.8 ± 0.9
Synodontis schall	13	-23.8 ± 1.7	7.0 ± 0.6
Polypterus bichir	13	-20.1 ± 1.5	7.6 ± 1.0
Hydrocynus forskalii	5	-22.6 ± 0.4	8.8 ± 0.9
Lates niloticus	12	-21.1 ± 1.3	9.2 ± 0.8
Clarias gariepinus	4	-23.4 ± 2.0	10.2 ± 2.2
Invertebrates			
Etheria elliptica (oyster)	5	-25.7 ± 1.1	6.4 ± 0.6
Plants			
Myriophyllum[1]	1	-29.0	4.3
Vossia cuspidata[2]	1	-12.0	3.0
F. cyperaceae or *Polygonaceae*[2]	1	-11.3	2.5

[1]Submerged plant. [2]Emergent plant.

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