South Asian J Exp Biol; 11 (4): 515-523; 2021 [DOI: 10.38150/sajeb.11(4).p515-523]

South Asian Journal of Experimental Biology

ISSN: 2230-9799 Vol. 11, Issue 4 Page 515-523 http://www.sajeb.org

REGULAR ARTICLE

Assessing the exposure of Sidi M'Hamed Benali lake (Algeria) to Organo -chlorinated compounds and pesticides in fishs

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ARTICLE INFO

Article History:
Received: 15 Apr 2021
Revised: 21 Jun 2021
Accepted: 23 Jun 2021

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Keywords: PCBs, PBDEs, DDTs, Lindane, Fish, Contamination

ABSTRACT

Sidi M'Hamed Benali lake (Algeria) is a reservoir used for recreational and fishing purposes that also harbors a rich fauna an flora. These are affected by use of pesticides in view of the increasing anthropogenic activities. In this study, levels of contaminants, polychlorinated biphenyls (PCBs), polybromodiphényléthers (PBDEs), dichlorodiphenyltrichloroethanes (DDTs), and Lindane were measured using gas chromatography with electron capture detection and gas chromatography mass spectrometry in four fish species (*Cyprinus carpio, Barbus barbus, Hypophthalmichthys molitrix, Rutilus rutilus*) of Sidi M'Hamed Benali lake. The results showed that PCBs, PBDEs and the insecticide Lindane contaminated the studied species but at concentrations, much lower that the guiding values. On the contrary, high levels of pp'DDE (p,p'dichlorodiphényldichloroéthylène) was recorded in all samples with values higher than the Maximum residue limit of 300 ng/g lipid weight (LW.) set by FAO with values as high as 3.87×10^3 ng/g LW (total DDTs) which indicated potential hazard not only to human consumers of the lake fishs but also a potential hazard expected to animals that prey on these fishes. 14 ng/g fresh weight (FW.) Canadian limit is also significantly lower than the values of fish from the studied lake (42-46 ng/g FW.). In light of these results, we conclude that this lake is exposed to organic pollution of anthropogenic origin and we encourage caution regarding the consumption of fish in this reservoir. It is time to make serious efforts to mitigate the lake pollution in order to protect aquatic wildlife for sustainable development.

1. Introduction

Surface and groundwater quality has suffered great deteriorations worldwide over the past decades due to the multiplication of industrial discharges, the intensification use of pesticides and fertilizers for agriculture and to the inconsiderate exploitation for water resources. Persistent organic pollutants such as polychlorinated biphenyls (PCBs) and its isomers, polybromodiphényléthers (PBDEs) or chlorinated pesticides including dichlorodiphenyltrichloroethane and its metabolites (DDTs) and Lindane have been known as global contaminants of the environment for long time. They still often found in surface or groundwater, following drainage by rainwater, soil leaching, due to accidental

spills or atmospheric deposition (Zhang et al., 2011; Lavandier et al., 2013; Akan et al., 2013).

PCBs are synthetic organic compounds. They form a large family of about 209 different congener molecules. The physicochemical properties of each congener (solubility, vapor pressure, octanol-water partition coefficient) as well as their toxic power are determined by their structural characteristics. PCBs are characteristic of chronic contamination of urban and industrial origin. Due to their great stability, hydrophobicity and persistence, their presence has been reported in all environmental compartments. In the aquatic environment, the toxic effects associated with contamination by PCBs appear to be rather sublethal and chronic. The mechanisms of toxicity are similar to those of dioxin-related compounds and characterized by the activation of particular enzyme systems (Akan et al., 2013; El Badaoui, 2016)

PBDEs are chemical compounds that contain bromine atoms. There are 209 congeners of PBDEs widely used as flame retardants. Numerous studies have reported the harmful effects of exposure to PBDEs on the environment and wildlife (increased mortality rates, malformations, and metabolic and thyroid dysfunctions). These substances have been shown to be persistent and toxic and have been shown to bioaccumulate (Pollack et al., 2016).

Chlorinated pesticides are known to be toxic to man and environment. They can cause serious health problems (reproduction and birth defects, immune system dysfunction, endocrine disruptions and cancer). DDT in particular can block potassium influx across the membranes of nerve fibres and causes increase negative after potentials. Its decomposition products in nature are DDE (dichlorodiphenyldichloroethylene) and DDD (dichlorodiphenyldichloroethane) which are highly persistent and have similar physical and chemical properties. DDT is a persistent organic pollutant with a half-life estimated between 2 and 15 years old. In water, its half-life can be much lower. Residues and metabolites of many Chlorinated pesticides are very stable, with long half lives in the environment (El Badaoui, 2016).

DDTs are still in use in Algeria despite their ban due to their high toxicity.

Bioaccumulation of these pollutants by aquatic organisms can lead to a potential risk to human health (Kumar et al., 2011; Mateo-Sagasta et al., 2017). According to Shinggu et al. (2015), fishes are suitable indicators for environmental pollution monitoring because they concentrate pollutants in their tissues directly from water and also through their diet.

Sidi M'Hamed Benali (SMB) lake is a decantation barrage, built in 1945 to attenuate the force of the current due to the rise of water during the rainy season and to prevent the flooding the Sidi Bel Abbes city. The overflow of water is diverted through a 5 km underground channel for feeding the Sarno wadi reservoir which water is used directly for irrigation and indirectly (after treatment) as drinking water. It is a natural reserve where many migrating birds stop and has been proposed as Ramsar site (El Badaoui, 2016). Its littoral is rich in reeds and macrophytes and cereal cultures spread around the lake. The lake is used all year round but particularly during summer for recreational purposes such as bathing, fishing and camping. Anthropogenic activities associated with the lake have increased during these last few years leading to increase in tourists and fishermen, and unfortunately, to an increase of illicit dumping of garbage in the lake. Moreover, the waters of the Mekerra wadi, which run through the city of Sidi Bel Abbes bring fish significant pollution from urban and industrial effluents. The ecosystem is thus potentially exposed to urban, industrial and agricultural contaminations (El Badaoui et al., 2015).

The aim of this study was to carry out a screening of the level of bioaccumulated organochlorine compounds in the most abundant fishes of lake SMB i.e. *Barbus barbus, Hypophthalmichthys molitrix, Cyprinus carpio and Rutilus rutilus*. The organochlorine compounds measured were PCBs, PBDEs and chlorinated pesticides, namely DDTs and Lindane. This study is the first to address the pollution of this lake by organochlorinated xenobioties and contributes to the assessment of the contamination of west Algeria by these pollutants.

2. Materials and methods

2.1. Study area

The lake is located at 4 km North of Sidi Bel Abbes city, has an altitude of 460 m (geographical coordinates: X_1 = 195.3, Y_1 = 220.7; X_2 = 195.2, Y_2 = 221.6); has an area of about 40 ha, a capacity of 3 million m^3 and a maximum depth of 30 m. It is subject to a semi-arid climate with cool winters and dry season followed by a short rainy season and it is fed by

runoff from the massifs of Tessala, Hajar, and Meraei Kerrouche, especially during the rainy periods and by the inflow of the Mekerra wadi (El Badaoui et al., 2015).

2.2. Fish samples

Four species of fish: *B. barbus* (barbel), *C. carpio* (common carp) *H. molitrix* (silver carp) and *R. rutilus* (roach) were sampled off SMB lake with a fishing net by professional fishermen. The samples were stored in an ice-chest at 4°C and transported to the analysis laboratory. Back in the laboratory, skinless fillets were removed from the fishes using a scalpel, crushed and frozen at -80°C. For each species, the individuals sampled were of similar size (ca 30 cm) and that the samples to be analyzed were pools of muscle tissue taken from four individuals. After freezing, the samples were placed in freeze-drying flask and placed in a freeze-dryer (the Tel Star mark) at -80°C and at an atmospheric pressure of between 1 and 100 millibars for 48 h. Freeze -dried samples were stored at -80°C before being sent at Animal Ecology and Ecotoxicology laboratory, Liege University (Belgium), for further analysis. Weighing of the samples was done before and after lyophilisation to determine fresh weight (FW.) and dry weight.

2.3. Organic pollutant analysis

2.3.1. Extraction

Extraction of organic pollutants was performed by Accelerated Solvent Extractor (Dionex ASE200, Dionex, United States) with hexane:dichloromethane (90:10 v/v), at 125°C and 1.5 $x10^3$ psi (10.3 MPa). About 500 mg of freeze-dried samples were mixed with 0.5 g of anhydrous Na_2SO_4 (drying agent) and the surrogate internal standard PCB 112 (hexanic solution) were added to the samples in the extraction cells in order to reach an expected concentration of 50 pg/µL of surrogate in the final extracts. After extraction, the fat content of the samples was determined gravimetrically by evaporating the solvent at 40°C under a stream of nitrogen until only the fat remained (according to method 20 of Animal Ecology and Ecotoxicology Laboratory, Liege University).

2.3.2. Clean-up procedure

After resuspension in 2 mL of hexane, a first purification of the extracts was performed by adding 2 mL of H_2SO_4 (98%) and intense mixing (Vibramax 110 HEIDOLPH) for 2 min. The hexanic phase was collected after centrifugation for 3 min at 3 x 10^3 rpm; 3mL of hexane was added to the acid and the procedure was run again in order to recover the maximum of lipid and pollutants from the acid phase. The pooled hexane extracts were concentrated to 1 mL under a stream of nitrogen gas. The samples were subjected to a second purification step on SPE Florisil columns (SUPELCO, envi-Florisil); SPE columns were pre-conditioned by eluting 5 mL of acetone, 5 mL of hexane:acetone mixture 1:1 (v/v) and 12 mL of hexane successively before adding the concentrated extract. The extracts once poured onto the pre-conditioned columns were eluted with 2 x 3 mL hexane:diethyl ether (85:15 v/v). Thereafter, the eluate was evaporated just to dryness under a gentle stream of nitrogen gas. The dried eluate was then reconstituted in 50 µL of hexane and 50 µL of PCB 209 hexanic solution at 100 pg/µL (injection volume internal standard).

2.3.3. Analyses of purified extracts

Organochlorinated pollutants present in the extracts were quantified by high-resolution gas chromatography using a Trace GC Thermoquest chromatograph (Thermo Quest, Italy) equipped with a ^{63}Ni GC-ECD (Electron Capture Detector) and a capillary column (Agilent DB5-MS, 60 m length, 0.25 mm i.d. and 0.25 µm film thickness). GC-ECD temperature was 300 °C. Hydrogen was used as the carrier gas with a flow rate of 130 kPa and the make -up gas was Ar:CH4 (95:05) at a flow rate of 40 mL/min. The injection volume was 1 µL with a splitless injection mode. The temperature conditions of chromatographic analysis were as follows: the initial column temperature was held at 60°C for 2 min, then increased to 160°C at a rate of 20 °C/min and maintained for 3 min, after increased to 280°C at 2.5 °C/min and held for 10 min, it was heated to 300°C at 20°C /min and then maintained for 10 min.

The following organochlorine residue components were identified by comparing their retention times with those of a standard mixture of PCBs and organochlorine pesticides standards (Dr Ehrenstorfer®) :

-PCB congeners most abundant in synthetic products and the most abundant as food contaminants (PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, PCB 180);

-Lindane ;

-DDT metabolites (p,p'DDT, p,p'DDE) ;

- PBDE congeners most persistent (PBDE 47, PBDE 99).

Quantification was based on comparison with external standards of the compounds in certified mixture (PCBs, DDTs) or solutions (Lindane) using linear calibration curves in the concentration range of 1.56 to 500 µg /µL.

2.3.4. Quality assurance

A blank (cod fished in Norway) was run with each sample series to control extractions and clean-up procedures. A quality control (QC) was also analysed in parallel: freeze-dried cod was enriched with all compounds to be quantified using standard solutions Dr Ehrenstorfer® so as to reach a concentration of 50 pg/µL of each compound in the final extract. The compounds recoveries were calculated on the basis of the concentration of the surrogate standard (PCB 112, Dr Ehrenstorfer®) (50 pg/µL). Recoveries of chlorinated contaminants in the QC were comprised between 70 and 130%.

2.3.5. Confirmation of results

Because the concentrations of p,p'-DDE measured in our samples by GC-ECD were quite high, the identification of the peak of p,p'-DDE detected in GC-ECD, we re-injected fishes extracts on a GC-MS (Gas Chromatography Mass Spectrometry) to confirm the identification of this molecule. The samples were analyzed by GC-MS using an Ultra GC trace coupled to a QIT 1.1 x 10^3 ion trap (Thermo Scientific) with a non-split injection group and electron impact ionization (EI) mode. A volume of 1 µl per sample was injected. The GC conditions were as follows: column, RTX-5ms (Restek Bellefonte, PA) 20 m 0.25 mm i.d., 0.25 µm thickness; column temperature program, 60°C for 2 min, then a first ramp at 15 °C/min until 160°C was reached and held for 1 min followed by a second ramp temperature of 6 °C/min to 265°C for 1 min and the third temperature ramp of 50 °C/min until reaching a final temperature of 300°C held for 10 min. Before cooling the unit for 2 min at a pressure of 130 kPa. The injector temperature was set at 290°C with a dividing rate of 25 mL/min and the fractionation time of 1 min at a pressure of 200 kPa for 1 min. Helium (He, Air Liquide, Belgium) was used as carrier gas at a flow rate of 1.1 mL/min. The temperature of the transfer line was set at 300°C.

The method of analysis used allowed the detection of DDT metabolites (o,p'-DDT, p,p'-DDT, p,p'-DDE and DDD). For each assay sequence, a procedure blank and a Quality Control standard (Wellington Laboratories) was included and the injection sequence was set as follows: five external calibration curves for pesticides, a sample QC, and seven unknown samples. The complementary external calibration points were inserted between the set of unknown samples to complete the injection sequence.

3. Results and Discussion

SMB lake is surrounded by farmlands so large amounts of chemicals (pesticides and fertilizers) are used there by farmers which can enter the wetland through running waters and subterranean canals, but it also receives the waters of the Mekerra river that carry wastewaters of urban and industrial origin. Garbage and wastewaters are also dumped in the wetlands around SMB lake by inhabitants. All of these factors may lead to the contamination of this Lake.

During the sampling campaign, the water characteristics were measured: the temperature was of 21,7 ± 1°C, the pH of 7,5 ± 0,3 , the dissolved oxygen content of 7,4 ± 0,1 mg/L, the conductivity of 1,5 ± 8,5 µS/cm, the turbidity of 67 ± 2,6 UNT and the salinity of 0,7±0,1‰. The fish were active when sampled from SMB lake.

The primary chemical compounds that are representative of industrial and urban pollution in this study are PCBs. Only 7 congeners of PCBs were searched and quantified in the samples: PCBs 28, 52, 101, 118, 153, 138, 180; these congeners include the six tracer congeners used in the European norm for maximum levels authorized in wild-caught fishes (EU/1259, 2011).

The results of the quantification of the PCB congeners studied in fish muscle are illustrated in Figure 1.

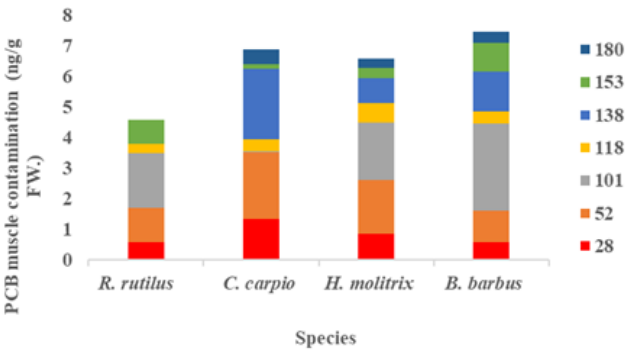

Figure 1: PCBs contamination levels in the four species of fish (ng/g FW.).

We found that the four fish species are contaminat-

ed with the 7 congeners except *R. rutilus* (5 congeners). The mean PCBs concentrations (sum of the 7 congeners) in the fish samples were, in descending order, of 7.5 ng/g FW. for *B. barbus*, of 6.9 FW. ng/g for *C. carpio,* of 6.6 ng/g FW. for *H. molitrix*, and of 4.6 ng/g FW. for *R. rutilus*. These values are low compared to values recorded in other areas of the world like e.g. Hudson river, USA (up to 263 ng/g FW.), Scotland (123 ng/g FW.), Negro River, Argentina (103 ng/g FW.) or Siravsky canal in Slovakia (6,4 x 10^4 ng/g FW.) (Kampire et al., 2015), but are higher than the levels reported by these authors for North End Lake, South Africa (34 ng/g lipid weight (LW.) compared to 157 to 540 ng/g LW. in our study). All our results are below the maximum value of 125 ng/g FW set for the sum of the 6 tracer PCBs found in regulation EU/1259 (2011) for wild-caught fishes.

Differences in accumulation of contaminants between species can be due to differences in fat content (Hugla and Thome, 1999; Manirakiza et al., 2002; Debier, 2006). It is to be noted that the higher contamination level of *B. barbus* is not due to its content in lipids as it is not the highest of the species tested (Figure 2).

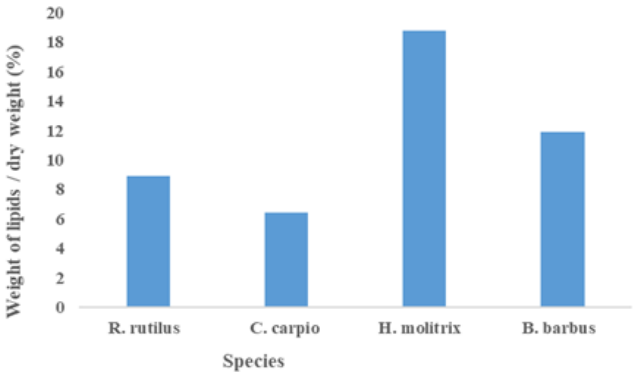

Figure 2: Percentage of lipids in species sampled by dry weight.

We also note that the pattern of contamination of SMB fishes is quite variable. *C. carpio* shows higher accumulation of PCBs 28, 52, 138, 180 in the muscle than the other species, but considerably less amounts of PCB 101 are found in this species. The highest concentrations of PCBs 101, 153 (2.8 ng/g and 0.9 ng/g respectively) were recorded in *B. barbus* and maximum concentration of PCB 118 (0.6 ng/g) was observed in muscle of *H. molitrix*. *R. rutilus* showed a contamination pattern that mainly differs from that of *H. molitrix* and *B. barbus* by the absence of PCBs 138 and 180.

Differences in contamination pattern in species with differing feeding habits is common (Edder et al., 2012). Age can also be a factor that induces higher bioaccumulation of certain congeners; for example in a contamination experiments accumulation of PCB 153 and 138 in old trouts was more marked than in young individuals (Vives et al., 2005). Moreover, Rypel et al. (2007) report that there is a significant difference in the level of contamination by sex among several species (*Micropterus salmoides*, *Micropterus punctulatus* and *Ictalurus punctatus*); according to this study, females have lower levels of contamination, due to the fact that females reject PCBs when laying eggs. But these authors point out that this is not always the case for all fish species. In our case, fish samples taken from SMB lake are pools of several individuals of similar size but undetermined age and sex; it is likely that this induced higher variability in the contamination patterns observed and the contamination levels among the sampled species.

It is also to note that the concentration of PCBs in the organisms studied are higher than the concentrations measured in this study; muscle (consumable part) is generally not considered as the organ showing the most marked bioaccumulation rates. Other organs, such as the liver and gonads, can show much higher levels of contamination than muscle (Rajendran et al., 2005; Edder et al., 2012; Akan et al., 2013).

The congeners with a high degree of chlorination detected in the muscles of the fish from the lake are typically found in commercial mixtures (for example, Aroclor 1254 and 1260). Since the production of PCBs with a high level of chlorination is not carried out in Algeria, their presence in SMB lake would be due either to a nearby emission source (emission from the nearby urban area of Sidi Bel Abbes) or, more likely to atmospheric depositions, Algeria being 35° from the northern hemisphere, the most chlorinated congeners tend to settle in areas along this latitude (Wania and Mackay, 1996).

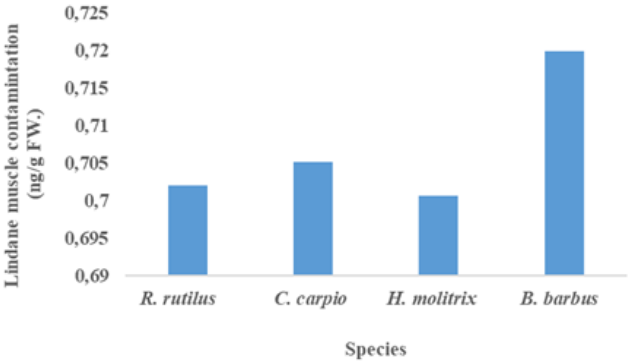

Figure 3: Lindane contamination levels in the four species of fish (ng/g FW.).

As for pesticides, we investigated the levels of the insecticides Lindane and p,p'DDT (and its metabolite p,p'DDE). Lindane concentration values vary between 0.7 and 0.72 ng/g FW. (Figure 3). These values were much lower than maximum residue limit (MRL) fixed by FAO (10 ng/g FW.) (Codex alimentarius, 2016).

The concentrations of p,p'DDT and p,p'DDE in the samples are presented in Figure 4.

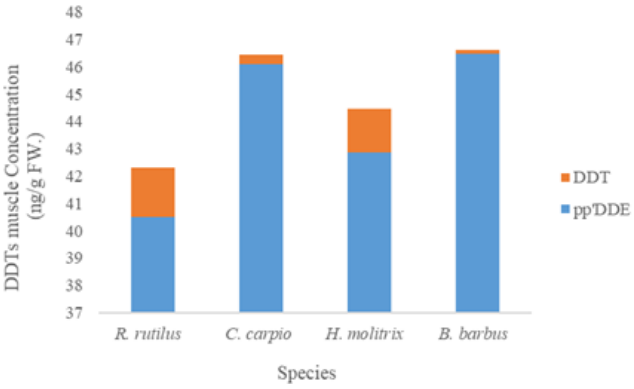

Figure 4: p,p'DDE and p,p'DDT contamination levels in the four species of fish (ng/g FW.).

High levels of p,p'-DDE were observed in the fish flesh while the p,p'DDT values were very low. Once released to the environment DDT is affected dominantly by biotic transformation; under anaerobic conditions the main metabolite is DDD, whereas under aerobic conditions DDE is the most abundant metabolite (Ricking and Schwarzbauer, 2012). The detection of a great proportion of p,p'-DDE is an indication of aerobic degradation of DDT. Moreover, DDE is more persistent and more stable in the environment than DDT and is decomposed more slowly by micro-organisms, heat and ultraviolet rays (Kafilzadeh et al., 2012; Nnamuyomba et al., 2014). Thus, when the use of DDT in a country ceases, the levels of this compound decrease more rapidly than the levels of DDE, there by producing an increasing DDE/DDT ratio.

The ratios of the two major compounds, DDT, DDE, can be used to understand the chronology of input of DDT in the environment. For instance, DDT/DDE ratio > 0.5 indicate recent DDT use/emission whereas ratios <0.3 indicate past use/emission (Duong et al., 2014). In this study, the DDT/DDE ratios were all lower than 0.3 (table 1), clearly indicating that there has been no recent inputs of DDT in the studied area.

In general, the concentrations of DDTs observed in this study were higher than, and in other cases comparable with those reported in edible and marketed fish collected from other parts of the world as shown in table 2. The identification of p,p'-DDE was verified by re-injecting the extracts on a GC-MS. This analysis confirmed the high contamination of the fishes by p,p'DDE and the presence of p,p'DDT, o,p'DDT and DDD in the samples. The concentrations of DDTs in all the fish species were higher than the FAO (Codex alimentarius 2003) set MRL of 300 ng/g LW, indicating a potential hazard for consumers of the fishes caught in SMB lake. Moreover, fish-eating birds and mammals are both likely to accumulate DDT when ingesting contaminated preys. According to the Canadian Council of Ministers of the Environment (1999) DDTs can pose a serious threat to wildlife species at the top of the food chain. This organization has established a Canadian recommendation for maximal tissue residues established for total DDTs (o,p '+ p,p' DDT, o,p '+ p,p' DDE, o,p '+ p,p' DDD) of 14 ng/g FW. as the maximum concentration of DDTs in aquatic biota which is not expected to produce adverse effects on wildlife species consuming aquatic biota; with concentration of DDTs of 42 to 46 ng/g F.W. (p,p'DDT + p,p'DDE), we determined that there is a potential risk from DDTs for aquatic organisms living in the SMB lake.

Samples species	Ratio DDT/DDE
R. rutilus	0.044
C. carpio	0.007
H. molitrix	0.037
B. barbus	0.003

Table 1: DDT/DDE ratios measured in the four fish species sampled.

Our analysis also included two PBDE congeners (BDE-47 and BDE-99) in order to determine whether these urban contaminants were present in lake SMB samples. BDE-47 was detected in *B. Barbus* (0.098 ng/g FW.) and *R. Rutilus* (0.098 ng/g FW.) but BDE-99 levels were below the detection limit (0.002 ng/g FW.). The recorded concentrations are way below the guideline value of the Canadian Environmental Protection Act (1999) of 88 ng/g FW. in fish tissues which indicates a very limited contamination by this type of pollutants (flame retardants mainly found in households and buildings) and also a much lower contamination than in other areas of the world like e.g. the Great lakes area where BDE-47 could still be found at concentrations around 50 ng/g FW. in 2008 (Great Lakes Open Makes Trend Monitoring Program: Polybrominated Diphenyl Ethers). The presence of this congener may be due to transport and atmospheric deposition or even to

Localisation	Fish species	DDTs (ng/g FW)	DDTs (ng/ g LW)	References
Lake SMB (Algeria)	*R. rutilus*	42	1.58×10^3	Present study
	C. carpio	46	3.64×10^3	
	H. molitrix	44	2.51×10^4	
	B. barbus	46	1.95×10^4	
Lake Victoria (Uganda)	*Rasteneobola argentea*	0.88		Nnamuyomba et al., 2014
Lake Kyoga(Uganda)		1		
Tien river (Southern Vietnam)	*Poissons sauvages*	-	15	Nguyen, 2009
Saigon river (Southern Vietnam)		-	148	
Lake Burullus (Egypt)	*Oreochromis niloticus*	5		Said et al., 2008
	Clarius sp.	12		
Lake Geriyo (Nigeria)	*Tilapia zlli*	342		Shinggu et al., 2015
	Chrysichthys nigrodigitatus	43		
Lake Parishan (Iran)	*Barbus brachycephalus caspius*	8		Kafilzadeh et al., 2012
Ouémé River (Bénin)	*Oreochromis niloticus*		129	Yehouenou et al., 2006
	Clarias gariepinus		1.64×10^3	
	Chrysichthys nigrodigitatus		196	
	Tilapia zlli		134	
	Polypterus endlicheri		473	
	Synodus intermedius		1.19×10^3	
Lake Kusawa (canada)	Lake trout	40		Ryan et al., 2005

Table 2: Comparative table of DDTs (pp'DDT +pp'DDE) concentration results (ng/g FW. or LW.) of this study and previous studies.

the debromination of BDE-99 (a congener also present in the commercial Penta-BDE mix) (Stapleton et al., 2004; O'Driscoll et al., 2016).

4. Conclusion

Our results indicated that fishes of SMB lake accumulate organochlorine compounds. PCBs concentrations measured were however relatively low compared to other areas of the world like USA, South America and Europe and were all lower than the maximal limit drawn in UE directive for wild-caught fishes (125 ng/g FW.). PBDEs and the insecticide Lindane were also detected but at concentrations much lower that the guide values of FAO and below the guideline value of the Canadian Environmental Protection Act (1999) for PBDEs. On the contrary, high levels of DDE (DDT metabolite) were recorded in all samples with values higher than the MRL of 300 ng/g LW set by FAO with values as high as $3,87 \times 10^3$ ng/g LW (total DDTs) which indicate potential hazard to human consumers of the lake fishs (birth defects, immune system dysfunction, endocrine disruptions and cancer) but also a potential hazard expected to animals that prey on these fishes as the 14 ng/g FW. limit set by Canadian Council of Ministers of the Environment (1999) is also significantly lower than the values recorded in this work (42-46 ng/g FW). The DDT/DDE ratios clearly show that the contamination source is not recent and can be due to ancient use in agriculture (mainly cereal fields), potentially also in households both occurring along the lake and upstream of the Mekerra river, but also potentially to atmospheric transport and deposition either from nearby areas or from other areas/countries where DDT use is still ongoing.

We conclude that this lake is exposed to organic pollution of anthropogenic origin and we encourage caution regarding the consumption of fish in this reservoir.

Acknowledgements

We thank Pr Benali Mohammed (U.D.L., Sidi Bel Abbes) for their assistance with lyophilisation technique. We thank Pr Djahed Benyounes (U.D.L., Sidi Bel Abbes) and Pr Boutiba Zitouni (Es-Senia Uni-

versity, Oran) for their valuable advice and constructive criticism

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