

Accumulation of PCBs and Infections of Parasitic helminthes in *Synodontis filamentosus* (Boulenger, 1901) and *Tilapia zillii* (Gervais, 1848) of Epe Lagoon, Lagos, Nigeria

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ABSTRACT

The study was carried out on 120 *Synodontis filamentosus* (11 – 26.5cm, 22 - 88g) and 120 *Tilapia zillii* (15 - 21cm, 67 – 187g) captured from Epe Lagoon, Lagos State, Nigeria. The aim was to comparatively analyze the bioaccumulation of polybiphenyl chlorides (PCBs) and prevalence of parasitic helminthes in *S. filamentosus* and *T. zillii* relative to their respective habits. The comparison was done using indices such as bioaccumulation factors, biota-soil accumulation factors, and parasite prevalence. Profiles of PCB accumulation showed that *T. zillii* followed by their endoparasites accumulated outstanding concentrations, suggesting that *T. zillii* might be a greater bioaccumulator of PCBs than *S. filamentosus*. Significant biota-soil accumulation factors observed in the *T. zillii* and their endoparasites were accompanied by significant sorption capacities of PCBs into the soil at impacted locations of the lagoon. This implies that *T. zillii* accumulated significant PCB from the soil and shared with its endoparasites, justifying host-parasite xenobiotic transfer. *S. filamentosus* had higher levels of parasitic infections than *T. zillii*, males of both species were more infected than the females. The intestine and liver tissues of *S. filamentosus* showed greater alterations than the tissues of *T. zillii*. Findings showed that *S. filamentosus* is a better bioindicator in histopathological studies while *T. zillii* is a better bioaccumulator.

INTRODUCTION

Polychlorinated biphenyls (PCBs) are a class of non-polar toxic chemical compounds consisting of 209 congeners of which only about 130 have been identified in commercial products (Berg *et al.*, 2017). PCBs are used in industrial applications such as hydraulic fluids, lubricants, inks, plasticizers, agrochemicals, etc. from which they leak into soil, surface and underground water (Cappelletti *et al.*, 2015). Discharge of industrial waste into water bodies, and incineration are predominant sources of PCBs in Nigeria (Wang, 2002; Okoh, 2015). Waste management in Epe, Nigeria include land filling, dumping site, and open incineration. These methods are liable to contaminate underground and surface water bodies, thereby gaining access to the aquatic food chain where they are biomagnified up the

pyramid of biomasses (Moore *et al.*, 2006; Araoye, 2008; Driedger, 2015; Okoh and Daniels, 2016; Isibor and Imoobe, 2017).

Fish contamination by PCBs, particularly in Nigeria has been widely reported (Araoye, 2008; Akinsanya *et al.*, 2015; Driedger, 2015; Okoh and Daniels, 2016). Following contamination, fish tend to undergo some detoxification processes such as depuration through gills, fecal ejection, metabolic transformation and excretion (Paterson *et al.*, 2010). Increase in size as the fish grows may also cause some dilution effects on the ingested xenobiotic. In the case of female fish, reproduction may also represent a significant elimination pathway (Peck *et al.*, 2015).

Bioaccumulation is the increase in concentration of a chemical or xenobiotic in an organism relative to its environment. This is mediated through ingestion, inhalation or absorption (Daley *et al.*, 2009). Fish have high potentials of concentrating considerable amounts of lipophilic compounds from water, sediment and food chain in their tissues (Livingstone *et al.*, 1994; Kaoud and Eldahshan, 2010; Isibor *et al.*, 2016). Sediments act as sink repository for various contaminants in the aquatic ecosystem, and the persistent and non-biodegradable ones such as PCBs may remain in the environment for extended periods (Kumolu-Johnson and Ndimele, 2010).

In ichthyology, eco-morphological studies focus on the interrelatedness of morphometrics (Wainwright & Richard 1995; O'Grady *et al.*, 2005) such as weight (Angelini and Agostinho, 2005) mouth (Karpouzi & Stergiou, 2003; Chalkia & Bobori, 2006; Karachle & Stergiou, 2011), intestine (Kramer & Bryant 1995; Karachle & Stergiou 2010), tail (Karachle & Stergiou, 2004), and body length of fish, to feeding habits. The indices are used in grouping fishes into fractional trophic levels which may provide some information as to susceptibility of the fish to contaminants and parasitic infections in the environment.

T. zillii is of high economic value in the Epe fish market as it is highly demanded. The fish has preference for shallow areas in a tropical climate and lives over sand, mud, or rock. The principal component of the adult's diet includes chironomid larvae and zooplankton. Supplemental sources are cyanophyte and dinoflagellate algae, periphyton, drifting insects, ostracodes, and porifera (Spataru, 1978; William and Bonner, 2008). Nematodes have also been recovered from the gut of *T. zillii* (Osho *et al.*, 2016; Adeyemi *et al.*, 2009). Parasites may impact the wellbeing (characterized by low condition factor) of a fish, thereby influencing its feeding habit and diet choice.

In the Epe Lagoon, *Syndontis filamentosus* is also a commercially significant fish as it is sold in the fish markets in Epe all year round. All members of *Syndontis* have a structure called a premaxillary toothpad, which is located on the front of the upper jaw of the mouth. This structure contains several rows of short, chisel-shaped teeth. In *Syndontis filamentosus*, the toothpad forms a short, broad band (Boulenger, 1909). On the lower jaw, or mandible, the teeth of *Syndontis* are attached to flexible, stalk-like structures and described as "s-shaped" (Cuvier, 1934). *Syndontis* is the most common genus of the Mochokidae family and of great commercial importance in the inland waters of Nigeria and West Africa (Lalèyè *et al.*, 2006).

High levels of PCBs previously detected in Epe Lagoon have also been linked to discharge of municipal waste into the lagoon (Akinsanya *et al.*, 2015; Akinsanya *et al.*, 2016). Fish in the lagoon, particularly those with high commercial values such as *Syndontis filamentosus* and *Tilapia zillii* are liable to bioaccumulate PCBs from the environment, thereby transferring the toxicant to the consumers of the fish. The contaminants may also result in immunosuppression of the fish, further culminating

in susceptibility to parasitic infections. Health concerns which may ensue from unregulated anthropogenic activities at Epe Lagoon necessitate assessment of PCBs in fishes from the lagoon.

The study aims at comparatively analyzing the bioaccumulation of PCBs and prevalence of parasitic helminthes in *Synodontis filamentosus* and *Tilapia zillii* captured from Epe Lagoon. The outcome of the study may contribute to the dearth knowledge of the complex interactions among parasites, hosts and toxicants.

MATERIALS AND METHODS

Description of study area

The study was carried out on Epe Lagoon (6°35'2.83" N 3°59'0.10" E) in Lagos State, Nigeria. It has a surface area of 243km². The lagoon is flanked on the sides by two other lagoons; the Lekki Lagoon (freshwater) eastwards and Lagos Lagoons (brackish water) westwards. The lagoon drains into the sea through the Lagos Harbour, within the tropical rainforest belt of southern Nigeria. The seasons include rainy season (May- November), and dry season (December-April). Annual rainfall ranged between 6 to 330 mm throughout the study period. Riparian vegetation at the bank of the lagoon consists mainly of grasses and secondary rainforest.

Three (3) sampling stations were selected (1 km apart) at strategic locations of anthropogenic perturbation at the lagoon (Fig. 1). The stations were labeled as Stations 1 (Oribo), 2 (Imode) and 3 (Ikosi).

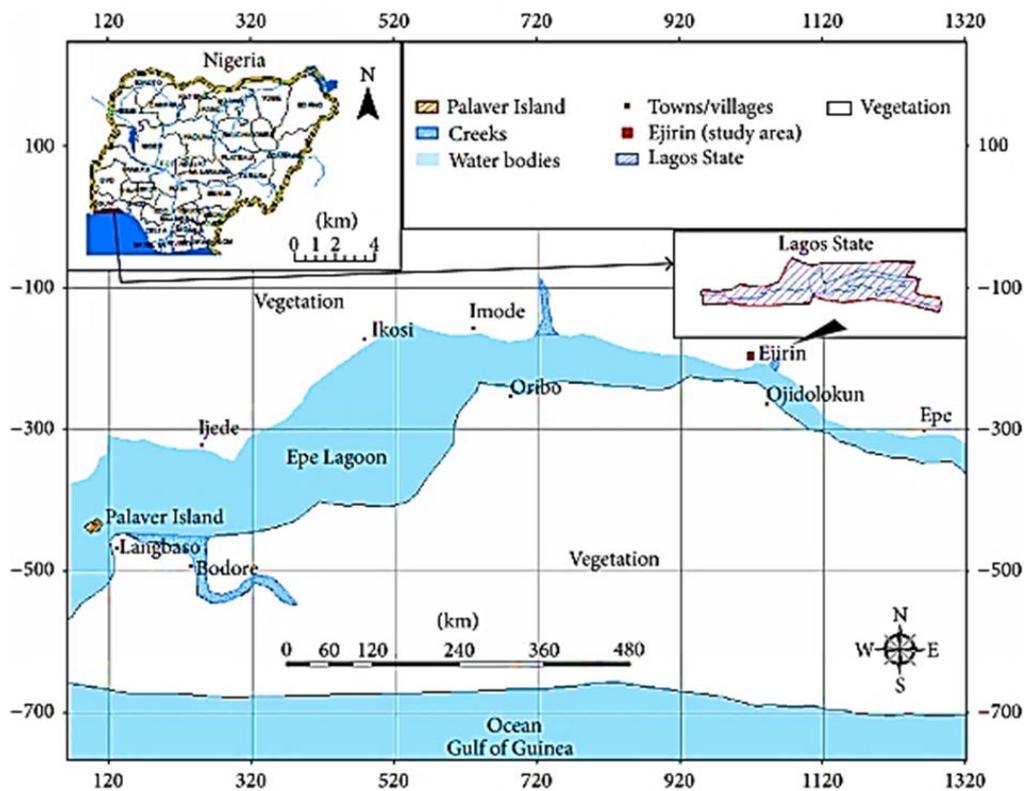


Fig. 1: A map of the study area

Fish samples

Collection of fishes

Synodontis filamentosus and *Tilapia zillii* were randomly captured at the sampling stations and some were purchased from artisanal fishermen at respective locations between the periods of July- September, 2017. A total of 120 *Synodontis filamentosus* (11 – 26.5cm, 22 - 88g) and 120 *Tilapia zillii* (15 - 21cm, 67 – 187g). The fish specimens were immediately preserved in an ice-chest with ice blocks prior and transported to the laboratory for analysis.

The sex and maturity of the specimens were determined by gross examination of the gonad and otoliths respectively. The weights were determined to the nearest 0.1 g using a digital Camry weighing balance (model EK-1A SERIES). The standard lengths and total lengths were recorded to the nearest 0.1cm using a meter rule. *S. filamentosus* was identified using the guidelines prescribed by Paugy and Roberts (2003), while *T. zillii* was identified using descriptions of Williams and Bonner (2008), and Froese and Pauly (2014). The fish individuals were euthanized and the intestines and livers were eviscerated and preserved in freezer at -10°C prior to further analysis.

Histopathological analysis

The intestine and liver of infected and uninfected fish specimens were resected for histopathological preparation after dissection. The intestines were stored in Bouin's solution in separate universal bottles for 6 h and decanted afterwards. 10% phosphate buffer formalin was added to preserve the intestine and liver tissues. The tissues were grouped into 2 categories namely; heavily infected and non-infected. We randomly selected samples from the preserved tissue from the groups to avoid bias and ascertain quality assurance and control.

The tissues were dehydrated through progressive increase in alcohol concentrations by 1% at 30 min intervals. Thereafter, the tissues were impregnated in molten paraffin three times and later embedded in molten paraffin wax. Afterwards, the tissues were allowed to solidify. The blocked tissues were sectioned at 4-5 microns, placed into pre-coated slides and allowed to dry. The sections were stained using haematoxylin and eosins (H&E) stains. The stained tissues were rinsed with distilled water and the excessively stained were rinsed with 1% acid alcohol to normalize the stain. For microscopic photography, the tissues were dried and mounted under microscope (model BA410E) using DPX mountant. The photomicrographs were taken at the pathology laboratory of the Department in Veterinary Pathology, University of Ibadan, Nigeria.

Analysis of endoparasites

Intestinal parasites of fish were obtained by evisceration of the intestine using sterile surgical blades according to the guidelines of Akinsanya *et al.* (2007). The endoparasites were identified morphologically using standard identification keys, in conjunction with pictorial guides provided in manuals such as Colombo *et al.* (2005), Xing *et al.* (2005), and Sures (2007). The parasites were fixed in 70% alcohol, counted and recorded accordingly.

Collection and analysis of water samples

From the 3 stations, water samples were collected using a sterile 5 L sampling bottle pre-cleaned with the surface water at each site. The collected samples were then stored in the refrigerator prior to analysis of physiochemical parameters.

Physicochemical parameters measured in-situ include temperature, using a mercury-in-glass thermometer, while salinity, dissolved oxygen, pH (hydrogen ion concentration), turbidity, total suspended solids (TSS) and total dissolved solids (TDS) and conductivity were measured using a handheld multi-parameter probe (Horiba Water Checker Model U-10).

Collection and analysis of sediment samples

The sediment samples were obtained using a Van Veen Grab (5 kg, 15x15 cm). Samples of sediment were collected in polythene bags treated with 10% nitric acid (Ademoroti, 1996). Salinity, dissolved oxygen, pH, turbidity, total suspended solids (TSS) and total dissolved solids (TDS) and conductivity were measured using a handheld multi-parameter probe (Horiba, Model U-10).

Test for PCBs in environmental media

Homogenized tissue and parasite samples (2 g) and 10 mL water samples were extracted employing column-solid/liquid extraction, using 30 mL DCM/Hexane (50% v/v) in a glass column of 35cm × 2cm. The extract was concentrated to approximately 5 mL with rotary vacuum evaporator. Analyses were performed with Perkin model 5890 gas chromatograph equipped with Ni 63 electron capture detector.

A low polar HP-5 column of 30 m length, 0.32 mm i.d and 0.25 mm film thickness was used. Nitrogen was used as a carrier gas at a flow rate of flow rate 40 ml/s. Data were processed using an HP 3396 integrator. PCB congeners in the fish and parasite samples were identified by retention time match with those of the standards. The standard mixture contains PCBs 8, 18, 28, 44, 52, 60, 77, 81, 101, 123, 138, 153, 156 and 167. Hence only these congeners were identified and determined in the samples.

Statistical Analysis

Statistical analyses were performed on PCBs concentrations in the tested environmental media, which were presented as mean ± SD per site. One-way ANOVA was used to compare the PCB concentrations in the water, sediment, fish and parasite tissues among the 3 selected stations. Prior to ANOVA the assumption of normality was verified using the Shapiro–Wilk test. Significantly different means were ascertained by post hoc Tukey’s HSD test and significance was declared at P < 0.05 for all analyses.

Bioaccumulation factor (BAF) was calculated thus:

$$\text{BAF} = \frac{\text{Concentration of PCB in fish}}{\text{Concentration of PCB in water}} \quad (\text{Sures } et \text{ al.}, 1999)$$

Biota-sediment accumulation factor (BSAF) was calculated thus:

$$\text{BAF} = \frac{\text{Concentration of PCB in fish}}{\text{Concentration of PCB in sediment}}$$

Quality assurance and quality control

To ascertain the integrity of data obtained, surrogate analytical grade PCB standards, blanks, replicates, and a certified reference material (CRM) (NMIJ CRM 7404-a, Japan) were adopted in the analysis. The limits of detection (LOD) were

0.03- 0.41 ng/kg for water, 0.04- 0.32 ng/kg for sediments, 0.02 to 0.60 ng/kg for fish, and 0.03 to 0.56 ng/kg parasites.

RESULTS

Physicochemistry of environmental media

The mean values of physicochemical parameters recorded at Stations 1, 2 and 3 respectively were temperature: 26.5±0.5, 25±0.3, 25.2±0.7; pH: 6.6±0.1, 6.4±0.3, 6.5±0.1; dissolved oxygen: 4.5±0.4, 3.50±0.3, 3.2±0.2 mg/l; total suspended solids: 11±5.5, 7.1±2.6, 9±1.5 g/l; total dissolved solids: 106.3±8.4, 113.9±6.3, 110.1±5.6 g/l; conductivity: 152.7±0.5, 172.3±2.6, 193.3±3, µS/cm; salinity: 4±0.5, 5±0.3, 4.5±0.5 ppt; turbidity: 10.3±3.5, 7.7±3.2, 7.7±2.5 NTU.

All the parameters were within the FEPA (Federal Environmental Protection Agency) standard regulatory limit (Table 1). However, the TSS and Turbidity recorded at Station 1 were significantly higher than other stations, while turbidity at Station 1 was slightly above regulatory limit ($p < 0.05$).

Table 1: Physicochemical parameters of water

PARAMETERS	Station 1	Station 2	Station 3	FEPA (2003)
Temperature (°C)	26.5±0.5	25.8±0.3	25.2±0.7	< 40
pH	6.6±0.1	6.4±0.3	6.5±0.1	6-9
DO (mg/L)	4.5±0.4	3.5±0.2	3.2±0.3	> 5.0
TSS (g/L)	11±5.5	7.1±2.6	9±1.5	30
TDS (g/L)	106.3±8.4	113.9±6.3	110.1±5.6	2000
Conductivity (µS/cm)	152.7±0.5	172.3±2.6	193.3±3	400
Salinity (ppt)	4±0.5	5±0.3	4.5±0.5	NA
Turbidity (NTU)	10.3±3.5	7.7±3.2	7.7±2.5	10

Emboldened figures are significantly higher at $p < 0.05$.

The parasites identified in the infected fishes were Cestodes- *Wenyonia spp.* and Nematodes- *Procamallanus sp.* and *Raphidascaroides spp.* Among t the *T. zillii* 14 of 107 males, and 8 of 13 females were infected, and total parasite prevalence for males and females were 13.1 and 61.5 respectively (Table 2). Among the *S. filamentosus* on the other hand, 79 of 88 males and 28 of 32 females were infected and the . total parasite prevalence were 89.8 and 87.5 for males and females respectively (Table 2). The overall parasite prevalence in *S. filamentosus* (117.3) was higher than in *T. zillii* (74.6). The mean parasite intensity in *S. filamentosus* was also higher than in *T. zillii*.

Table 2: Gastrointestinal helminthes infections relative to morphometrics of fish

Sex	SL (cm)	NE	NI	Prevalence (%)	Worm load	Mean Intensity
<i>Tilapia zillii</i>						
MALE	(14.6-16.5)	10	2	20	12	6
	(16.6-19.5)	56	4	7.1	47	11.8
	(19.6-22.5)	41	8	19.5	102	12.8
TOTAL		107	14	13.1	326	30.6
FEMALE	(14.6-16.5)	2	2	100	3	1.5
	(16.6-19.5)	7	3	42.9	5	1.7
	(19.6-22.5)	4	3	75	8	2.7
TOTAL		13	8	61.5	140	5.9
<i>Synodontis filamentosus</i>						
MALE	(11.0-16.5)	4	3	0.75	34	11.3
	(16.6-21.5)	31	30	96.8	137	4.5
	(21.6-26.5)	56	49	87.5	240	4.9
TOTAL		88	79	89.8	377	20.7
FEMALE	(11.0-16.5)	3	3	100	9	3
	(16.6-21.5)	14	13	92.9	75	7.8
	(21.6-26.5)	17	11	64.8	96	8.7
TOTAL		32	28	87.5	140	19.5

SL= standard length, NE= number examined, NI= number infected

Comparative bioaccumulation

Analysis of PCB congeners in the parasites recovered from the intestine of *T. zillii* (Fig. 2) revealed outstandingly high concentration of PCB 81 in parasites from Station 1. Fairly high concentrations of PCB 8 were observed in Stations 2 and 3. PCB 81 was outstandingly high in the tissues of *T. zillii* at Station 3, followed by Station 1 (Fig. 3). Some levels of PCB 28 (Station 2), and PCB 44 (Stations 1 and 2) were also observed in the tissues of *T. zillii*.

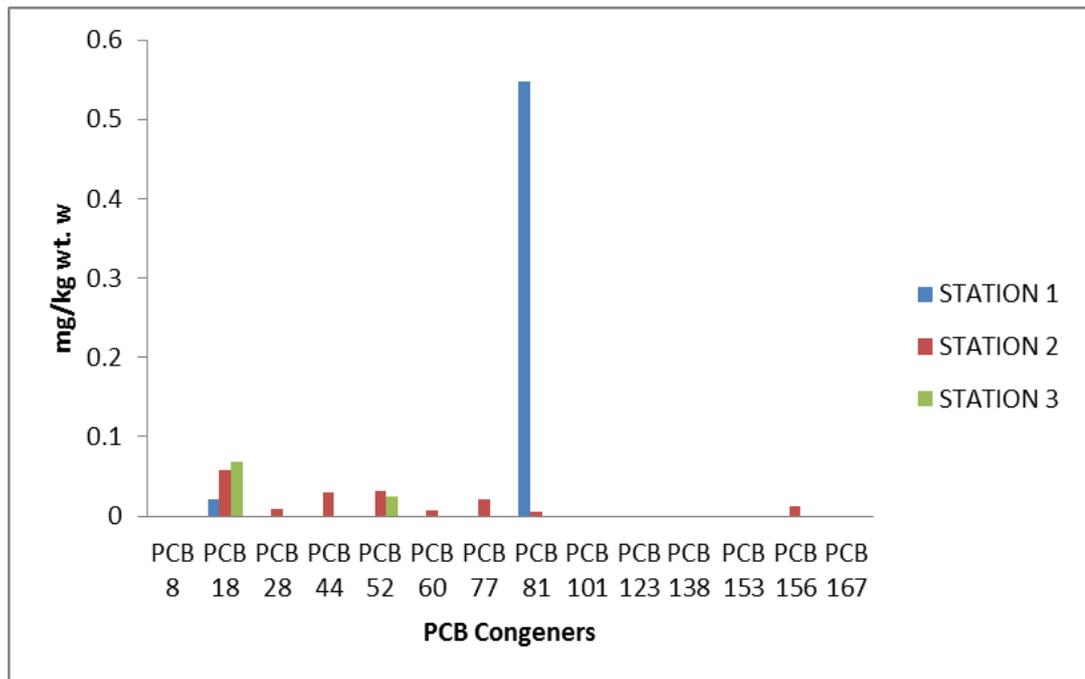


Fig. 2: PCB congeners in *Tilapia zillii* parasites across stations

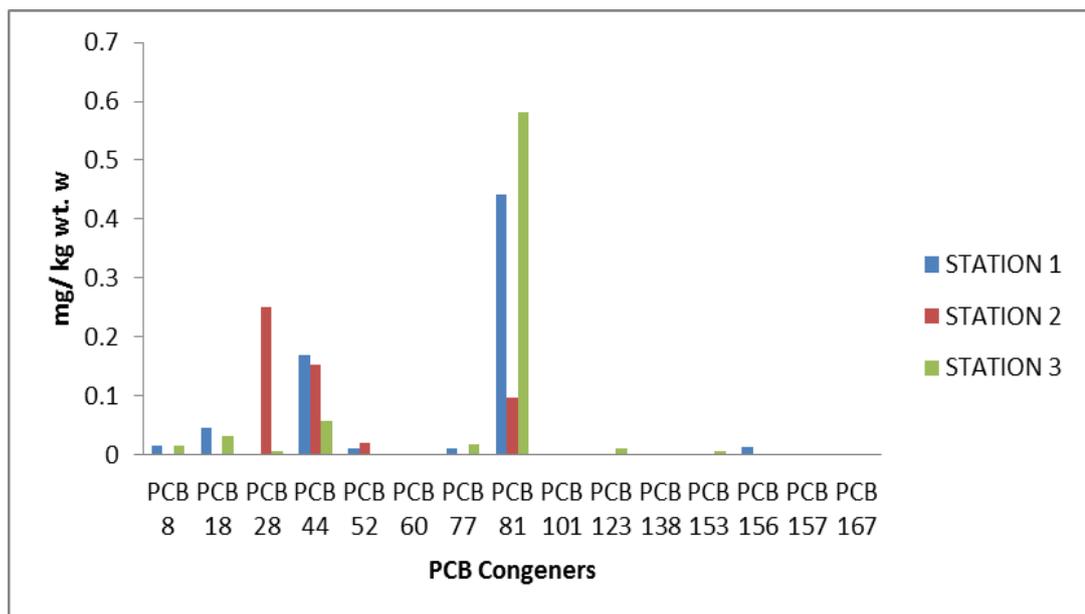


Fig. 3: PCB congeners in the tissues of *Tilapia zillii* across stations

Most of the PCB congeners detected in the tissues of the parasites were also observed in *S. filamentosus*. Parasites of *S. filamentosus* at Station 1 had the highest concentrations of most of the PCB congeners analyzed (Fig. 4). PCB 81 was distinctively high at Station 2 (Fig. 5).

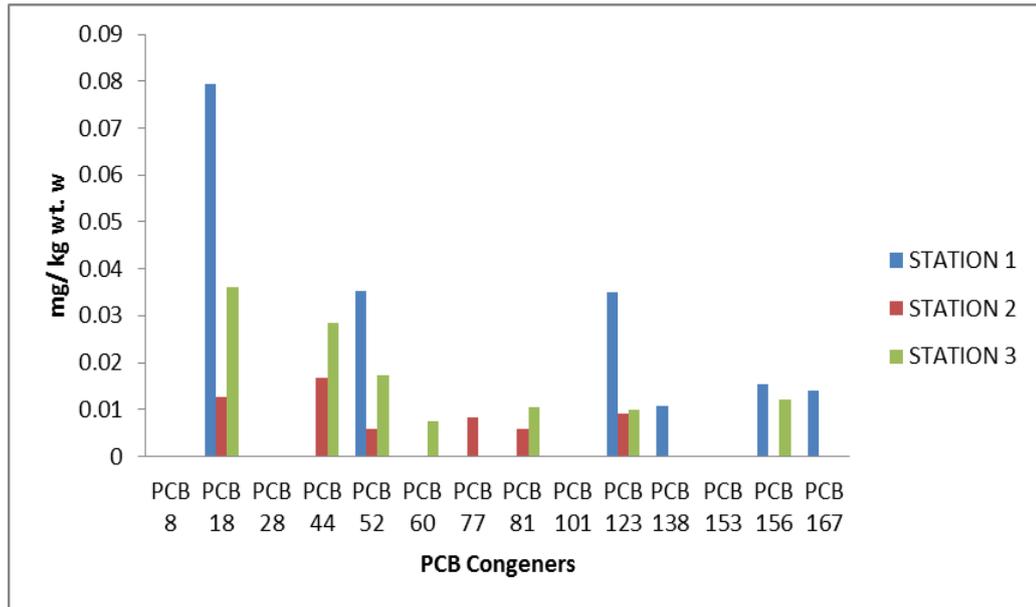


Fig. 4: PCB congeners in *Synodontis filamentosus* parasites across stations

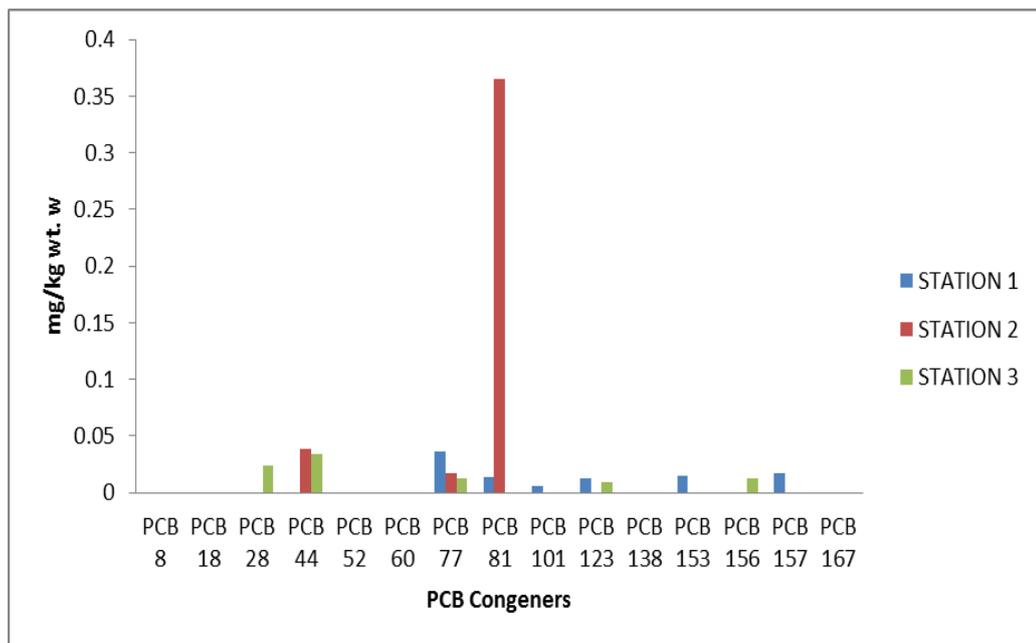


Fig. 5: PCB congeners in the tissue of *S. filamentosus* across stations

Sediment samples collected at the 3 stations showed distinctively high concentrations of PCB 81; particularly at Station 2 (Fig. 6). In the water concentrations of PCBs 8, 28, 44, and 156 at station 1 was outstandingly higher than the concentrations at other stations (Fig. 7).

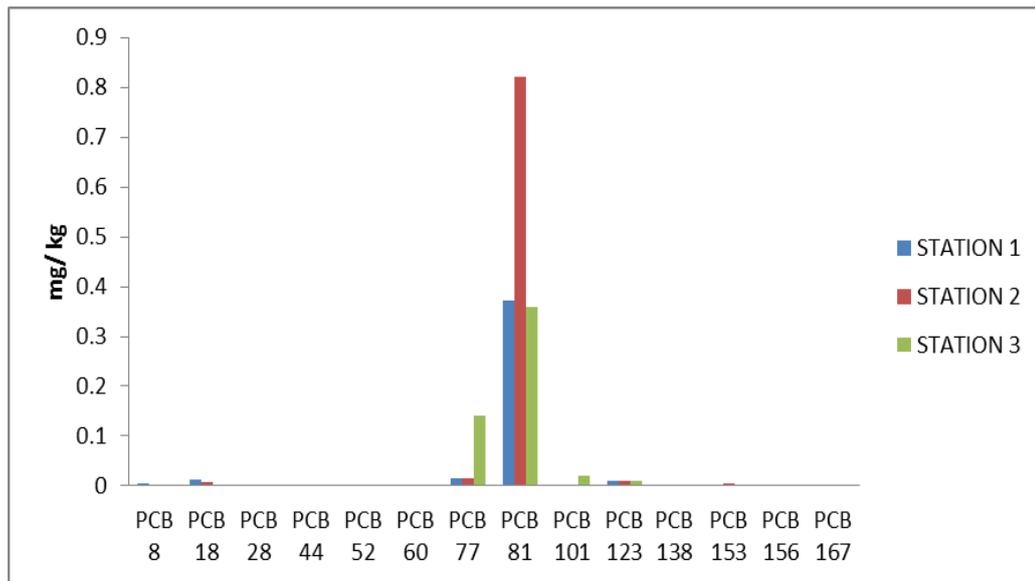


Fig. 6: PCB congeners in sediment samples across stations

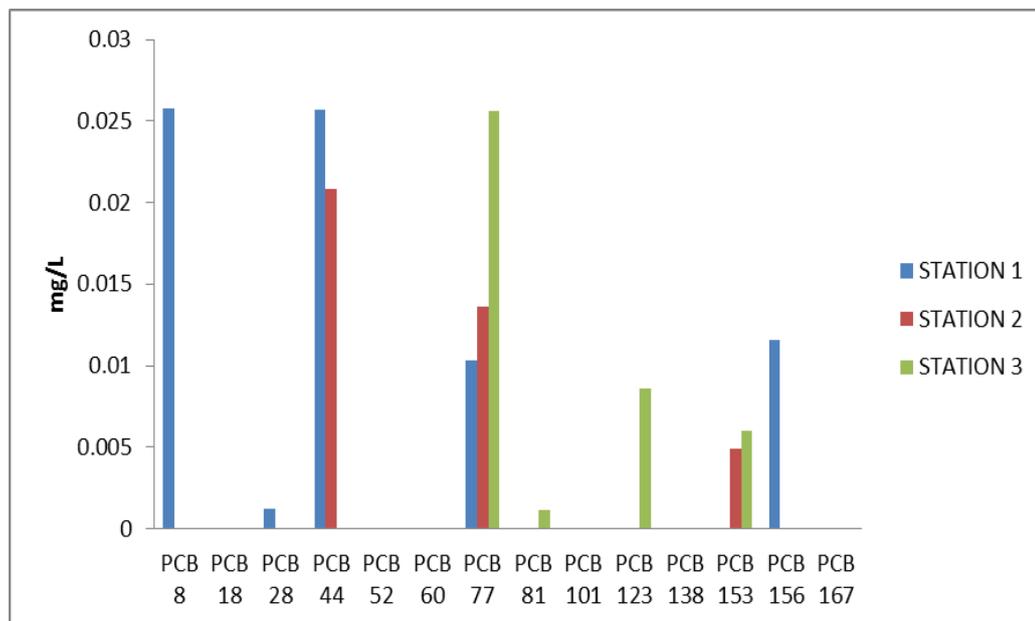


Fig. 7: PCB congeners in water samples across stations

At Station 1, the sequence of PCB accumulation in the environmental media was *T. zillii* > *T. zillii* parasites > sediment > *S. filamentosus* parasites > *S. filamentosus* > water, at Station 2 the sequence was sediment > *T. zillii* > *S. filamentosus* > *T. zillii* parasites > *S. filamentosus* parasites > water, while at Station 3 the sequence was *T. zillii* > sediment > *S. filamentosus* parasites > *T. zillii* parasites > *S. filamentosus* > water (Fig. 8).

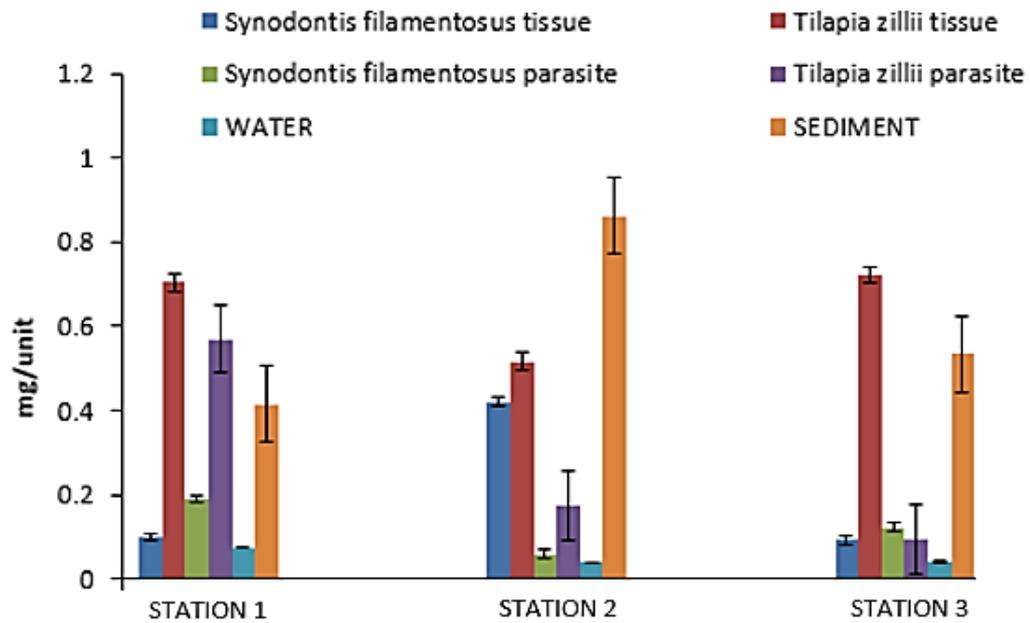


Fig. 8: Comparison of total PCBs in environmental matrices across stations

T. zillii, *S. filamentosus*, and their parasites all accumulated significant concentrations of PCBs at all the stations. *T. zillii* exhibited the highest bioaccumulation factor particularly at Station 3. This was accompanied by a significant bioaccumulation factor in the endoparasites of the fish. Some appreciable levels of bioaccumulations were detected in the *S. filamentosus*; particularly at Station 2. This was however not accompanied by appreciable bioaccumulation levels in the endoparasites (Fig. 9).

Significant biota-soil accumulation factors were detected in *T. zillii* at Station 1, followed by *S. filamentosus* at the same station. The least significant biota-sediment accumulation factor was observed in *T. zillii* at Station 3 (Fig. 10). Other biota-sediment accumulation factors observed were not significant.

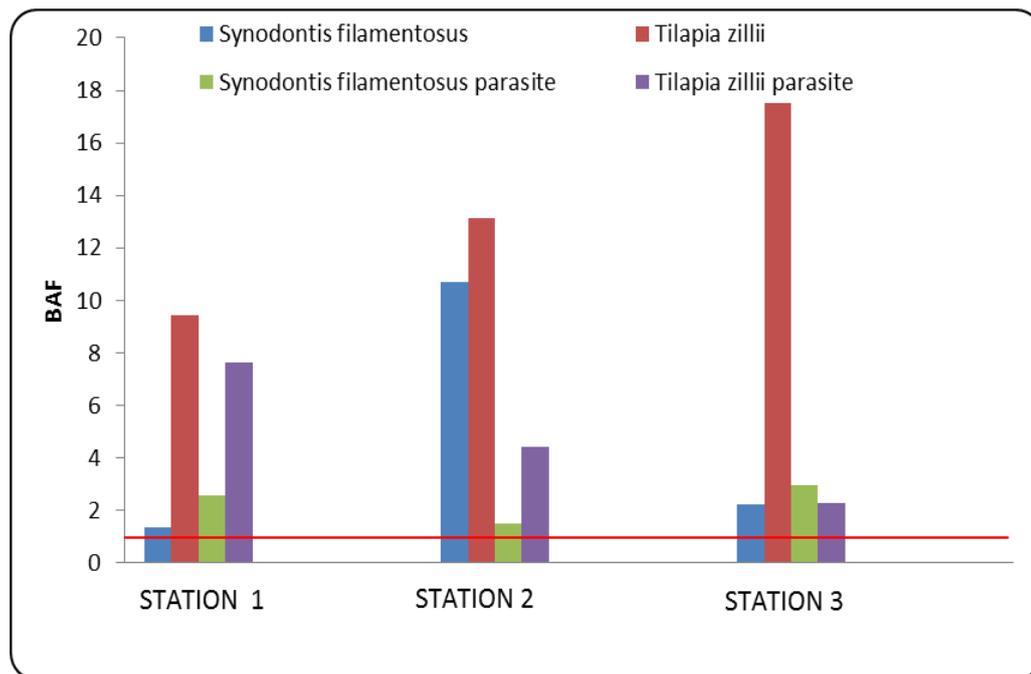


Fig. 9: Bioaccumulation factors (BAFs) of PCBs in biota across stations

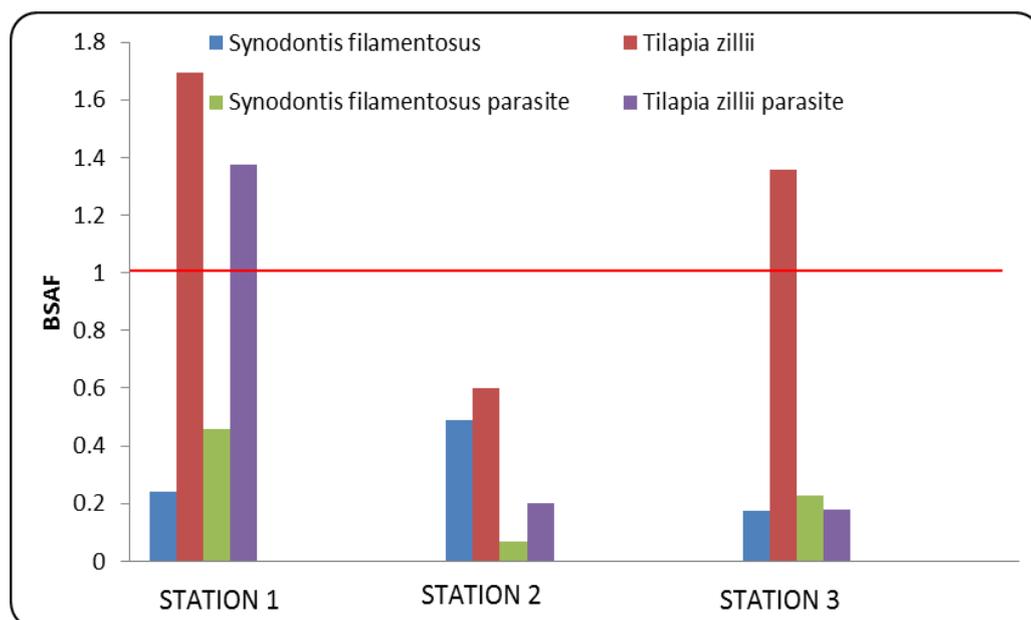


Fig. 10: Biota-soil accumulation factors (BSAFs) of PCBs in biota across stations.

Histopathological analysis

Microscopic study of the infected intestine and liver eviscerated from both fish species revealed some pathological observations. Intestinal section of *T. zillii* showed vacuolation and slight degeneration in the lumen (Plate 1: A and B), while the infected intestine of *S. filamentosus* showed degeneration of the epithelial layer and desquamation of the mucosa (Plate 1: C and D).

Sections of the liver of *T. zillii* shows hyperplasia and desquamation of hepatocytes and epithelial mucosa respectively (Plate 2: A and B), while section of *S.*

filamentosus liver shows desquamation, hyperplasia and fusion of hepatocytes (Plate 2: C and D).

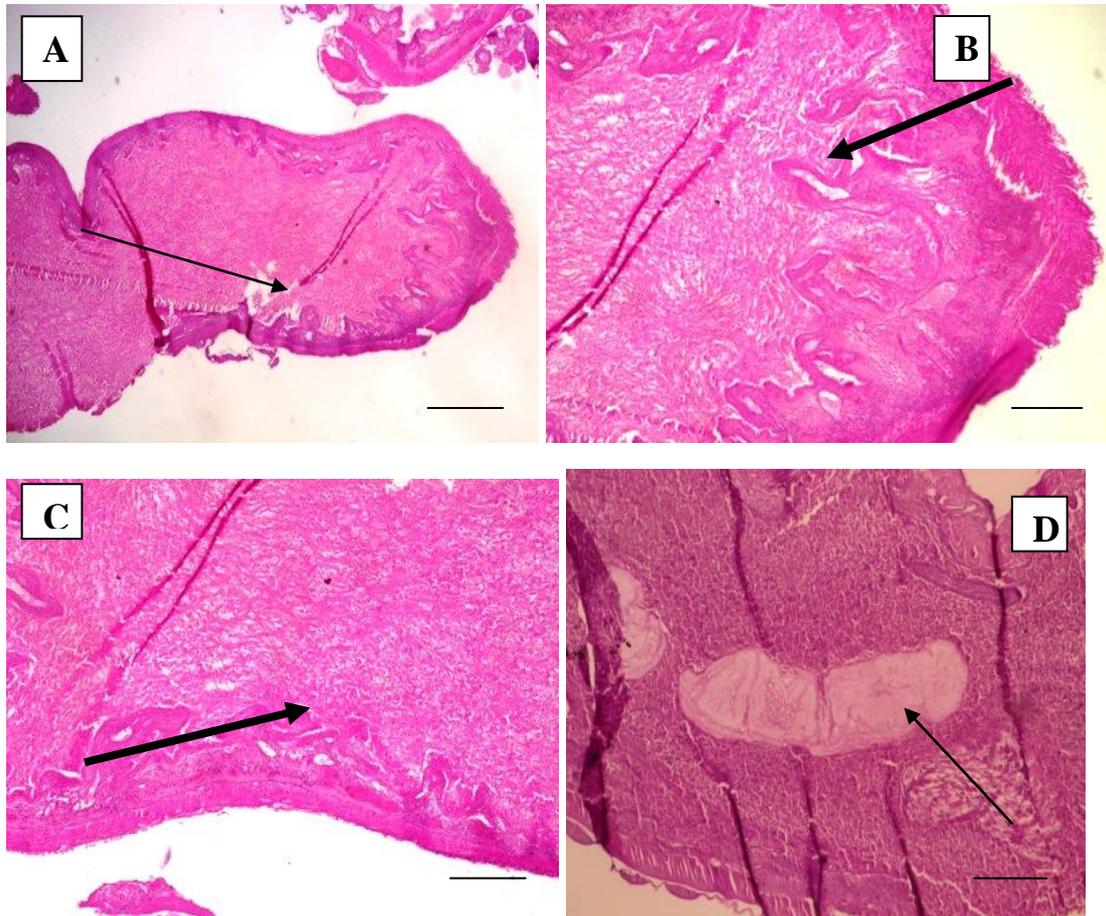
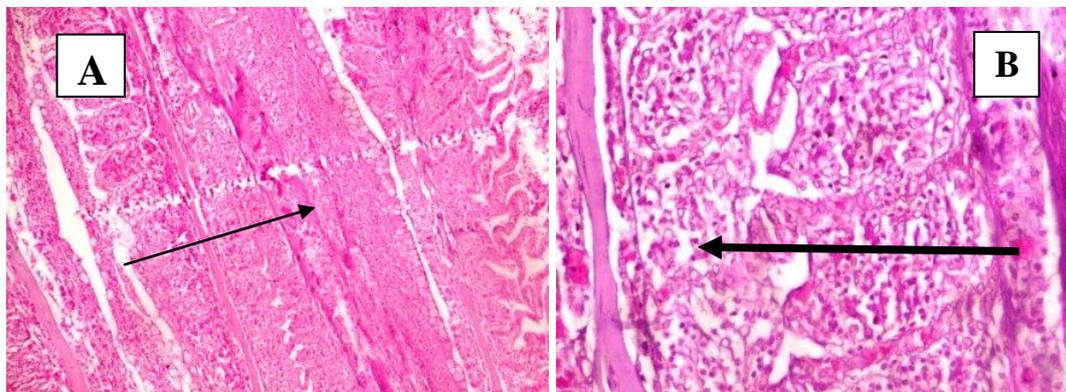


Plate 1: Histopathological section of intestine (Scale bar= 25 μ m)

(A and B- *T. zillii*): Section of the intestinal tissues show vacuolation (thin arrow) and degeneration (thick arrow) in the lumen.

(C and D- *S. filamentosus*): Section shows degeneration (thin arrow) and desquamation of the epithelial layer of the mucosa (thick arrow).



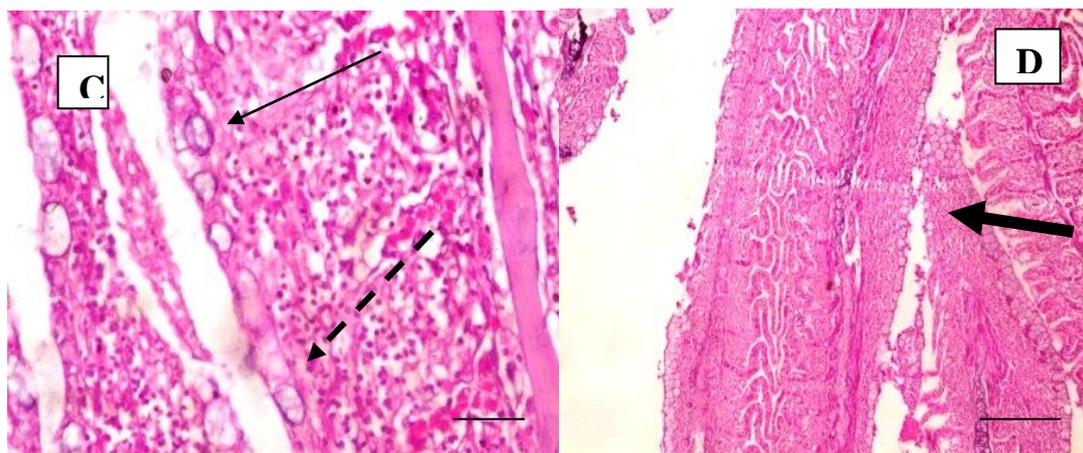


Plate 2: Histopathological section of liver (Scale bar= 25µm)

(A and B- *T. zillii*): Sections of the liver show hyperplasia (thin arrow) and desquamation of epithelial (thick arrow).

(C and D- *S. filamentosus*): Sections of the liver show fusion of hepatocytes (thin arrow), desquamation (thick arrow), and hyperplasia (broken arrow).

Numbers of *S. filamentosus* which exhibited fusion in the liver and desquamation in the intestine were significantly higher than that of *T. zillii*. While the number of *T. zillii* which exhibited vacuolation in the liver was significantly higher than the observed *S. filamentosus*. Overall comparative analysis of the respective tissues of both fishes showed that *S. filamentosus* exhibited significantly greater histopathological alterations than *T. zillii* (Table 3).

Table 3: Comparative histopathological alterations

Histopathological Alterations	<i>T. zillii</i> affected (%)		<i>S. filamentosus</i> affected (%)	
	Intestine	Liver	Intestine	Liver
Hyperplasia	-	52	-	76.5
Fusion	-	-	-	88.2*
Degeneration	82.5	-	73.8	-
Desquamation	-	76.6	92.4	85.5
Vacuolation	-	78.2*	-	-
Total	160.7	128.6	166.2	250.2*

Asterisked figures are significantly higher ($p < 0.05$). Sample size (N)=120

DISCUSSION

All physicochemical parameters observed across all stations were within standard regulatory limits, except for Turbidity (10.3 NTU) at Station 1 which was significantly higher than other stations ($p < 0.05$) and FEPA standard regulatory limit (10 NTU). High TSS and Turbidity levels observed at Station 1 can be attributed to proximity to points of discharge of municipal and industrial wastes.

More severe histopathological injury observed in *S. filamentosus* than *T. zillii* is attributable to higher parasitic infections in the former than the latter (Akinsanya *et al.*, 2007; Araneda *et al.*, 2008; Edah *et al.*, 2010). Koponen *et al.* (2001) earlier observed vacuolation in the liver of feral fish in a PCB-contaminated river. Correlation of current observation with previous indicates that the detected PCBs

must have been responsible for the vacuolation in the liver of *T. zillii* in Epe Lagoon. While parasitic infections must have contributed to greater alterations observed in the *S. filamentosus* (Onyedineke *et al.*, 2010), the extent of damage to the tissues and host nutrient loss are largely dependent on the prevalence of the endoparasites in the hosts. However, prevalence of parasites is greatly influenced by the defense systems of the host fish which is susceptible to PCB toxicity. Therefore, PCB toxicity may cause immunosuppression in the fish thereby enhancing prevalence of the parasites (Rosas-Valdez *et al.*, 2011).

Simultaneous occurrence of nematodes (*Procamallanus* sp. and *Raphidascaroides* sp.) and cestode (*Wenyonia* sp.) in the gastrointestinal tracts of *S. filamentosus* and *T. zillii* is similar to observations of Akinsanya *et al.* (2008). Result shows that parasite intensity was length-dependent i.e. the parasite intensity was directly proportional to the weight of the fish individuals. This trend was evident in both males and females of both species. This observation conforms to the observation of de la Cruz *et al.* (2013) on Nile tilapia.

Higher parasitic prevalence in the male *S. filamentosus* (68.33%) compared to its female counterpart (23.33%), and 11.67% in the male of *T. zillii* compared to the female counterparts (6.67%) conforms to the higher susceptibility of male fish than females observed by Akinsanya *et al.* (2008) and Idris *et al.* (2013). This is attributable to gender-based variability in ecological activities i.e. males are often more active and voracious in search for suitable mates and other ecological resources. In the process, they take in more of the intermediate hosts containing the developing states of parasites than the females (Sagerup *et al.*, 2000; Stahl *et al.*, 2009; Ekanem *et al.*, 2011; Esiest, 2013; Oluoch-Otiego *et al.*, 2016)

Lipophilic organic pollutants such as PCBs in aqueous phase are readily bioconcentrated by aquatic fauna and the rate is species-specific. Depending on the octanol-water partition coefficients, pollutants may reach manifold concentrations in biota, in concentrations higher than the source water. Outstandingly high concentrations of PCB 81 were detected in *T. zillii*, particularly at Station 1 and 3 (Fig. 3). High concentration of PCB 81 was also detected in the parasite of *T. zillii* Station 1 (Fig. 2). This suggests a high bioaccumulation of PCB 81 by the parasites from the host. The presence of PCB congeners in the lagoon can be linked to run-off from industrial sites around the metropolis in the catchment area. The most PCB congeners were detected in the parasites of *S. filamentosus*; except PCBs 28, 101 and 153 which were absent in *S. filamentosus* parasites across the stations (Fig. 4). While only PCB 81 was detected in the host *S. filamentosus* at Station 2 (Fig. 5). Results show that the endoparasites of *S. filamentosus* might have inefficiently metabolized the PCBs and the host (*S. filamentosus*) might have metabolized other PCB congeners, except PCB 81. PCB 81 was also poorly metabolized in the *T. zillii* and their endoparasites, hence high concentrations of PCB 81 in all the biota analyzed.

The high concentrations of PCB 81 in all biota can be linked to their exceedingly high concentrations in the bottom soil across the stations; with Station 2 exhibiting the highest concentration. However, in the overlying water column the PCB congeners detected were PCB 8 (Station 1), PCB 41 (Stations 1 and 2), PCB 77 (all stations), PCB 123 (Station 3), PCB 153 (Stations 2 and 3), and PCB 156 (Station 1). Low concentration of PCB 81 in the water might be as a result of high sorption capacity of the congener in the bottom soil. Results show that the fish might have accidentally ingested high levels of PCB congeners from the bottom soil in the process of foraging.

A general overview of the profile of PCB accumulation showed that *T. zillii*, followed by their endoparasites accumulated outstanding concentrations (Figure 8). This is an indication that *T. zillii* may be a more bioaccumulator of PCBs than *S. filamentosus*. However, the toxicant burden of *T. zillii* was appreciably shared by its endoparasites. Furthermore, significant biota-soil accumulation factors observed in the *T. zillii* (Stations 1 and 3) and their endoparasites (Station1) support the fact that PCBs had significant sorption capacity into the soil at Stations 1 and 3. The endoparasites of *T. zillii* had accumulated appreciable concentration from its host. Results show evidences of host-to-parasite xenobiotic transfer.

CONCLUSION

Accumulation of toxicants in parasites is a function of the concentration in the host. The tissue injuries are linkable to both PCB toxicity and parasitic infections. Findings show that *S. filamentosus* is a better bioindicator of tissue injury while *T. zillii* is a better bioaccumulator.

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