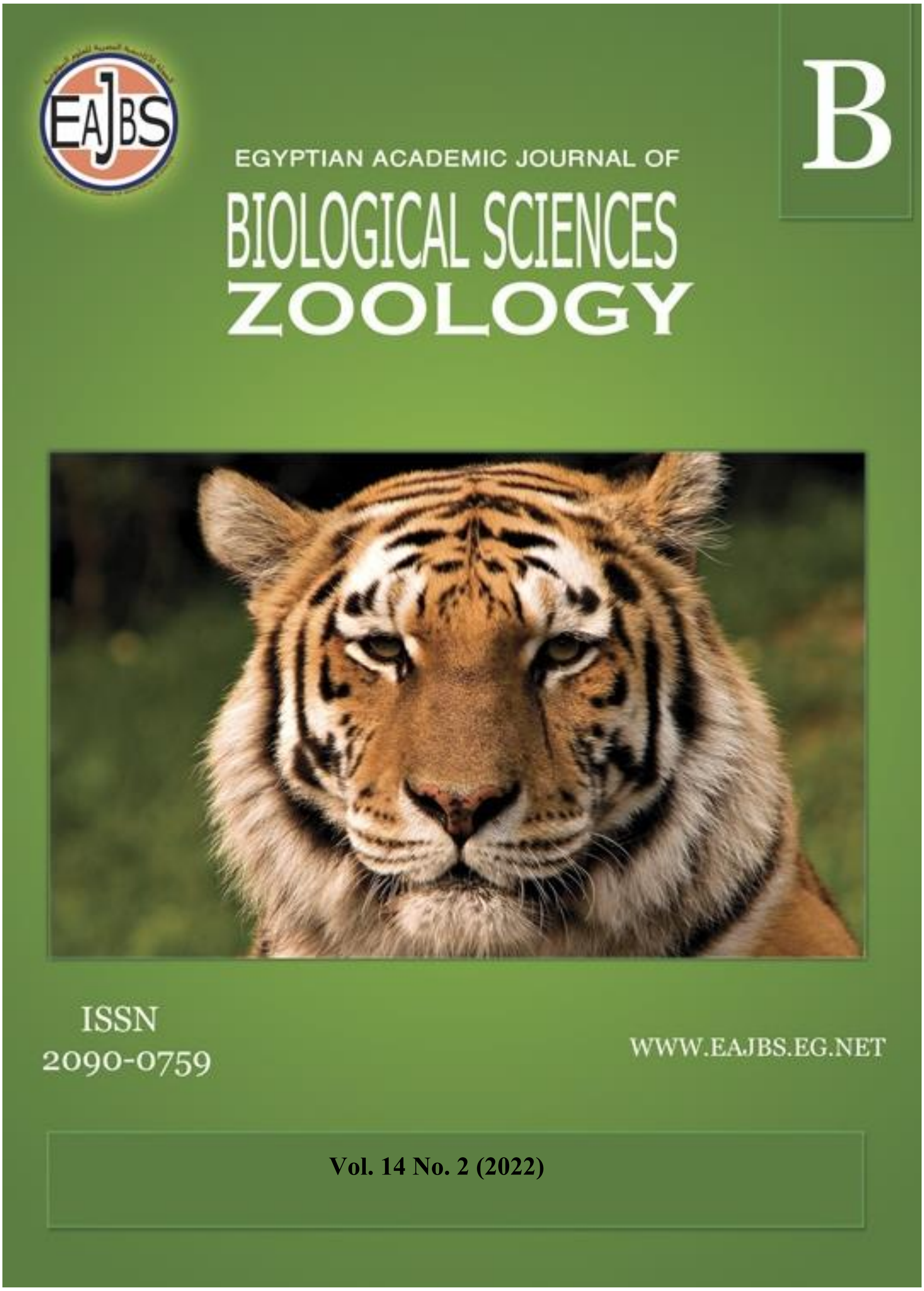

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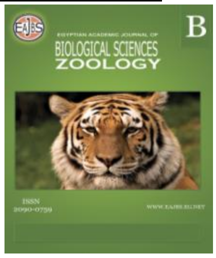

The Role of *Electrotaenia malopteruri* (Fritsch,1886) (Cestoda: Proteocephalidae) in the Fish host Gut Polycyclic Aromatic Hydrocarbons Accumulation, Lipid Profile and Histopathological Alterations in Lekki Lagoon

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ABSTRACT

Background: This study investigates the contamination of Polycyclic Aromatic Hydrocarbon residues in the environmental media, *Malapterurus electricus*, and the parasite, *Electrotaenia malopteruri*, in the Epe axis of the Lekki Lagoon. The paper also investigates the role of the intestinal parasite in the host-gut PAH accumulation and the effect on the gut lipid profile, anti-oxidants and histological alterations. Grab samples of surface water, sediment, fish liver, intestines and intestinal parasites were collected and analyzed for PAH residues using gas chromatography. The intestines of infected and non-infested fish and the parasite were analyzed for pathological alterations, lipid profile and antioxidant enzymes. **Results**: The prevalence of the cestode parasite, *Electrotaenia malopteruri* was 37.21%, among these infected fishes, 14 (16.28%) were females while 18 (20.93%) were males. Among PAHs congeners with 2-3 and 4-6 aromatic cyclic rings, naphthalene had the highest bio-concentration in the fish organs from the environmental media. The fish intestine bioaccumulated naphthalene 181 times more than the surface water concentrations, and 48 times more than the sediment. Other congeners that bioaccumulated in the fish intestine were fluorine, pyrene, dibenz (a,h)anthracene, dibenzo(a,l)pyrene, and benzo(g,h,i)perylene. The parasite bioaccumulated benz (a)anthracene, chrysene, benzo(a)pyrene, and benzo (g,h, i)perylene 18, 23, 3 and 2 times more than the host intestine respectively. The cholesterone, triglycerides and low-density lipid levels in *Electrotaenia malopteruri* were higher than that in the intestines of the infected and non-infected individuals. The intestinal anti-oxidants induced in the infected and non-infected individuals and in the parasite, *Electrotaenia malopteruri* were SOD, CAT, MDA, GSH and GPx. The parasite had more SOD, CAT and GPx than the infected and non-infected individuals. The intestine of the infected individuals had more SOD, CAT, GSH and GPx than the intestine of non-infected individuals.

Conclusions: These infected individuals had a higher frequency of gut pathological alterations compared to the non-infected individuals. The parasites are capable of depurating Polycyclic Aromatic Hydrocarbons in the fish host and were also subjected to more stress than both the infected and non-infected hosts probably as a result of the bioaccumulated contaminants within its tissues.

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INTRODUCTION

The field of environmental parasitology is a new and unique one involving the relationship between parasites and their host coupled with the interaction of contaminants within the hosts (Sures, 2004). Akinsanya *et al.* (2007) had earlier reported Electrotaenia malopteruri from Malapterurus electricus from the Lekki lagoon. Helminth parasites of fishes are known as important sentinels organisms for the biomonitoring of some contaminants within the environments. (Akinsanya *et al.* ,2018a; Sures, 2004).

The resultants bioaccumulation of these contaminants within the hosts and the resident parasites is the oxidative stress biomarker responses of both the host and the resident parasites coupled with the attendant histopathological alterations within the hosts' tissues. (Akinsanya *et al.,* 2018 a).

The oxidative stress response is high in the infected hosts which has both contaminants and parasitism as stressors and mild in the uninfected hosts (Akinsanya et al, 2019). The coastal lagoon and its resources in the metropolitan cities in Lagos have been under environmental disturbance. This disturbance is due to increasing population and industrial development. PAHs are found in the coastal waters either as a result of accidental oil spillage or through human discharge of petroleum byproducts (petrogenic source) (Mascarelli, 2010) or through the combustion of fuel and other organic substances (pyrogenic source) (Feng and Pisula, 2009) or natural processes (Durand *et al.,* 2004).

There has been reported discharge from human and industrial activities into the Lagos coastal lagoon (Anyakora *et al.,* 2004; Alani *et al.,* 2012). The most important classes of environmental pollutants in coastal areas are polycyclic aromatic hydrocarbons (PAHs). The PAH in Lagos coastal lagoons have been reported to be of petrogenic sources (Anyakora *et al.,* 2004; Alani *et al.,* 2012; Sogbanmu *et al.,* 2016; Akinsanya et al, 2018b). The lipophilic and persistent nature of these organic compounds makes them bioaccumulate in aquatic organisms (Anyakora *et al.,* 2004; Alani *et al.,* 2012; Akinsanya *et al.,* 2018b).

The feeding relationship among the aquatic organisms in a PAH-contaminated environment and the physicochemical characteristics are determining factors for biomagnification in the food chain (Anyakora *et al.,* 2004; Alani *et al.,* 2012; Akinsanya *et al.,* 2018b).

Parasites are not left out in the bioaccumulation trend in the host food chain. Some macroparasites inhabit the fish host intestine, where they have an avenue to circumvent the host nutrients to obtain needed energy and sustenance. These intestinal macroparasites are exposed to PAH residues in the host food chain. Akinsanya *et al.,* (2018) reported the accumulation and distribution of PAH residues in various compartments; water, sediment, benthic invertebrates, benthopelagic fishes and their parasito-fauna in Snake Island, Lagos coastal lagoon. This report linked PAH concentrations in the surface water and sediment to the benthic invertebrate intermediate host, the bentho-pelagic fish host and their intestinal macroparasites. It also stated that there was an accumulation of PAH residues in fish intestinal trematodes and cestodes. There are limited studies that explain the role of these macroparasites in contaminant accumulation and magnification along the host food chain (Saliu *et al.,* 2014; Ukwa *et al.,* 2018).

Most macroparasites are biological stressors in fish that cohabit with the fish host for energy and nourishment. Infected fishes exposed to contaminants have to utilize more energy in fighting stress than that in the non-infected individuals (Sures, 2004; Saliu *et al.,* 2014; Akinsanya *et al.,* 2015; Ukwa *et al.,* 2018). These stressors affect health and limit their survival potential. The host immunity is one major factor that regulates parasite infection prevalence and intensity, PAH, on the other hand, modulates immunity in the host. PAH in the host fish has been reported to reduce fish immunity to fight infection.

The aim of this study is to determine the contamination of PAH residues in the aquatic environment, fish and parasites and the role of the intestinal parasite in the host gut PAH accumulation and the effect on the gut lipid profile, anti-oxidants and histological alteration.

MATERIALS AND METHODS

Study Area:

Lekki lagoon supports a major fishery in Nigeria. The Lekki lagoon is located in Lagos State Nigeria and lies between longitudes 4º 0 and 4º15'E and between latitudes 6º25' and 6º37'N, has a surface area of about 247 km^2 with a maximum depth of 6.4m(Fig 1). A large portion of the lagoon is shallow and less than 3.0m deep. A major feature of the lagoon is the Floating vegetation of Water Hyacinth which occurs on the periphery of the lagoon and has been identified as a major indicator of the presence of pollution in the water (Nwankwo and Onitiri, 1992).

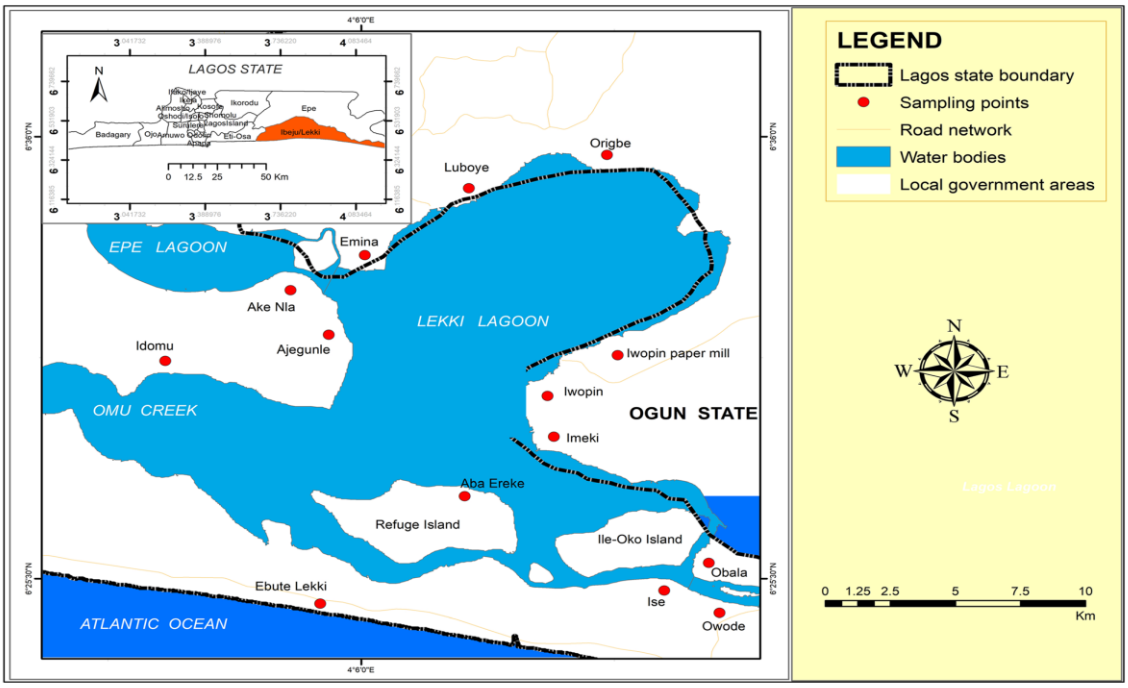

Fig. 1: Map of Epe-Lekki Lagoon

Collection and Preservation of Fish Parasites and Organ Samples:

A total number of Eighty-Six (86) life fish specimens of *Malapterurus electricus* were freshly obtained from the study area between the periods of June to November 2019. The fish were caught at the designated study location with the help of fishermen. Morphometric measurements of the fish (weight, standard length and total length), sex determination and examination of the specimen tissues for gastrointestinal parasites, were carried out. The identified parasites and fish intestines were collected for lipid profile and PAH analysis and preserved at a temperature below 4ºC. Part of these collected organs for histopathology was preserved in bouin's fluid.

Collection of Surface Water and Sediment Samples:

Grab samples of surface water and sediment were collected from four sampling locations with the Epe axis of the lagoon at the mid-fish sampling period (September 2019); top and bottom at three different time intervals of 5 mins and mixed to form a composite sample. They were stored in ice bags at a temperature below 4ºC and transported to the laboratory.

Analysis of Polycyclic Aromatic Hydrocarbon Residues in Environmental Media, Fish Organs and Parasites:

The extraction method was carried out employing the modified methods of ASTM D3328 and ASTM 3415. This method has been used by Durand et al. (2004) and Alani et al. (2012). The polycyclic aromatic hydrocarbon residues in the various samples were analyzed using gas chromatography.

Analysis of Lipid profile, Protein and Anti-oxidant Enzymes:

The parasite and intestines of the infected and non-infection fishes were analyzed for lipid profile, protein, lipid peroxidation, reduced glutathione, catalase and superoxide dismutase.

Determination of Lipid Profile:

The intestinal samples of the fish and parasites were subjected to colorimetrical analysis of total protein content (Henry 1964) using buiret reagent and total cholesterone, lipoproteins (High and Low Density) and triglycerides according to Tietz (1995) using the enzymatic colorimetrical method. Glycogen was determined by the anthrone reagent method (Seifter et al. 1950).

Determination of Anti-oxidant Enzymes:

Lipid peroxidation was determined and measured by the methods of Niehaus and Samuelsson (1968) and Jiang *et al., (*1992) respectively. The absorbance of clear supernatant was measured against a reference blank at 535 nm. Reduced glutathione (GSH) was determined by the method of Ellman (1959) and Catalase (CAT) was assayed calorimetrically at 620nm and expressed as moles of hydrogen peroxide (H_2O_2) consumed/min/mg protein as described by Quinlan *et al.,* (1994). SOD activity in tissue homogenates was determined following the procedure of Marklund (1984) with some modifications. The assay was performed in thermo-stated cuvettes at 25°C and changes in absorption were recorded by a spectrophotometer (Spectronic 20D) at 480nm. One unit of SOD activity was defined as the amount of enzyme that can inhibit the auto-oxidation of 50% of the total pyrogallol in the reaction.

Histopathology:

The histopathological alterations of the intestine were examined using the method by Schwaiger et al, (1997). Infected tissues were fixed in 10% formalin, dehydrated in graded ethanol (Schwaiger *et al.,* 1997), cleared in xylene, embedded in paraffin wax and sectioned at 5 µm on a rotary microtome. Slides were stained using the haematoxylin and eosin technique for light microscopy (Schwaiger *et al.,* 1997).

RESULTS

Morphometrics and Condition Factor (K) of *Malapterurus electricus* in Epe Axis, Lekki Lagoon, Lagos:

Table 1 shows the morphometrics and condition factor (K) of *M. electricus* in the lagoon. Eighty-six (86) fishes were caught, weighing 34.00g to 159g with a mean value of 69.06g and the standard-length ranging, from 11.00cm to 24.00cm with an average length of 17.70cm (Mean ± SD) significant at 0.01 level. The female fishes had more weight, mean weight, 72.82g compared to the males, 66.59g. This also includes their standard length, 15.28cm and 14.76cm both had (Mean ± SD) significant at 0.05 levels respectively. The total condition factor of the fish ranged from 1.20 to 3.00, with an average, of 1.94 (Mean ± SD) significant at a 0.01 level. The female fishes were in better condition, with an average condition factor, of 1.95 and the males, 1.92, both had (Mean ± SD) significant at 0.05 level.

Table 1: Morphometrics and Condition Factor (K) of *Malapterurus electricus* in Epe Axis, Lekki Lagoon, Lagos**.**

Morphometrics	Number	Min-Max	Mean ± S. D.
Total Standard Length (cm)	86	11.00-24.00	17.70 ± 2.52**
Total Body Weight (g)	86	14.00-159	69.06±30.73
Total Condition Factor	86	1.20-3.00	1.94±0.37**
Length of Females (g)	34	13.00-19.80	15.28±1.56*
Weight of Females (g)	34	38.00-159.00	72.82±30.06
Length of Males (cm)	52	9.50-19.90	14.76±2.42*
Weight of Males (g)	52	14.00-144.00	66.59±31.21
Female Condition Factor	34	1.20-2.50	1.95±0.34**
Male Condition Factor	52	1.20-3.00	1.92±0.39**

*Signifies Mean ± SD is significant at p<0.05; **Signifies Mean ± SD is significant at p<0.01.

Prevalence of Intestinal Parasite of *Malapterurus electricus* in Epe Axis, Lekki Lagoon, Lagos:

Eighty-six (86) fishes were caught, weighing 34.00g to 159g with a mean value of 69.06g and the standard-length ranging, from 11.00cm to 24.00cm with an average length of 17.70cm (Mean ± SD) significant at 0.01 level. Table 2 shows the prevalence of intestinal parasites of *M. electricus* in the Lagoon. The prevalence of the cestode parasite, *Electrotaenia malopteruri* of *M. electricus* in the Lagoon is 37.21%, meaning 32 fishes were infected out of 86 fishes. Among the infected fishes, 14 (16.28%) were females while 18 (20.93%) were males. There were more males infected with the parasite. The distribution of parasitic infection among the fish population was significant at 0.05 level, Chi-Square $\chi^2 = 15.72$ (Table 2).

Table 2: Prevalence of Intestinal Parasites of *Malapterurus electricus* in Epe Axis, Lekki Lagoon, Lagos

Sex	Infected Individuals	Non-infected Individuals	Total Population
Female	14 (16.28%)	20 (23.26%)	34 (39.26%)
Male	18(20.93%)	34 (39.53%)	52 (60.47%)
Combined Sex	32 (37.21%)	54 (62.79%)	86(100.00%)
Chi-Square $\chi^2 = 15.72$, df = 1, $p<0.05$			

Table 3 shows the bioaccumulation factor and distribution of polycyclic aromatic hydrocarbon congeners in environmental media and in infected and non-infected individuals of *Malapterurus electricus* in Epe Axis, Lekki Lagoon, Lagos. Among PAHs congeners with 2-3 and 4-6 aromatic cyclic rings, naphthalene had the highest bio-concentration in the fish organs from the environmental media. The fish organ bioaccumulated naphthalene 181 times more than the surface water concentrations, and 48 times more than the sediment, likewise the liver. Other congeners that bioaccumulated in the fish organ were fluorine, pyrene, dibenz (a,h)anthracene, dibenzo(a,l)pyrene, and benzo(g,h,i)perylene.

Table 3: Bioaccumulation Factor and Distribution of Polycyclic Aromatic Hydrocarbon Congners in Environmental Media and in *Malapterurus electricus* in Epe Axis, Lekki Lagoon, Lagos.

Group of PAHs based on Molecular size	Congeners of Polycyclic Aromatic Hydrocarbon	Surface water (ppm)	Sediment (ppm)	Bioaccumalation Factors (BAF)				WHO Limits
				$BAF_{w/i}$	$BAF_{w/n}$	$BAF_{s/i}$	$BAF_{s/n}$	
2 to 3 RINGS	Naphthalene	0.01	0.15	181.00	48.00	48.00	4.00	0.01
	Acenaphthylene	0.33	0.45	1.00	1.00	1.00	0.00	0.01
	Acenaphthene	0.00	0.11	ND	ND	ND	2.00	0.01
	Fluorene	0.06	0.07	8.00	8.00	8.00	7.00	0.01
	Phenanthrene	0.00	0.00	ND	ND	ND	ND	0.01
4 to 6 RINGS	Anthracene	0.00	0.11	ND	ND	2.00	3.00	0.002
	Fluoranthene	1.38	1.52	0.00	0.00	0.00	0.00	0.002
	Pyrene	0.02	0.46	9.00	6.00	5.00	0.00	0.01
	Benzo(c)phenanthrene	0.16	0.21	2.00	1.00	1.00	0.00	0.002
	Chrysene	0.00	0.03	ND	ND	ND	7.00	0.002
	Benzo(a)anthracene	1.45	1.47	0.00	0.00	0.00	0.00	0.002
	Benzo(e)pyrene	0.00	0.00	ND	ND	ND	ND	0.007
	Benzo(b)fluoranthene	0.44	0.00	1.00	1.00	ND	ND	0.002
	Benzo(k)fluoranthene	0.00	0.00	ND	ND	ND	ND	0.002
	Benzo(a)pyrene	0.00	0.96	ND	ND	0.00	0.00	0.002
	3-Methylcholanthrene	0.59	1.84	1.00	1.00	0.00	0.00	0.002
	Indo (1.2,3-cd)pyrene	0.00	0.05	ND	ND	ND	6.00	0.002
	Dibenz(a,h)anthracene	0.02	0.03	23.00	29.00	25.00	16.00	0.002
	Benzo(g, h,i) perylene	0.16	1.07	2.00	3.00	8.00	0.00	0.002
	Dibenzo(a,l)pyrene	0.69	0.24	2.00	2.00	8.00	1.00	0.002
	Dibenzo(a,i)pyrene	0.00	0.00	ND	ND	ND	ND	0.002
	Dibenzo(a,h)pyrene	1.11	0.29	0.00	0.00	2.00	2.00	0.002

$BAF_{w/i}$ – Intestine relative to water PAHs Concentration, $BAF_{w/L}$ - Liver relative to water PAHs Concentration, $BAF_{s/i}$ - Intestine (Infected) relative to sediment PAHs Concentration, $BAF_{s/n}$ - Intestine (Non-infected) relative to sediment PAHs Concentration; ND: Not detected

Table 4 shows the bioaccumulation of polycyclic aromatic hydrocarbon congners in the intestinal parasite. The parasite, bioaccumulated benz (a)anthracene, chrysene, benzo(a)pyrene, and benzo(g,h,i) perylene 18, 23, 3 and 2 times more than the host organs respectively. Among the seven USEPA classified cancinogenic PAH congeners, dibenz (a,h) anthracene is highly bioaccumulated in the fish organs and the parasite bioaccumulated .chrysene 5 times more than the intestine.

Table 5 shows the lipid profile and antioxidant enzymes in the intestine of infected and non-infected individuals of *Malapterurus electricus* and its parasite, *Electrotaenia malopteruri* in Epe Axis, Lekki Lagoon. The mean values of cholesterone, HDL and protein for the host intestine were significant at 0.01 level ($p<0.01$). The cholesterone, triglycerides and low-density lipid levels in *Electrotaenia malopteruri* were higher than that in the intestines of the infected and non-infected individuals. The protein, high-density lipid and glucose levels were higher in the host intestines, but the non-infected individuals had more concentrations of intestinal protein and glucose.

The intestinal anti-oxidants induced in the infected and non-infected individuals and in the parasite, *Electrotaenia malopteruri* were SOD, CAT, MDA, GSH and GPx. The parasite had more SOD, CAT and GPx than the infected and non-infected individuals. The intestine of the infected individuals had more SOD, CAT, GSH and GPx than the intestine of non-infected individuals.

Table 4: Bioaccumulation Factor and Distribution of Polycyclic Aromatic Hydrocarbon Congeners in *Malapterurus electricus* and Its Parasite in Epe Axis, Lekki Lagoon, Lagos

Group of PAHs based on Molecular size	Congeners of Polycyclic Aromatic Hydrocarbon	Intestine (ppm) Mean (Min-Max)	Liver (ppm) Mean (Min-Max)	Parasite (ppm)	Bioaccumalation Factors = (BAF)	
					$AF_{i/p}$	$BAF_{n/p}$
2 to 3 RINGS	Naphthalene	1.81(0.12-3.66)	0.48(0.00-0.91)	0.00	0.00	0.00
	Acenaphthylene	0.30(0.19-0.40)	0.24(0.00-0.30)	0.23	1.00	1.00
	Acenaphthene	0.23(0.00-0.71)	0.27(0.8-0.56)	0.16	0.00	0.00
	Fluorene	0.46(0.25-0.68)	0.45(0.00-1.04)	0.23	1.00	1.00
	Phenanthrene	0.68(0.17-1.40)	0.33(0.00-0.61)	0.46	0.00	1.00
4 to 6 RINGS	Anthracene	0.44 (0.21-0.79)	0.27(0.00-0.37)	0.10	0.00	0.00
	Fluoranthene	0.29(0.09-0.55)	0.20(0.00-0.31)	10.37	0.00	3.00
	Pyrene	0.17(0.00-0.39)	0.11(0.00-0.30)	0.65	0.00	5.00
	Benzo(c)phenanthrene	0.37(0.03-0.74)	0.13(0.00-0.40)	0.08	0.00	0.00
	Benz(a)anthracene	0.26(0.20-0.46)	0.20(0.00-0.34)	4.74	18.00	23.00
	Chrysene	0.25(0.20-0.29)	0.26(0.00-0.34)	5.67	23.00	23.00
	Benzo(e)pyrene	0.71(0.17-0.71)	0.45(0.00-0.56)	1.00	1.00	1.00
	Benzo(b)fluoranthene	0.42(0.00-0.52)	0.45(0.00-0.50)	0.67	1.00	1.00
	Benzo(j)fluoranthene	0.25(0.00-0.86)	0.17(0.00-0.44)	0.00	0.00	0.00
	Benzo(k)fluoranthene	0.22(0.19-0.90)	0.39(0.00-0.45)	0.27	1.00	1.00
	Benzo(a)pyrene	0.32(0.00-2.54)	0.45(0.00-0.65)	0.86	3.00	2.00
	7,12-Dimethylbenz(a) anthracene	069(0.00-0.81)	0.36(0.00-0.65)	0.42	0.00	1.00
	3-Methylcholanthrene	0.34(0.28-0.41)	0.43(0.00-0.77)	0.34	1.00	1.00
	Indo(1.2,3-cd)pyrene	0.28(0.00-0.38)	0.32(0.00-0.39)	0.38	1.00	1.00
	Dibenz(a,h)anthracene	0.45(0.00-1.06)	0.58(0.00-0.65)	0.69	1.00	1.00
	Benzo(g,h,i) perylene	0.31(0.00-0.41)	0.51(0.00-0.95)	0.46	2.00	1.00
	Dibenzo(a,l)pyrene	1.12(0.31-3.31)	1.44(0.00-0.39)	0.36	1.00	0.00
	Dibenzo(a,i)pyrene	0.23(0.00-3.31)	0.35(0.00-0.54)	3.24	1.00	16.00
	Dibenzo(a,h)pyrene	0.05(0.00-0.48)	0.61(0.00-0.83)	0.00	0.00	0.00

$BAF_{i/p}$ – Parasite relative to host intestine (Infected) PAHs Concentration, - $BAF_{n/p}$ Parasite relative to host intestine (Non-infected) PAHs Concentration.

Table 5: Lipid Profile and Anti-oxidants in the intestines of *Malapterurus electricus* and Its Parasite in Epe Axis, Lekki Lagoon.

Organ	Parameters	No	Non-Infected Mean ± S.D.	Infected Mean ± S.D.	*E. malopteruri*
Intestine Lipid Profile	Cholesterone (mg/dl)	10	2.35± 0.82	1.30± 0.60*	4.27
	High Density Lipids (mg/dl)	10	0.42± 0.11	0.44±0.09**	0.14
	Triglycerides (mg/dl)	10	2.05± 0.61*	0.65± 0.30	3.09
	Low Density Lipids (mg/dl)	10	1.00± 0.63*	0.45± 0.34	2.73
	Proteins (g/l)	10	16.83± 3.04	8.82±1.26**	8.41
	Glucose (mg/dl)	10	5.45± 4.54	0.53± 0.19	1.13
Intestinal Anti-oxidants	Total Protein (g/l)	10	35.45± 5.50*	31.72±12.02	18.43
	Superoxide Dismutase, SOD (min/mg protein)	10	167.49±7.21*	172.56±9.44*	379.28
	Catalase, CAT (min/mg protein)	10	1.56±0.91	1.82±1.46	4.60
	Malondialdehyde, MDA (nmol/ml)	10	24.81±9.62	21.49±7.56*	18.17
	Reduced Glutathione, GSH (µmol/ml)	10	9.01±2.01*	9.21±4.61	7.38
	Glutathione Peroxidase, GP_X (µmol/ml)	10	29.71±1.99**	32.45±2.51*	43.96

*Signifies Mean ± SD is significant at p<0.05; **Signifies Mean ± SD is significant at p<0.01.

Histopathological Alterations in the fish sp.:

The histopathological analysis in the fish host revealed different pathological alterations as a result of the parasitic infections of the cestode parasite, *Electrotaenia malopteruri*. The non-infected tissues revealed normal crypt–villous architecture and normal mucosa and submucosa with no significant lesion observed. The infected tissues however revealed mild haemorrhagic lesion, mild fibrosis of the submucosa, moderate oedema and focal area of stunting villous structure with the presence of parasites embedded in the mucosa. Plates 1 and 2 revealed different histopathological alterations in photomicrographs.

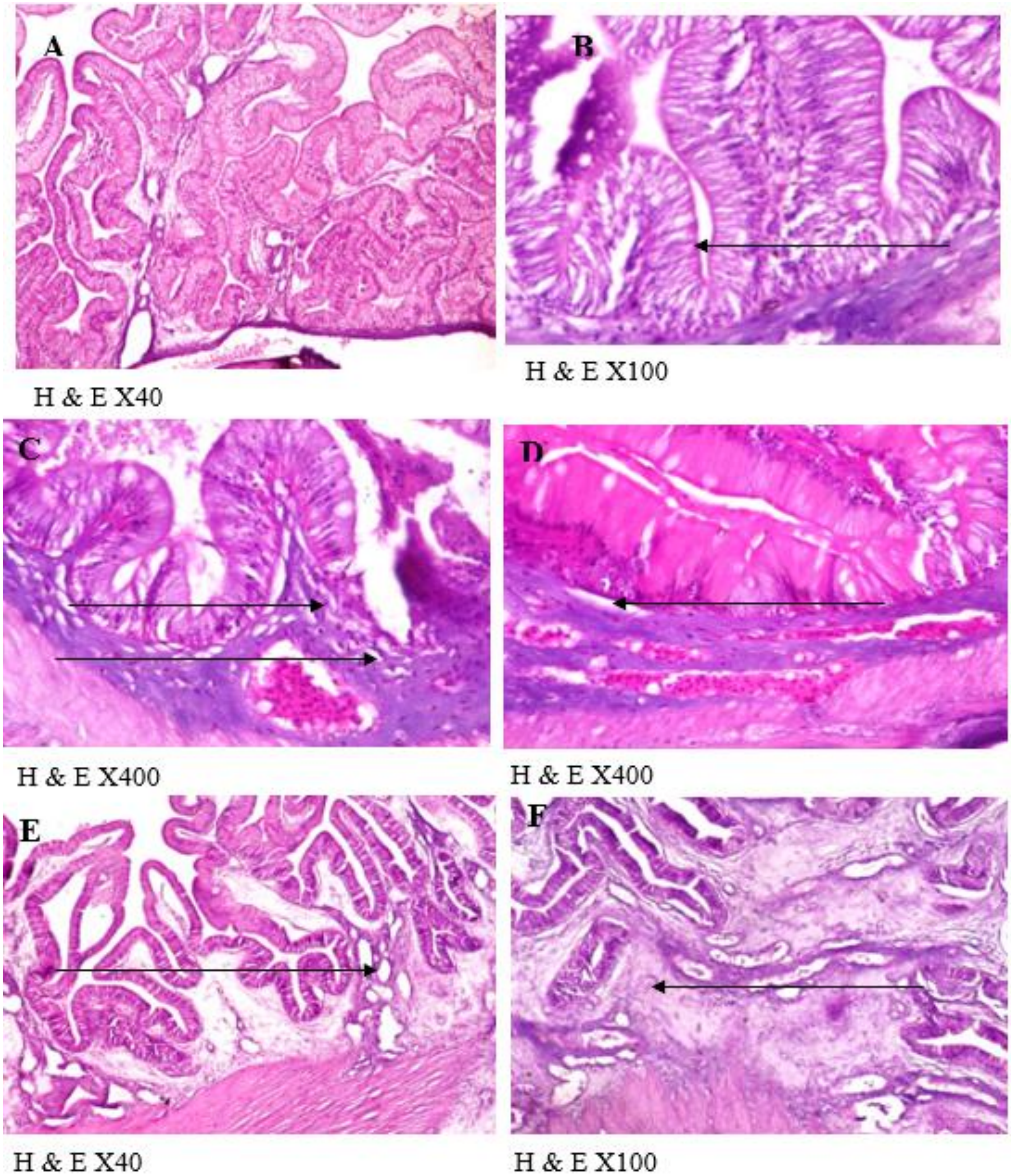

Plate 1: A & B: Normal villi structure, normal mucosa and submucosa. The normal crypt-villous architecture is well preserved. No significant lesion seen; **C & D:** Mild haemorrhagic lesion (black arrow) and mild fibrosis of submucosa (slender arrow); **E & F:** Moderate oedema (black arrow) and mild fibrosis (slender arrow) in the submucosa

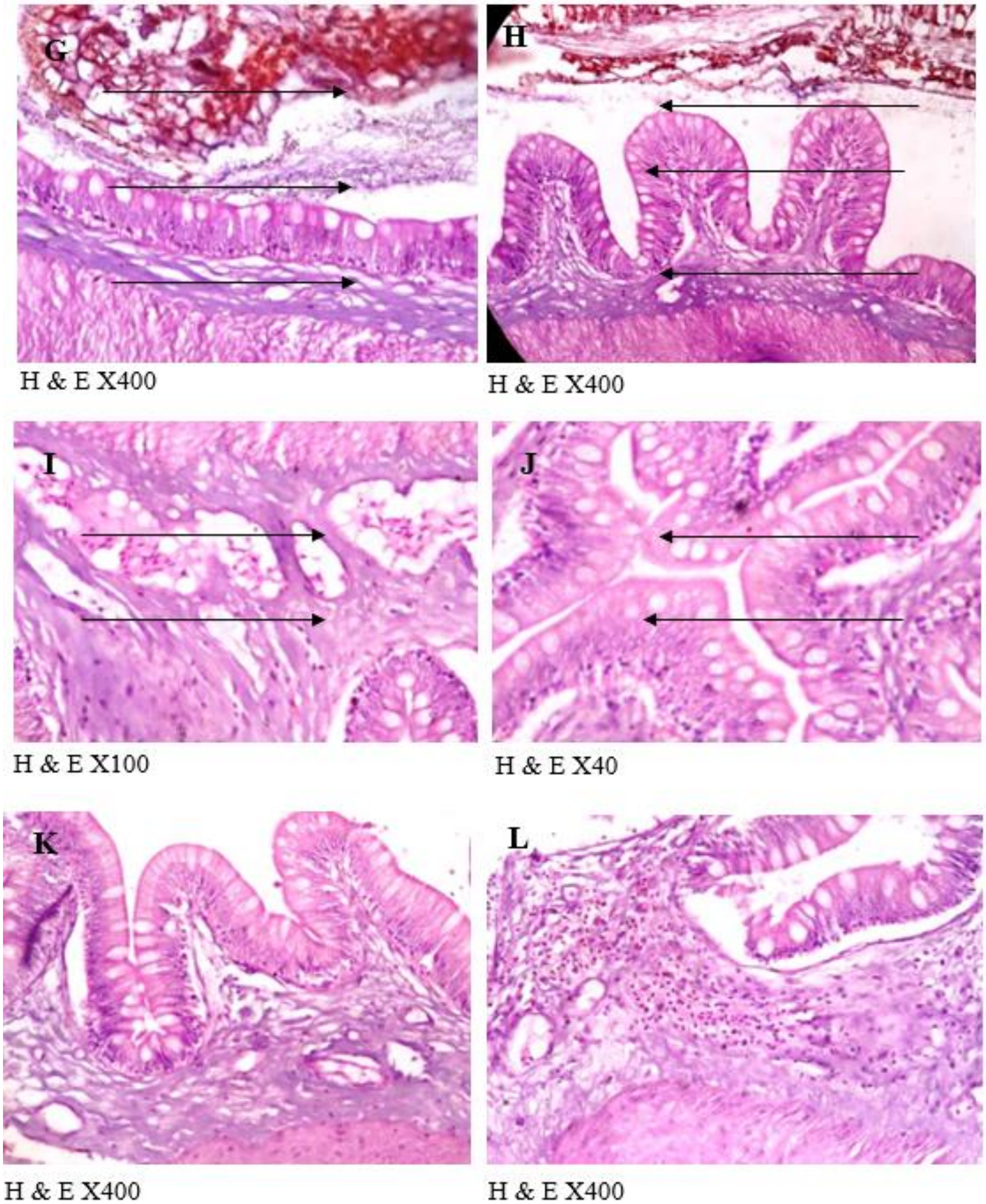

Plate 2: G & H: Presence of parasite (black arrow) and focal area of stunting of villous structure (slender arrow); **I & J:** Normal villi structure, normal mucosa and submucosa. The normal crypt-villous architecture is well preserved. However, there is a focal area of fibrosis of the submucosa (slender arrow); **K & L:** Moderate stunting of the villous structure (black arrow) and mild fibrosis of the submucosa (slender arrow).

DISCUSSION

The depuration role of the cestode, *Electrotaenia malopteruri* in this study has been confirmed. The parasite had earlier been reported by Akinsanya *et al.,* (2007) and has also been confirmed by Akinsanya *et al.,* 2015 to bioaccumulate heavy metals in some fishes of Lekki lagoon, Lagos, Nigeria. The cestode has only been reported to infect *Malapterurus electricus* and has not been reported in any other fish species. It is worthy to note that the parasitic infections in the fish host at this time are beneficial since the parasites sequestrate some of the congeneers of the contaminant within the host.

Parasitism, therefore, is beneficial from an ecotoxicological point of view and harmful from a parasitic point of view. A non-infected fish host bears all the burdens of bioaccumulation while an infected fish host shares the burdens through the depuration ability of the resident parasites. The major sources of hydrocarbon-based pollution in the aquatic environment include runoffs from land-based anthropogenic activities and industrial discharge. These could be as a result of incomplete combustion of fossil fuels and decomposition of organic substances (pyrogenic), also as components of crude oil and its refined products (petrogenic) (Alani *et al.,* 2012). In this study, four congeners with 2 to 3 rings and thirteen congeners with 4 to 6 rings of PAH residues were found in the surface water, sediment, the fish and its parasites. The fishes are directly and indirectly exposed to the presence of PAH residues in the surface water and sediment in the aquatic environment. These exposures could be from the surface water by direct absorption through the skin and gills and through the food chain. The persistent nature of these PAH residues in the environment and biota are significantly responsible for the bioaccumulation and biomagnifications along the food chain (Akinsanya *et al.,* 2018).

Every fish host needs food as its major source of nutrients. Nutrients are chemical substances needed for growth, repair of damaged tissues and aid energy supply for metabolic processes (Metcalfe, 1986). The metabolic site for digestion and absorption of these nutrients in the fish host in the gut. Helminth parasites infect almost all the regions of the alimentary tract of fish (Lafferty, 2008). Any damage to the alimentary canal will alter the physiological activities of fish. For cestode and nematode parasites the most favourable and selected site is the alimentary canal which is mainly to meet their primary need for food from the host. The energetic cost of parasitic infection is evident by the variety of nutrients parasites directly consume from their host (Lafferty, 2008).

The intestinal parasites are also exposed to the PAH residues in the fish host food chain. In this study, The parasite, *Electrotaenia malopteruri* bioaccumulated benz(a)anthracene, chrysene, benzo(a)pyrene, and benzo(g,h,i)perylene 18, 23, 3 and 2 times more than the host intestine respectively. This gut cestode parasite has been reported as voracious (Barber and Syenson, 2003). It actively absorbs amino acids, glucose (Williamson 2003), fatty acids (Smith 1994) and whole proteins (Whitfield 1993) from the host's alimentary canal. Also, the cestode parasite with high lipid content as shown in this study is able to bio-accumulate PAH residues from the host gut. Like the PAH residual bio-concentrations, the cholesterone, triglycerides and low-density lipid levels in *Electrotaenia malopteruri* were higher than that in the intestines of the infected and non-infected individuals. The outcome of this was a higher lipid level in the intestines of non-infected individuals as compared to the infected.

Most infected fish hosts show behavioral changes which are induced by energetically demanding parasites, altering the host tissue bio-concentration and toxicity. *Electrotaenia malopteruri* induces antioxidants when faced with stress in the host gut as well as the host. Antioxidants secreted by the intestinal parasite are both offensive and defensive, unlike that of the host. Parasitic secretions in the gut often irritate the host gut mucosal cells and slow down the absorption process, this gets the parasite the foraging advantage (Dzik, 2006). The host secretions often affect the parasite establishment at the same time the parasite has a defense mechanism for reducing this effect (Dzik, 2006). One of these defense mechanisms is the use of the antioxidant system.

One significant role *Electrotaenia malopteruri* plays in the host contaminant bioaccumulation is the ability to help the host accumulate some of its tissue contaminants. This is shown in this study; the parasite accumulated more of the light polycyclic aromatic hydrocarbons than the host tissues. This might not be the same as for the heavy polycyclic aromatic hydrocarbons. This could also be noticed in the host antioxidant system; the presence of the parasite has led to more enzyme secretions among the infected individuals. In this study, the intestine of the infected individuals had more SOD, CAT, GSH and GPx than the intestine of non-infected individuals. This incisively indicates that the use of certain biomarkers in-field assessment could give either false-negative or false-positive results, which does not truly represent the actual response within a studied population.

Alteration in net energy due to multi-stress can lead to a change in physiological trends within the population (Bayne *et al.,* 1983). This study shows that parasitic infections have been shown to decrease energy stores in fish as reported by Bakker and Mundwiler (1999), but is only evident among multi-stressed individuals in the population. This is dependent on the relative abundance, prevalence and intensity of the parasitic infestation (Marcogliese 2005; Lafferty 2008; Saliu *et al.,* 2014), extrinsic stressors (Sures *et al.,* 1997) and the impact on host gross energy content (Metcalfe 1986; Adams 1999; Dicks 2009). In this study, the cholesterone, triglycerides and low-density lipid levels in *Electrotaenia malopteruri* were higher than that in the intestines of the infected and non-infected individuals. The protein, high-density lipid and glucose levels were higher in the host intestines, but the non-infected individuals had more concentrations of intestinal protein and glucose. The intestine of the infected individuals had more SOD, CAT, GSH and GPx than the intestine of non-infected individuals. These infected individuals had a higher frequency of gut pathological alterations compared to the non-infected individuals.

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