RELEVANCE OF INTESTINAL HELMINTH PARASITES OF *Parachanna Obscura and Sarotherodon Melanotheron* ON HOST METAL ACCUMULATION IN LEKKI LAGOON, LAGOS, NIGERIA

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ABSTRACT

This paper assesses the role of intestinal helminth parasites of Parachanna obscura and Sarotherodon melanotheron on host metal accumulation in Lekki Lagoon, Lagos, Nigeria. Heavy metal concentrations were determined in water, sediment, intestinal parasites, liver and gill of infected and non-infected individuals of the fishes. Water, sediment, intestinal parasites, the liver and gill were analyzed using Atomic Absorption Spectrophotometer to determine concentrations of iron, cadmium, lead, nickel, zinc and copper. The parasites of Parachanna obscura, Procamallanus sp and Spirocamallanus sp accumulated less metals compared to their host tissues. Procamallanus sp and Spirocamallanus sp did not accumulate zinc and lead respectively while Procamallanus sp only accumulated more lead than the host organs. The parasite of Sarotherodon melanotheron, Clinostomum sp, a trematode larva, accumulated more concentration of cadmium and zinc, (mg/l), 0.23 ± 0.26, 8.31 ± 1.83 respectively compared to the host liver; cadmium (mg/l), 0.01 ± 0.01, zinc (mg/l), 4.92 ± 1.43. Infected individuals of Parachanna obscura accumulated more metal concentrations in their tissues compared to non-infected ones. This is because their parasites, Procamallanus sp and Spirocamallanus sp have very low bioaccumulation potential for metals such as iron, nickel, cadmium, zinc and copper except lead. These parasites had similar concentrations of these metals in their tissues as that contained in the water and sediment media. Infected individuals of Sarotherodon melanotheron accumulated more of iron, nickel, zinc and copper, while the non-infected one accumulated more of cadmium and lead. Its parasite, Clinostomum sp, accumulated 23 times more cadmium and twice more zinc. This parasite must have accumulated these metals from its host, reducing the concentration of these metals in the tissues of the infected fishes compared to non-infected present. Integration of multiple stressors increases accumulation of heavy metals in fish tissues, an indicator of susceptibility as shown in this study.

Keywords: Heavy Metals, Fish, Intestinal Parasites, Lekki Lagoon, Atomic Absorption Spectrophotometer.

INTRODUCTION

Over the past few decades, heavy metal contamination of aquatic system has attracted the attention of several investigators both in the developed and developing countries of the world. Many industrial and agricultural processes have contributed to the contamination of aquatic ecosystems causing adverse effects on aquatic biota and human health (Wang, 2002). The fact that heavy metals cannot be destroyed through biological degradation and their ability to accumulate in the environment make these toxicants deleterious to the aquatic environment and consequently to humans who depend on aquatic products as sources of food. Heavy metals can accumulate in the tissues of aquatic animals and as such tissue concentrations of heavy metals can be of public health concern to both animals and humans (Kalay *et al.*, 1999; Ashraf, 2005). In the Lekki Lagoon, metals are reported to be well concentrated in the water, sediments and biota (Don-Pedro *et al.*, 2004). Bioaccumulation of these metals in many fish species and their organs have been variously reported (Kumada *et al.*, 1980; Westernhagen *et al.*, 1980; and Osborne *et al.*, 1981).Studies have indicated that certain organs in fishes accumulate more metals than other organs (Seymore *et al.*,1995, Robinson and Avenant Oldewage, 1997; Nussey *et al.*, 1999). Crafford 2000), Parasites are ubiquitous in nature (Marcogliese, 2005) and it has been suggested they are useful indicator species of contaminant-impacted ecosystems (Mackenzie *et al.*, 1995) and impaired food webs (Marcogliese *et al.*, 2006). Numerous studies have shown the sensitivity of parasites to contaminants such as metals (Pietrock and Marcogliese, 2003). Certain parasites may be vulnerable partly due to their ability to accumulate metals (Sures *et al.*, 1997). Cestodes, for example, have been shown to accumulate metals to levels that can exceed host tissue concentrations by several orders of magnitude (Sures *et al.*, 1997). Parasites that are in direct contact with the environment such as monogeneans and the free-living stages of some intestinal parasites may be especially vulnerable to heavy metals (Pietrock and Marcogliese, 2003).

A few species of cestodes and nematodes that infect electric fish require a fish intermediate host, to complete their life cycle. Therefore, the absence of intestinal parasites in the high exposure fish may be an indirect effect owing to the lack of an intermediate host species. The vast majority of monogenean species, on the other hand, complete their life cycle with only one host. Their absence at the high exposure water body could more easily signify a direct toxic action of metals especially since these parasites live on the external surface of their host. To maintain their population, all parasites need to eventually reproduce and infect new hosts. Studies have also indicated that intestinal parasites attach themselves to the host leading to mechanical damage, inflammation and necrosis and the blocking of the intestine (Scott and Grizzle, 1979, Boomker *et al.*, 1980, Hoffman, 1980). These bioindicators measure exposure to pollutants at different levels of organization, from the subcellular to the ecosystem level, and are useful for effect indication. Certain parasites such as acanthocephalans and cestodes of fish are known to accumulate heavy metals at concentrations that are orders of magnitude higher than those in the host tissue or the environment (Jirsa *et al.*, 2008, Sures *et al.*,1999), while parasites such as trematodes and nematodes have been reported as poor accumulators (Margcogliese, 2005). Presence of intestinal macro-parasites could either increase or decrease metal accumulation in the host, they could either dilute or concentrate the mean value in sample population. This is dependent on relative abundance of the parasitic congeners, their bioaccumulation potential in the host and prevalence in the host population (Sures *et al.*, 1999). This study aims to investigate the significance of macro-intestinal parasites of fish in the host metal accumulation in Lekki lagoon, Lagos, Nigeria.

MATERIALS AND METHODS

Study Area: Lekki lagoon supports a major fishery in Nigeria. The Lekki lagoon located in Lagos State Nigeria lies between longitudes $4^0 00'$ and $4^0 15'$ E and between latitudes $6^0 25'$ and $6^0 37'$ N, has a surface area of about 247 km^2 with a maximum depth of 6.4m.

A large portion of the lagoon is shallow and less than 3.0m deep. The Lekki lagoon is part of an intricate system of waterways made up of lagoons and creeks that are found along the coast of South-Western Nigeria from the Dahomey border to the Niger Delta stretching over a distance of about 200 km. It is fed by the River Oni discharging to the North-Eastern and the Rivers Oshun and Saga discharging into the North-Western parts of the lagoon.

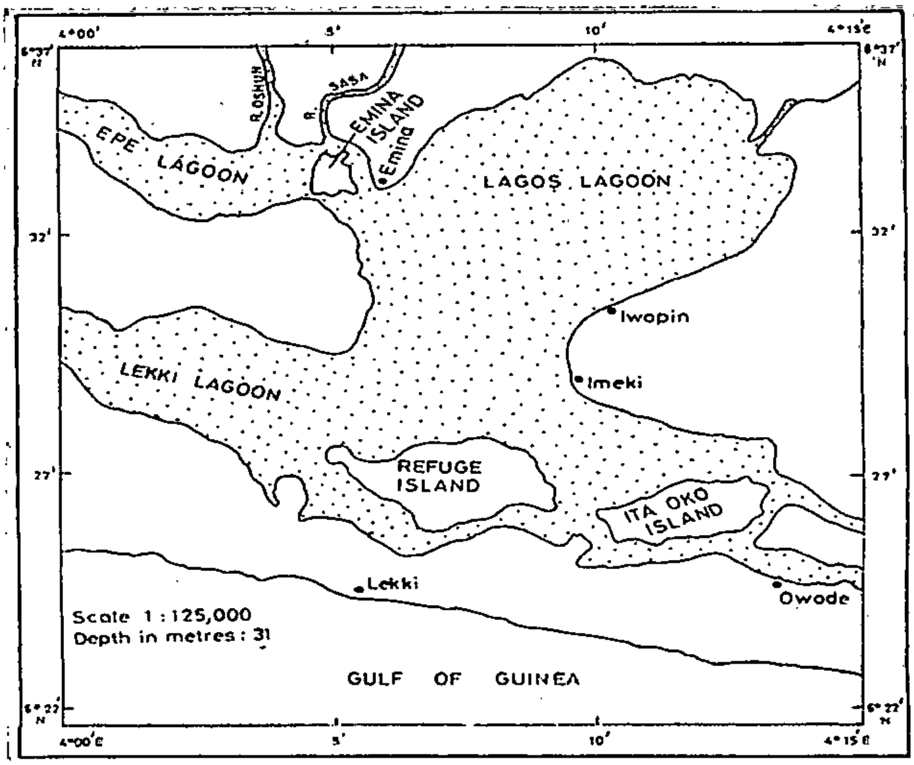

Fig. 1: The map of Lekki lagoon, Lagos, Nigeria.

Field Sampling

Geographical locations of sampling sites were determined with the use of GPS. The water sediment and water samples of the lagoon were also collected from each site locations using Grab and water sampler for heavy metal analysis and physiochemical parameters of the water body i.e Total Dissolved Solids (TDS), Turbidity, pH, Dissolved Oxygen (DO), Salinity, Temperature and Conductivity were taken on site using Horiba U10 multi-parameter analyzer model.

Collection and Examination of Specimens for Parasities

Ninety randomly selected fresh specimens each of *Parachanna obscura* and *Sarotherodon melanotheron* recovered from Lekki lagoon were purchased from fishermen at Oluwo Market at Lekki, Lagos, Nigeria. They were thereafter examined for

parasites. The weights, standard lengths and total lengths of the fishes were recorded. The fishes were dissected and the alimentary canals were removed and cut into parts in physiological saline for parasite recovery. The intestines were further carefully slit open to aid the emergence of parasites. The recognition of the worms was enhanced by the wriggling movements on emergence. Condition factors (K) of the fishes were estimated.
Parasite Prevalence = No of infected individuals in the population/ Total No
*Fulton's Condition Factor (K) = K = (W/L3)*105* ((Le Cren, 1951)

Processing of Parasites Recovered
The recovered helminth parasites were fixed in 70% alcohol, counted and recorded. The parasites were identified with the aid of light microscope and standard keys and classified accordingly.

Heavy Metal Analysis
Individuals were also grouped based on infection status. The livers and gills of eight infected and non-infected individuals, making a total of 16 individuals for each species including the identified parasites, were selected for heavy metal analysis.

Digestion of Samples
Water sample collected from the experimental station was filtered and digested using standard digestion procedure (APHA/AWWA/WPCF, 1995). Sediment sample was dried, sieved through a 200 micrometer sieve to normalize for size, and digested using the method provided by Agemian and Chau (1976). The livers, gills and the parasites were homogenized and digested using the method described by FAO/SIDA (1986).

The heavy metal concentration in each digested sample was determined by extrapolation with those of standards (Solutions of known metal concentration) using AAS, Atomic Absorption Spectrophotometer, AES, 2000 series. An acetylene air mixture was used as the flame. The working standard for each of the metals was aspirated as flame in the order of 0.0 ppm, 0.8 ppm and 1.6 ppm. The values were used to plot a standard curve. The tissues were then aspirated into the flame and the values were obtained by extrapolation from the standard curve. In addition, factory prepared AAS Standard solutions were run as sample for accuracy check after every five measurements.

Statistical Analysis
Analysis of variance (ANOVA) was used to compare means of metal concentrations in media (fish parasite, fish tissue, water and sediment) of the lagoon ecosystem.

RESULTS
Physiochemical Parameters of Lekki Lagoon, Lagos, Nigeria
Table 1 shows mean values of the physiochemical parameters of various stations in the Lagoon; pH; (Mean±SD), 7.46±0.32, Conductivity (ms/cm); (Mean±SD), 12.36±0.48, Dissolved Oxygen (mg/l); (Mean±SD), 0.74±0.05, Turbidity; (Mean±SD),50.40±17.52,

Temperature (0C); (Mean±SD), 30.60±0.55 and Salinity (ppt); (Mean±SD), 0.02±0.02. These mean values except that of salinity were significant at 0.05 level, $p < 0.05$.

Table 1: Mean Values of Physiochemical Parameters of Lekki Lagoon, Lagos, Nigeria

Parameters	Minimum	Maximum	Mean±SD
pH	7.10	7.90	*7.46±0.32
Conductivity (ms/cm)	11.50	12.70	*12.36±0.48
Dissolved Oxygen (mg/l)	0.70	0.80	*0.74±0.05
Turbidity	28.00	76.00	*50.40±17.52
Temperature (^{0}C)	30.00	31.00	*30.60±0.55
Salinity (ppt)	0.00	0.10	0.02±0.02

Asterisk (*) Means mean value significant at 0.05 level

Mean Concentration of Heavy Metals in Organs of Infected and Non-infected Individuals of *Parachanna obscura* and *Sarotherodon melanotheron*

Table 2 shows the mean concentration of heavy metals in organs of infected and non-infected individuals of *Parachanna obscura* and *Sarotherodon melanotheron.* The liver of infected individuals of *Parachanna obscura* accumulated more metals; Iron (mg/l); (Mean±SD), 149.43±107.09, $p < 0.05$, Cadmium (mg/l); 0.47±0.31, Lead (mg/l); 0.69±0.37, Nickel (mg/l); 8.05±17.47, Zinc (mg/l); 3.72±1.08, $p < 0.05$ and Copper (mg/l); 3.98±3.34, $p < 0.05$, than their gills and the organs of non-infected individuals. Among the non-infected individuals, the gills accumulated more iron (mg/l); (Mean±SD), 129.97± 183.44, Lead (mg/l); 0.58±0.49, $p < 0.05$, Nickel (mg/l); 0.83±0.76, $p < 0.05$, Zinc (mg/l); 2.92±3.18, $p < 0.05$ and Copper (mg/l); 3.51±6.82, while the liver accumulated more Cadmium (mg/l); 0.23±0.42.

The liver of infected individuals of *Sarotherodon melanotheron* accumulated more metals; Iron (mg/l); (Mean±SD), 14.92±5.26, $p < 0.05$, Cadmium (mg/l); 0.01±0.01, Lead (mg/l); 0.22±0.13, Nickel (mg/l); 1.12±0.13, $p < 0.05$, Zinc (mg/l); 4.92±1.43, $p < 0.05$, and Copper (mg/l); 2.70±0.97, $p < 0.05$ than their gills. They also accumulated more of these metals than the liver and gill of non-infected individuals except for cadmium and lead. The liver of non-infected individuals accumulated more Iron (mg/l); 10.90±4.83, $p < 0.05$, Cadmium (mg/l); 0.25±0.54, Lead (mg/l); 0.27±0.35, $p < 0.05$, Nickel (mg/l); 0.89±0.27, $p < 0.05$, Zinc (mg/l); 2.76±1.31, $p < 0.05$ and Copper (mg/l); 2.10±0.99, $p < 0.05$ than their gills. They accumulated more Cadmium and Lead than the organs of infected individuals.

Table 2: Mean Concentration of Heavy Metals in Organs of Infected and Non-infected Individuals of *Parachanna obscura* and *Sarotherodon melanotheron* in Lekki lagoon, Lagos Nigeria

Status	Tissue	Iron (Fe) (mg/l)	Cadmium (Cd)(mg/l)	Lead (Pb) (mg/l)	Nickel(Ni) (mg/l)	Zinc(Zn) (mg/l)	Copper(Cu) (mg/l)
Parachanna obscura							
Infected Individuals	Liver	*149.43±107.09	0.47±0.31	0.69±0.37	8.05±17.47	*3.72±1.08	*3.98±3.34
	Gill	82.44±72.75	*0.28±0.51	0.46±0.51	1.45±2.07	*3.09±2.18	*3.37±3.64
Non-infected Individuals	Liver	88.44±72.75	0.23±0.42	*0.41±0.49	*0.26±0.32	*0.31±0.68	*1.17±0.46
	Gill	129.97±183.44	0.16±0.27	*0.58±0.49	*0.83±0.76	*2.92±3.18	3.51±6.82
Sarotherodon melanotheron							
Infected Individuals	Liver	*14.92±5.26	0.01±0.01	0.22±0.13	*1.12±0.13	*4.92±1.43	*2.70±0.97
	Gill	*7.94±5.08	0.00±0.00	0.11±0.16	*0.73±0.61	*2.25±2.72	*1.17±1.06
Non-infected Individuals	Liver	*10.90±4.83	0.25±0.54	0.27±0.35	*0.89±0.27	*2.76±1.31	*2.10±0.99
	Gill	5.57±3.95	*0.03±0.07	0.12±0.13	*0.64±0.25	*2.26±0.91	0.97±0.87

Asterisk (*) Means mean value significant at 0.05 level

Mean Concentration of Heavy Metals in Organs of Infected Individuals of *Parachanna obscura* and *Sarotherodon melanotheron* and their Intestinal Helminth Parasites

Table 3 shows the mean concentration of heavy metals in organs of infected individuals of *Parachanna obscura* and *Sarotherodon melanotheron* and their intestinal helminth parasites. The parasites of *Parachanna obscura, Procamallanus sp* and *Spirocamallanus sp* accumulated less metals compared to their host tissues; Iron (mg/l), 3.40±0.62, 2.90±0.79, $p < 0.05$, for the parasites, 149.43±107.09, $p < 0.05$, for the host liver, Cadmium (mg/l), 0.01±0.02, 0.02±0.02, for the parasites, 0.47±0.31 for the host liver, Nickel (mg/l), 0.29±0.20, 0.31±017 for the parasites, 8.05±17.47, for the host liver, Zinc (mg/l), 0.00±0.00, 0.62±0.45 for the parasites, 3.72±1.08 for the host liver and Copper (mg/l), 1.92±1.02, 2.20±0.30 for the parasites, 3.72±1.08 for the host liver. *Procamallanus sp* and *Spirocamallanus sp* did not accumulate lead and zinc respectively while *Procamallanus sp* only accumulated more lead than the host organs.

The parasite of *Sarotherodon melanotheron, Clinostomum sp,* a trematode larva, accumulated more concentration of cadmium and zinc, (mg/l), 0.23±0.26, 8.31±1.83 respectively compared to the host liver; cadmium (mg/l), 0.01±0.01, zinc (mg/l), 4.92±1.43. *Clinostomum sp* accumulated over 23 times more cadmium and twice more zinc as the host organs.

Table 3: Mean Concentration of Heavy Metals in Organs of Infected Individuals of *Parachanna obscura* and *Sarotherodon melanotheron* and their Intestinal Helminth Parasites in Lekki Lagoon, Lagos Nigeria

Status	Tissue	Iron (Fe) (mg/l)	Cadmium (Cd)(mg/l)	Lead (Pb) (mg/l)	Nickel(Ni) (mg/l)	Zinc(Zn) (mg/l)	Copper(Cu) (mg/l)
Parachanna obscura							
Infected Individuals	Liver	*149.43±107.09	0.47±0.31	0.69±0.37	8.05±17.47	*3.72±1.08	*3.98±3.34
	Gill	82.44±72.75	*0.28±0.51	0.46±0.51	1.45±2.07	*3.09±2.18	*3.37±3.64
Procamallanus sp		*3.40±0.62	0.01±0.02	1.13±0.98	0.29±0.20	0.00±0.00	1.92±1.02
Spirocamallanus sp		*2.90±0.79	0.02±0.02	0.00±0.00	0.31±017	0.62±0.45	2.20±0.30
Sarotherodon melanotheron							
Infected Individuals	Liver	14.92 ±5.26	0.01±0.01	0.22±0.13	1.12±0.13	4.92±1.43	2.70±0.97
	Gill	7.94±5.08	0.00±0.00	0.11±0.16	0.73±0.61	2.25±2.72	1.17±1.06
Clinostomum sp		*1.40±0.28	0.23±0.26	0.04±0.00	*0.42±0.04	8.31±1.83	1.28±0.35

Asterisk (*) Means mean value significant at 0.05 level

Comparison of Mean Metal Concentrations in Water Medium, Sediment and the Intestinal Helminth Parasites.

Table 4 shows comparison of the mean metal concentrations in water medium, sediment and the intestinal helminth parasites. Iron concentration in water and sediment media were 0.45±1.16 (mg/l), $p < 0.05$ and 4.62±0.23 (mg/l), $p < 0.05$. The sediment had more iron than that accumulated in the parasites. Among the parasites, *Procamallanus sp* had most iron concentration, 3.40±0.62 (mg/l), $p < 0.05$. The water medium, sediment and the parasites of *Parachanna obscura*; *Procamallanus sp,* and *Spirocamallanus sp* had similar cadmium concentrations (0.01±0.00, 0.04±0.02, 0.01±0.02 and 0.02±0.02 (mg/l) respectively) compared to the parasite of *Sarotherodon melanotheron, Clinostomum sp,* 0.23±0.26 (mg/l). There were also similar lead concentrations in the water medium, sediment, *Spirocamallanus sp* and *Clinostomum sp* (0.03±0.02, 0.01±0.00, 0.00±0.00 and 0.04±0.00 mg/l) except in *Procamallanus sp* (1.13±0.98 mg/l). The parasites accumulated nickel more than those found in water and sediment media, *Clinostomum sp,* had the highest nickel concentration, 0.42±0.04 mg/l, $p < 0.05$. *Clinostomum sp,* also had the highest zinc accumulation, 8.31±1.83 mg/l. The parasites had more copper concentration than that found in the water and sediment media.

Table 4: Comparison of Mean Metal Concentrations In Water Medium , Sediment and The Intestinal Helminth Parasites.

Media/Parasite	Iron (Fe) (mg/l)	Cadmium (Cd)(mg/l)	Lead (Pb) (mg/l)	Nickel(Ni) (mg/l)	Zinc(Zn) (mg/l)	Copper(Cu) (mg/l)
Water	*0.45±1.16	0.01±0.00	*0.03±0.02	*0.15±0.05	*0.13±0.06	0.23±0.30
Sediment	*4.62±0.23	*0.04±0.02	*0.01±0.00	*0.03±0.00	*0.17±0.00	*0.04±0.00
Procamallanus sp	*3.40±0.62	0.01±0.02	1.13±0.98	0.29±0.20	0.00±0.00	1.92±1.02
Spirocamallanus sp	*2.90±0.79	0.02±0.02	0.00±0.00	0.31±017	0.62±0.45	2.20±0.30
Clinostomum sp	*1.40±0.28	0.23±0.26	0.04±0.00	*0.42±0.04	8.31±1.83	1.28±0.35

Asterisk (*) Means mean value significant at 0.05 level

DISCUSSION

Heavy metals such as lead, iron and zinc are contained in industrial waste, metal plating and generated through microbial actions (Nwankwo, 2004). The properties of metals ionized in water depend largely upon the nature and behavior of the metal species (Bhatia, 2010). Speciation and complexation of these metal species depend on the physiochemical properties of the aquatic environment which are influenced by seasonal variation and other factors (Salomons and Forstner,1984). These processes determine their bioavailability, transport, accumulation and biological effect (Bhatia, 2010). Complexation may cause changes in oxidation states of the metals and result in metals becoming ionized, its interaction with organic species is a function of hydrogen ion concentration (Bhatia, 2010). The formation of insoluble complex compound removes metal ions from the water medium.

In the lagoon, the metal concentration in the sediment were more than that in the water medium. The various metal concentrations in the water medium and sediment were very low, but greater concentrations were found in the fish and parasites. Some metals are available for uptake into organisms from solution only as free ions, whereas others are transported over biological membranes as inorganic complexes (Bienvenue *et al.,* 1984). Variation in the behavior of metallic species, properties and complexation is responsible for the variation in the bioaccumulation gradient in the fish and the parasites. Experimental studies have shown that there are variations in the trend of accumulation of metals in tissues and is dependent on species, sex, age, diseases, nutritional and genetic factors (Farombi *et al.,* 2007).

Studies from the field and laboratory experiment also showed that accumulation of heavy metals in the tissues is mainly dependent upon water concentration of metals and exposure period, although some other environmental factors such as salinity, pH. Hardness and temperature play significant roles in metal accumulation (Authmann, 2008). Ecological needs, sex, age, size, feeding habitat as well as biological conditions of the fish affect the heavy metal accumulation in their tissues (Canli *et al.,* 2003, Shakweer *et al.*, 2005). The presence of a given metal at high concentration in water and sediments does not involve direct toxicological risk to the fish, especially in the absence of significant bioaccumulation.

It is important to examine what happens when stressors to a population of fish overlap with parasitism. There are several possible qualitative outcome when parasite interact with other stressors (heavy metal pollution, or/and water temperature). The most obvious concept is that some stressors may make hosts more susceptible to parasitism. This appears to be due to an increase in susceptibility because toxic conditions compromise a fish's immune system (Paperna, 1996; Cecchini, 1998). However, one obvious prediction is that pollutants, as heavy metals may reduce immunological capabilities of host, rendering them more susceptible to parasites. Infected individuals of *Parachanna obscura* and *Sarotherodon melanotheron* accumulated more metals in the organs compared to non-infected individuals except in the case of metals like cadmium and lead in *Sarotherodon melanotheron.*

Bioaccumulation is a measure of exposure response to stress in fishes (Paperna, 1996). Infected individuals of *Parachanna obscura* accumulated more of metals in their tissues compared to non-infected ones. This is because their parasites, *Procamallanus* sp and *Spirocamallanus* sp have very low bioaccumulation potential for metals such as iron, nickel, cadmium, zinc and copper except lead. These parasites had similar concentration of these metals in their tissues as that contained in the water and sediment media. Certain parasites could help the fish accumulate metals in its tissues but this is not true for all metals. Infected individuals of *Sarotherodon melanotheron* accumulated more of iron, nickel, zinc and copper, while the non-infected ones accumulated more of cadmium and lead. Their parasite, *Clinostomum sp,* accumulated 23 times more cadmium and twice more zinc. This parasite must have accumulated these metals from its host, reducing the concentration of these metals in the tissues of the infected fishes compared to non-infected ones. Similar study in Lagos lagoon by Saliu *et al.* (2014), had also shown among the infected *Tilapia guineensis*, high condition individuals (> 2.62) accumulated more metals in their livers than the low condition infected individuals (< 2.62), but irregular trend was found among the non-infected individuals. Saliu *et al.* (2014) also reported parasite prevalence among the infected individuals of low condition factor as; *Heterostomum euclinostomium* a trematode; 0.25, nematodes; 0.75, *Acanthogyrus tilapae* an acanthocephalan; 0.05 and cestodes were absent and the high condition individuals had parasite load; *Heterostomum euclinostomium*; 0.45, nematodes, 0.05, cestodes; 0.05, *Acanthogyrus tilapae*; 0.25. Relative abundance and diversity in intestinal parasites with varying metal bioaccumulation potentials in high and low condition individuals could have been responsible for the difference in metal accumulation in their host tissue.

CONCLUSION

The presence of intestinal macro-parasites could either increase or decrease metal accumulation in the host, they could either dilute or concentrate the mean value in sample population. This is dependent on relative abundance of the parasitic congeners, their bioaccumulation potential in the host and prevalence in the host population (Sures *et al.*,1999). This is due to the fact that within the host populations, individuals differ in their ability to compete for limited resources (Begon *et al.*, 1990) and the resulting unequal division of nutrients leads to variation in growth rates, body sizes and nutritional condition (Westerberg *et al.*, 2004). These variations determine differences in bioenergetics utilized for detoxification, growth and reproduction. Integration of multiple stressors increases accumulation of some heavy metals in fish tissues as shown in this study.

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