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ASSESSMENT OF PUBLIC HEALTH RISK ASSOCIATED WITH CONSUMPTION OF DOMINANT EDIBLE ANIMAL SPECIES OF THE LAGOS LAGOON, NIGERIA

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ABSTRACT

Heavy metals bio-accumulated in edible aquatic animal species pre-dispose final consumers to adverse health effects of these toxins. Edible animal species were collected from the Lagos lagoon, Nigeria where elevated concentrations of heavy metals have been documented over the years. The concentrations of heavy metals in the animal species were determined and the potential health risk to three age groups of the population, associated with consumption of these species was assessed by calculating Daily Intake of Metals (DIM) and Health Risk Index (HRI). The levels of heavy metals recorded in the tissues of the animal species were below Food and Agricultural Organization (FAO) recommended limits in food, except for Zn (47.60 ppm) in *Tympanotonus fuscatus*. FAO recommended limits for Zn in food is 30.00 ppm. The DIM and HRI for all heavy metals analyzed were < 1 (unity) in the three animal species and for all age groups indicating that utilization of the species as a protein source does not currently pose serious health risk to consumers. The relative safety associated with utilization of edible animal species from the Lagos lagoon as a protein source reported in this study can only be maintained if heavy metal concentrations in the lagoon are kept within acceptable limits by setting effective effluent limitation standards and enforcing the set standards.

Key words: Bio concentration, Heavy Metals, Pollution, Risk indices, Public Health

INTRODUCTION

Heavy metals are natural components of the earth crust but their concentrations in the environment via air, land and water have increased steadily over the years due to anthropogenic activities. Heavy metal pollution especially in aquatic ecosystems remains a recurrent global problem due to heavy metal persistence in the environment, toxicity and bioaccumulation potential in biological systems. Untreated or under treated effluent discharge from industry is a major contributor to heavy metal pollution in aquatic ecosystems.

Aquatic organisms take up heavy metals through the integument, digestive or respiratory pathways (Alexander, 1999). Accumulation in biological systems occurs when rate of uptake by the organism exceeds rate of excretion. Heavy metals are scavenged by low-molecular weight cysteine rich proteins and vesicle-bound granules in organisms where they become unavailable for metabolism and possible excretion, and hence could account for accumulation and bio-magnification along the food chain (Deb and Fukushima, 1999). Edible aquatic organisms including crabs, periwinkles and especially fishes are principal sources of protein for local coastal populations thus pre-disposing them to health risks associated with heavy metal load in these organisms.

The Lagos lagoon in Lagos State Nigeria lies within latitude 6° 17'N and 6° 28' N, and longitude 3° 22'E and 3° 40'E. It is a major depository of solid and liquid wastes generated within the state which harbors 75% of industries in Nigeria. Several studies have reported increased concentrations of heavy metals in surface water and sediments of the lagoon (Okoye *et al.,* 1991; Oyewo, 1998; Otitoloju, 2000) and also accumulation of heavy metals by edible species inhabiting the lagoon (Otitoloju and Don Pedro 2006; Ajagbe *et al.,* 2011.). However, no study has documented the public health risks associated with consumption of these edible species obtained from the Lagos lagoon. Thus, this study determined the concentration of heavy metals commonly associated with environmental pollution in three dominant edible animal species of the Lagos lagoon and also assessed public health risks associated with the consumption of these species by three different age groups of the population.

MATERIALS AND METHODS

Study Area

The animal samples used in this study were collected from the Lagos lagoon, western Nigeria. The Lagos lagoon is the largest of the four lagoon systems of the Gulf of Guinea (Webb, 1958). It has a surface area of about 6,354 km^2 and a maximum length and width of 50 km and 13 km respectively. The lagoon ecosystem stretches about 257 km from Cotonou in the Republic of Benin to the western edge of the Niger Delta, it borders a forest belt and receives a number of important large rivers namely Yewa, Ogun, Ona and Osun, draining more than 103,626 km of the country (Don-Pedro *et al.,* 2004). The Lagos lagoon is surrounded by urban development hence, it is a major recipient of industrial effluents, sewage discharges and urban/storm water runoffs from the surrounding metropolitan populations.

Sampling Operations

Sampling was carried out at the peak of dry and rainy seasons from year 2012 to 2014.

Sampling Sites

Five sampling zones, with three stations each (to serve as replicates) were chosen based on their nearness to pollution sources, urban settlements and suitability for comparative and future survey. Zones one to three are closer to major entry points for various pollutants while zones four and five are farther away from pollution sources and closer to mainly residential areas (Figure 1). The Global Positioning System (GPS) of each sampling station was taken during the first sampling exercise to establish the geographical position of each sampling station and to ensure that same points are sampled during subsequent sampling exercise.

Collection of edible animal species

Edible animal species collected were selected based on availability irrespective of season. Live fish (*Sarotherodon melanotheron*) and crab (*Callinectes amnicola*) samples were bought from local fishermen that were contracted to fish at designated sampling stations at the time of sample collection. Benthic species were sieved out of sediments collected at designated sampling stations using 2 mm soil sieve. The organisms were transported live, using ice packs to the Ecotoxicology Laboratory, Department of Zoology, University of Lagos where further analyses were immediately carried out on them.

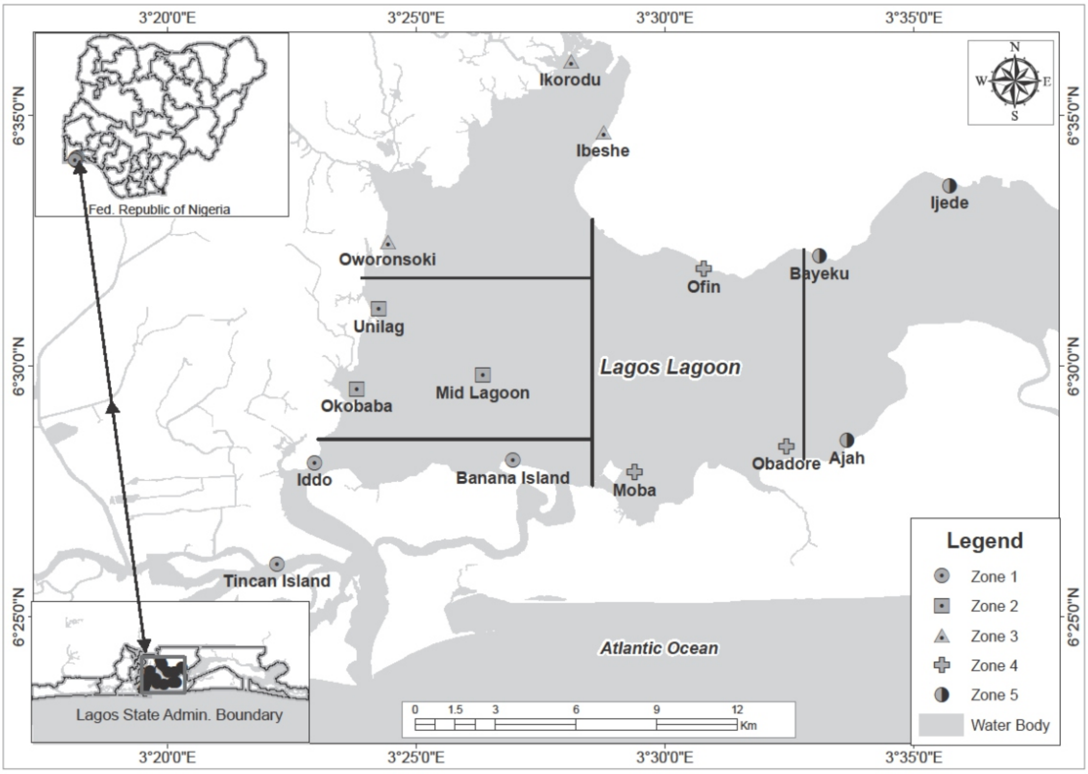

Figure 1: Sampling stations on the Lagos Lagoon.

Determination of Heavy Metal Concentrations in Collected Samples

The concentration of six heavy metals commonly detected in polluted aquatic ecosystems were determined in tissues of the animal species

Collection of tissues

The fish and crab samples were dissected using sterilized dissecting utensils to avoid contamination of samples. The gill and liver of the fish and the muscle of the crab samples were extracted, transferred into individual 2 ml sterile plain specimen tubes and stored at $4^{\circ}C$ till further analyses. Whole biomass of benthic samples was extracted according to a modified method described by Benson and Essien (2009). The biomass samples were kept in sterile tubes and stored at $4^{\circ}C$ till further analyses.

Digestion of samples

Pre-determined weight (1.0 g) of homogenized tissue samples was weighed into a clean 250 ml borosilicate beaker for digestion. A mixture of hydrochloric acid (HCl) and nitric acid (HNO_3) in ratio 3:1 (30 ml) was added to the sample in the beaker and placed on a hot plate for digestion in a fume cupboard. The sample was allowed to cool after digestion and another 20 ml of the digesting solution was added and the sample digested further in the fume cupboard, the sample was then allowed to cool to room temperature. The sample was filtered into another 250 ml borosilicate beaker and made up to desired volume with de-ionized water (APHA-AWWA-WPCF, 1995).

Determination of heavy metal content

The modified Association of Official Analytical Chemists (AOAC, 1990) method was employed in carrying out heavy metal analysis. All digested samples were sub-sampled into clean borosilicate glass containers for Flame Atomic Absorption Spectrophotometer (FAAS) analysis. Standards of concentrations 0.2, 0.4, 0.6, 0.8 and 1.0 mgL^{-1} of each of the heavy metals (Cd, Pb, Zn, Co, Cr and Ni) were made from stock solutions of 1000 mgL^{-1}. The set of standard solutions for each heavy metal and the filtrate of the digested samples were then analyzed using FAAS. The detection limit of the heavy metals in each sample was 0.0001 mgL^{-1} by means of this spectrophotometer (UNICAM 929 Flame Atomic Absorption Spectrophotometer powered by the SOLAAR software). Cadmium, Pb, Zn, Co, Cr and Ni cathode lamps at respective wavelengths were used for the analysis of the respective heavy metal ions in the standards and the filtrate of the samples. Gas mixtures were used in the generation of the flame.

Assessment of Public Health Risk Associated with Consumption of Edible Animal Species Collected from the Lagos Lagoon

The public health risk associated with consumption of edible species collected from the lagoon was assessed by calculating the Daily Intake of Metals (DIM) and Health Risk Index (HRI) as described by Khan *et al.* (2009) and Okunola *et al.* (2011).

$$DIM\ (daily\ intake\ of\ metal) = \frac{Cmetal \times Dfish \times Cfactor}{B^{o}}$$

Where:

C_{metal} is the concentration of heavy metal in the edible organism ($mg\ kg^{-1}$)

D_{fish} is recommended daily intake of fish/protein per age group ($kg\ day^{-1}$): 0.051 kg for 18 and above; 0.035 kg for 6-18 years and 0.016 kg for 1-6 years (IMNA, 2005)

C_{factor} is the conversion factor of fresh weight to dry constant weight (0.208) considering 79% moisture content (Krishna *et al.,* 2014)

B_o is average body weight per age group: 70 kg for 18 years and above; 48 kg for 6-18 years and 19 kg for 1-6 (Abubakar *et al.,* 2015)

$$HRI\ (health\ risk\ index) = \frac{DIM}{RfD}$$

Where:

RfD is the reference dose for respective elements ($mg\ kg^{-1}\ day^{-1}$): Zn 0.3, Ni 0.2, Co 0.0003, Cr 0.003, Pb 0.0014, Cd 0.0001 (US EPA, 2004; Wu *et al.,* 2009; Li and Zhang 2010).

Data Presentation and Analysis

Data presentation

All data are presented as mean ± standard deviation (SD) unless otherwise indicated.

The BCF of the aquatic organisms collected during sampling was measured as a ratio of heavy metal concentration in the tissue of the organisms to heavy metal concentration in surrounding media with the formula:

$$BDF = \frac{Concentration\ in\ orgs}{Concentration\ in\ media/environment}$$

RESULTS

Public Health Risk Assessment of Edible Animal Species Collected from the Lagos Lagoon

Concentrations of all heavy metals analyzed in edible species were below Food and Agricultural Organization (FAO, 1983) recommended maximum limits in food except for Zn (47.60 ppm) in *Tympanotonus fuscatus* compared to its maximum limit in food (30.00 ppm). *Callinectes amnicola* had lower concentrations of heavy metals in its tissues compared to concentrations in *Sarotherodon melanotheron* and *T. fuscatus*. *Sarotherodon melanotheron* bio-concentrated Zn and Pb by factors of 2.35 and 11.00 respectively from the surrounding media, *C. amnicola* bio-concentrated Pb by a factor of 4.00 while *T. fuscatus* bio-accumulated Zn by a factor of 2.62 from surrounding media during the dry season, same results were observed during the rainy season. All other metals analyzed were not bio-concentrated by the edible species (Table 1).

The public health risk associated with consumption of edible species was assessed by calculating the Daily Intake of Metals (DIM) and the Health Risk Index (HRI) for three age groups (1 – 6 years, > 6- 18 years and 19 years and above) utilizing any of the edible species as a protein source. The results of the public health risk assessments of heavy metal levels in edible species are provided in tables 2 - 4. The DIM and HRI for all heavy metals analyzed were < 1 (unity) in the three species and for all age groups indicating that utilization of the animal species as a protein source does not currently pose public health risk to consumers.

Table 1: Heavy Metal Accumulation in Edible Animal Species Collected from the Lagos Lagoon, Nigeria

ORGANISM (n = 6)	HEAVY METAL	LIMITS IN FOOD (ppm)	DRY SEASON			RAINY SEASON		
			Concentration in organism (ppm)	**Concentration in media (ppm)**	**BCF**	**Concentration in organism (ppm)**	**Concentration in media (ppm)**	**BCF**
Sarotherodon melanotheron (Black-chin Tilapia)	Zinc	30.00	29.18 ± 0.69	12.42 ± 1.81	2.35*	25.99 ± 2.41	11.65 ± 1.67	2.23*
	Nickel	80.00	0.38 ± 0.06	6.33 ± 1.34	0.06	0.37 ± 0.05	5.74 ± 1.24	0.06
	Cobalt	-	0.03 ± 0.01	0.24 ± 0.05	0.13	0.02 ± 0.00	0.25 ± 0.06	0.08
	Chromium	12.00	0.27 ± 0.02	4.77 ± 1.68	0.06	0.23 ± 0.01	4.62 ± 1.53	0.05
	Lead	2.00	0.22 ± 0.01	0.02 ± 0.01	11.00*	0.21 ± 0.03	0.02 ± 0.01	10.50*
	Cadmium	0.05	0.09 ± 0.00	6.55 ± 0.83	0.01	0.09 ± 0.01	4.93± 0.64	0.02
Calinectes amnicola (Lagoon crab)	Zinc	30.00	5.60 ± 2.09	12.42 ± 1.81	0.45	4.63 ± 0.82	11.65 ± 1.67	0.40
	Nickel	80.00	0.05 ± 0.01	6.33 ± 1.34	0.01	0.07 ± 0.01	5.74 ± 1.24	0.01
	Cobalt	-	0.01 ± 0.00	0.24 ± 0.05	0.04	0.01 ± 0.00	0.25 ± 0.06	0.04
	Chromium	12.00	0.04 ± 0.01	4.77 ± 1.68	0.01	0.03 ± 0.01	4.62 ± 1.53	0.01
	Lead	2.00	0.08 ± 0.02	0.02 ± 0.01	4.00*	0.07 ± 0.01	0.02 ± 0.01	3.50*
	Cadmium	0.05	0.04 ± 0.01	6.55 ± 0.83	0.01	0.03 ± 0.00	4.93 ± 0.64	0.01
Tympanotonus fuscatus (Perriwinkle)	Zinc	30.00	47.60 ± 2.34	18.15 ± 2.59	2.62*	49.53 ± 2.14	18.31 ± 2.68	2.71*
	Nickel	80.00	0.43 ± 0.02	16.96 ± 2.41	0.03	0.48 ± 0.02	17.92 ± 2.56	0.03
	Cobalt	-	0.01 ± 0.00	4.09 ± 1.01	0.00	0.02 ± 0.00	4.20 ± 1.04	0.00
	Chromium	12.00	2.07 ± 0.01	12.37 ± 2.65	0.17	1.74 ± 0.02	11.72 ± 2.86	0.15
	Lead	2.00	0.03 ± 0.00	0.15 ± 0.03	0.20	0.03 ± 0.00	0.15 ± 0.02	0.20
	Cadmium	0.05	0.06 ± 0.02	5.22 ± 1.39	0.01	0.05 ± 0.01	4.88 ± 1.48	0.01

Key: *BCF (Bio-concentration factor) > than unity
Limits: FAO (1983),
USFDA (1993a and b)

Table 2: Public Health Risk Associated with Consumption of *Sarotherodon melanotheron* as a Protein Source

Heavy Metal	Mean ± SD (mg kg^{-1} wet weight)	DIM (mg kg^{-1} day^{-1})			HRI		
		Children (1-6 yrs)	**Children (> 6-18 yrs)**	**Adults (>18 yrs)**	**Children (1-6 yrs)**	**Children (> 6-18 yrs)**	**Adults (>18 yrs)**
		DRY SEASON					
Zinc	29.18 ± 0.69	5.111E-3	4.425E-3	4.422E-3	1.703E-2	1.475E-2	1.474E-2
Nickel	0.38 ± 0.06	6.656E-5	5.763E-5	5.759E-5	3.328E-3	2.882E-3	2.879E-3
Cobalt	0.03 ± 0.01	5.250E-6	4.550E-6	4.550E-6	1.752E-2	1.517E-2	1.515E-2
Chromium	0.27 ± 0.02	4.729E-5	4.095E-5	4.092E-5	1.567E-2	1.365E-2	1.364E-2
Lead	0.22 ± 0.01	3.853E-5	3.337E-5	3.334E-5	2.752E-2	2.383E-2	2.381E-2
Cadmium	0.09 ± 0.00	1.576E-5	1.365E-5	1.364E-5	1.576E-1	1.365E-1	1.364E-1
		RAINY SEASON					
Zinc	25.99 ± 2.41	4.552E-3	3.941E-3	3.938E-3	1.517E-2	1.313E-2	1.313E-2
Nickel	0.37 ± 0.05	6.481E-5	5.612E-5	5.607E-5	3.240E-3	2.806E-3	2.804E-3
Cobalt	0.02 ± 0.00	3.500E-6	3.030E-6	3.030E-6	1.168E-2	1.011E-2	1.010E-2
Chromium	0.23 ± 0.01	4.029E-5	3.488E-5	3.485E-5	1.343E-2	1.163E-2	1.162E-2
Lead	0.21 ± 0.03	3.678E-5	3.185E-5	3.182E-5	2.627E-2	2.275E-2	2.283E-2
Cadmium	0.09 ± 0.01	1.576E-5	1.365E-5	1.364E-5	1.576E-1	1.365E-1	1.364E-1

Key: DIM (Daily Intake of Metals)
HRI (Health Risk Index)
Values < 1 indicate that protein source does not pose health risk to final consumers

Table 3: Public Health Risk Associated with Consumption of *Callinectes amnicola* as a Protein Source

Heavy Metal	Mean ± SD (mg kg^{-1} wet weight)	DIM (mg kg^{-1} day^{-1})			HRI		
		Children (1-6 yrs)	**Children (> 6-18 yrs)**	**Adults (>18 yrs)**	**Children (1-6 yrs)**	**Children (> 6-18 yrs)**	**Adults (>18 yrs)**
		DRY SEASON					
Zinc	5.60 ± 2.09	9.808E-4	8.493E-4	8.486E-4	3.269E-3	2.831E-3	2.829E-3
Nickel	0.05 ± 0.01	8.758E-6	7.583E-6	7.577E-6	4.379E-4	3.791E-4	3.789E-4
Cobalt	0.01 ± 0.00	1.750E-6	1.520E-6	1.520E-6	5..839E-3	5.056E-3	5.051E-3
Chromium	0.04 ± 0.01	7.066E-6	6.067E-6	6.061E-6	2.335E-3	2.022E-3	2.021E-3
Lead	0.08 ± 0.02	1.401E-5	1.213E-5	1.212E-5	1.000E-2	8.667E-3	8.659E-3
Cadmium	0.04 ± 0.01	7.006E-6	6.067E-6	6.062E-6	7.006E-2	6.067E-2	6.062E-2
		RAINY SEASON					
Zinc	4.63 ± 0.82	8.109E-4	7.022E-4	7.016E-4	2.703E-3	2.341E-3	2.339E-3
Nickel	0.07 ± 0.01	1.226E-4	1.062E-5	1.061E-5	6.130E-3	5.308E-4	5.304E-4
Cobalt	0.01 ± 0.00	1.750E-6	1.520E-6	1.520E-6	5.839E-3	5.056E-3	5.051E-3
Chromium	0.03 ± 0.01	5.254E-6	4.550E-6	4.546E-6	1.752E-3	1.517E-3	1.515E-3
Lead	0.07 ± 0.01	1.226E-5	1.062E-5	1.061E-5	8.757E-3	7.583E-3	7.577E-3
Cadmium	0.03 ± 0.00	5.255E-6	4.550E-6	4.546E-6	5.225E-2	4.550E-2	4.546E-2

Key: DIM (Daily Intake of Metals)
HRI (Health Risk Index)
Values < 1 indicate that protein source does not pose health risk to final consumers

Table 4: Public Health Risk Associated with Consumption of *Tympanotonus fuscatus* **as a Protein Source**

Heavy Metal	Mean ± SD (mg kg^{-1} wet weight)	DIM (mg kg^{-1} day^{-1})			HRI		
		Children (1-6 yrs)	**Children (>6-18 yrs)**	**Adults (>18 yrs)**	**Children (1-6 yrs)**	**Children (>6-18 yrs)**	**Adults (>18 yrs)**
DRY SEASON							
Zinc	47.60 ± 2.34	8.338E-3	7.219E-3	7.213E-3	2.779E-2	2.406E-2	2.404E-2
Nickel	0.43 ± 0.02	7.532E-5	6.522E-5	6.516E-5	3.765E-3	3.260E-3	3.258E-3
Cobalt	0.01 ± 0.00	1.750E-6	1.520E-6	1.520E-6	5.839E-3	5.056E-3	5.051E-3
Chromium	2.07 ± 0.01	3.626E-4	3.139E-4	3.136E-4	1.209E-1	1.047E-1	1.046E-1
Lead	0.03 ± 0.00	5.250E-6	4.550E-6	4.550E-6	3.753E-3	3.250E-3	3.247E-3
Cadmium	0.06 ± 0.02	1.051E-5	9.100E-6	9.090E-6	1.051E-1	9.100E-2	9.092E-2
RAINY SEASON							
Zinc	49.53 ± 2.14	8.676E-3	7.512E-3	7.596E-3	2.891E-2	2.504E-2	2.502E-2
Nickel	0.48 ± 0.02	8.408E-5	7.280E-5	7.274E-5	4.204E-3	3.640E-3	3.637E-3
Cobalt	0.02 ± 0.00	3.500E-6	3.030E-6	3.030E-6	1.168E-2	1.011E-2	1.010E-2
Chromium	1.74 ± 0.02	3.048E-4	2.639E-4	4.588E-4	1.016E-1	8.797E-2	1.529E-1
Lead	0.03 ± 0.00	5.250E-6	4.550E-6	4.550E-6	3.753E-3	3.250E-3	3.247E-3
Cadmium	0.05 ± 0.01	8.760E-6	7.580E-6	7.580E-6	8.757E-2	7.583E-2	7.577E-2

Key: DIM (Daily Intake of Metals)
HRI (Health Risk Index)
Values < 1 indicate that protein source does not pose health risk to final consumers

DISCUSSION AND CONCLUSION

All the heavy metals analyzed except Zn and Pb had bio-concentration factors of less than unity (1) in the edible species. Similar results were reported by Falusi and Olanipekun (2007) when the bio-concentration factors of heavy metals in tropical crab (*Carcinus sp*) from River Aponwe, Ado Ekiti Nigeria were assessed. The low concentration of heavy metals in edible species compared to the high concentrations in water and sediments reported in this study may be related to the bioavailability of heavy metals in the ecosystem. Heavy metal accumulation by aquatic organisms depends principally on bioavailability of the heavy metals which is a function of interrelated factors such as total concentration and speciation of the heavy metal, mineralogy, pH, redox potential, salinity (for brackish water ecosystems), total organic matter, suspended solids as well as volume of water (Davis *et al.,* 1994). These factors affect the partitioning of metals into various fractions such as dissolved, exchangeable, carbonate, iron-manganese oxide, organic and crystalline fractions; bioavailability of metals decreases from the dissolved fractions to the crystalline fractions which are the least bioavailable for uptake by organisms (Elder, 1989; Salomons, 1995). The lagoon crab (*Callinectes amnicola*) had the lowest concentration of heavy metals in its tissue compared to other edible species (*Sarotherodon melanotheron* and *Tympanotonus fuscatus*) assessed. This can be attributed to its non-permeable exocuticle which could inhibit diffusion of metals through the integument and restrict uptake to respiration and ingestion routes. This finding confers a relative advantage to the utilization of the crab species as protein source as opposed to other edible species with permeable integuments. The concentrations of the heavy metals (Pb, Co, Cr, Ni and Cd) detected in the three edible species (*S. melanotheron*, *T. fuscatus* and *C. amnicola*) were lower than the maximum recommended limits by FAO (1983), these results corroborate earlier results which showed that the heavy metals were not bio-concentrated by the organisms. Ajagbe *et al.* (2011) also reported Pb concentrations below maximum recommended limits in 12 out of the 18 edible fish species of the Lagos lagoon they studied. Damodharan and Reddy (2013) investigated heavy metal bioaccumulation in edible fish species of a polluted river in Poland and they also reported that the heavy metals (Zn, Co and Mn) in the fish were within maximum residuals limits recommended by World Health Organisation (WHO)/FAO. Similar results of low concentration of heavy metals below WHO permissible limits was reported by Edward *et al.*

(2013) for edible fish species in Odo-Ayo River, Ado Ekiti. Concentration of heavy metals (Cd, Zn, Ni, Fe and Pb) below WHO permissible limits in *C. amnicola* was also reported by Oyebisi *et al.* (2012). Assessment of public health risk associated with utilization of the edible species (*S. melanotheron*, *T. fuscatus* and *C. amnicola*) as a protein source carried out in this study also revealed that the species currently pose no health risk to final consumers. The health risk index (HRI) for the three age groups assessed were below unity (1) indicating that the utilization of the edible species as protein sources is currently safe for humans. This further corroborates the low concentration of heavy metals detected in the organisms. However, some studies including that of Krishna *et al.* (2014) have reported cancer and non-cancer health risk associated with consumption of edible species from polluted aquatic ecosystems. Thus, the relative safety associated with utilization of edible species from the Lagos lagoon as a protein source reported in this study can only be maintained if heavy metal concentrations in the lagoon are kept within acceptable limits. This can only be achieved with setting of effective effluent limitation standards and enforcement of standards by regulatory agencies and also continuous ecological surveys to monitor pollution in vulnerable ecosystems.

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