

Health status of *Chrysichthys nigrodigitatus* in response to aquatic pollution in Epe, Lagos and Ologe Lagoons, Southwest Nigeria

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Abstract

The aquatic ecosystem is frequently the final recipient of pollutants, which may be hazardous to aquatic organism. In this study, in 2012 the following factors were examined: level of Pb, Ni, Cd and Zn in water, sediments, and liver, tissue and gills of *Chrysichthys nigrodigitatus* from Epe, Lagos and Ologe Lagoon. Superoxide dismutase, catalase, glutathione peroxidase activity, glutathione and thiobarbituric acid-reacting substance concentrations in fish samples were also determined, and liver histopathology was conducted. A condition factor for fish was also determined. The results revealed higher levels of Zn in water samples from Lagos lagoon compared to Epe lagoon. Ni and Cd in tissue of samples from Lagos and Ologe Lagoon respectively and Pb in samples from both lagoons were higher than the FAO 1983 limit. Glutathione concentration was higher at Lagos lagoon ($0.84 \pm 0.55 \mu\text{mol mL}^{-1}$) compared to Ologe ($0.72 \pm 0.62 \mu\text{mol mL}^{-1}$). Vacuolar degeneration and bile stains were observed in liver of fish samples from Lagos and Ologe lagoon, respectively. The study showed that *C. nigrodigitatus* is adversely affected by pollutants in the lagoons.

Key words: antioxidants, biomarkers, *Chrysichthys nigrodigitatus*, condition factor, heavy metals, histopathology, oxidative stress.

Abbreviations: BAF, bio accumulation factor ; BSAF, biota-sediment accumulation factor; CAT, catalase; CF, condition factor; DO, dissolved oxygen; GPOx, glutathione peroxidase; GSH, glutathione; SOD, superoxide dismutase; TBARS, thiobarbituric acid-reacting substances; TDS, total dissolved solids.

Introduction

All over the world, aquatic pollution is a major concern. Over 400 million tons of chemical products are discharged from domestic, agricultural and industrial activities into aquatic ecosystems (Schwarzenbach et al. 2006). Trace metals such as As, Hg, Se, Cd, Ni, Pb, Cr, Mo, Sb, Zn, Cu, Mn and Ni are discharged into the aquatic environment from coal-burning power plants, iron and steel plants, non-ferrous metals smelters, domestic effluents and sewage sludge disposal (Nriagu et al. 1988). In the aquatic environment, trace metals are not degraded and due to their affinity for biomolecules such as lipids and amino acids, they accumulate in cells of phytoplankton and zooplankton. In this way, high concentrations of the metals in organisms can be found on tops of food chain. Considering that the aquatic environment is the final sink of trace metals and chemical products, the essential ecological services provided by fish i.e. nutrient cycling, regulation of trophic structure, aquatic food web dynamics, and carbon flux (Holmlund, Hammer 1999) may be affected.

Fish health can be adversely affected by temperature changes, habitat deterioration and aquatic pollution (Skouras et al. 2003). Fish species have attracted consi-

derable interest in studies assessing the biological effects of environmental contaminants (Powers 1989). The ability of fishes to accumulate pollutants in their cells, tissues or body fluids and respond to these pollutants, some times in a specific way, makes them valuable biomonitoring tools for water quality assessment. Fishes may also accumulate trace metals to a level that may pose health risk to the fish and humans via dietary intake. Biomarkers have often been employed to assess the health status of organisms and can serve as early-warning indicators of the effects of environmental pollution (Payne et al. 1987). Biomarkers are measureable biological responses that may indicate exposure to and/or effects from anthropogenic substances at sub-lethal concentrations. A number of biochemical, physiological, enzyme and immune assays are considered suitable markers of exposure to and effects of aquatic contamination (Zelikoff et al. 2000; Skouras et al. 2003; Farombi et al. 2007; Olarinmoye et al. 2009; Obiakor et al. 2010).

The lagoons in Lagos State Nigeria are the final sink of effluents from over 2000 medium and large-scale industries. Also, the Ogun River discharges its municipal waste water into the lagoons (Uaboi-Egbenni et al. 2010). There has been a decline in artisanal fishery in Lagos and

deteriorating water quality was reported by Oribhabor and Ezenwa (2005) as one of the factors responsible. Among the fish species present in the lagoons, silver catfish is in high demand and remains a commercially important source of revenue for fishermen in Nigeria and West Africa. The fish is also a vital source of animal protein in the human diet. The discharge of effluents into the lagoons may affect vital physiological process, cause stress or organ damage and ultimately affect the fish population. Thus, the aim of the study was to assess the health condition of silver cat fish, evaluate their biological responses to water contamination and determine if heavy metal concentrations present in the fish were within the recommended limits for human consumption.

Materials and methods

Description of the study area

Lagos State, which is located in Southwest Nigeria lies approximately at longitude 2°42'E and 3°22' East respectively and between Latitude 6°22'N and 6°42'N. Epe, Lagos and Ologe Lagoons (Fig. 1) are among the four major lagoons in Lagos State, Southwest Nigeria (Kumolu-Johnson et al. 2010). Epe lagoon lies between longitudes 6°33.710'N, 4°03'.710' E and latitudes 6°31.893' N, 3°31.912' E. It has a surface area of about 243 km² with a maximum depth of about 2.8 m (Edokpayi et al. 2008). The lagoon is the major source of water for the inhabitants of Epe and other villages situated along its bank. Lagos lagoon lies between latitude 6°26' to 6°37' N and longitude 3°23' to

4°20' E. Its brackish nature is a consequence of the influence of tidal sea water incursion and freshwater discharge from the adjoining rivers and creeks (Ajao). It provides place of abode for the Ilajes and Ijaws, means of livelihood for fishermen and inland waterway transportation. The lagoon is often used as an open dump for municipal solid waste, disposal of raw human faeces and sinks for residential and commercial effluent (Nubi et al. 2008). Ologe Lagoon lies between longitudes 20°42' to 4°42' E and latitude 6°22' to 6°42' N. It sustains a thriving artisanal fisheries industry and serves as a source of water for domestic and industrial use, transportation, logging and sand dredging (Anetekhai et al. 2003). Fishing activity is affected by effluents from Agbara industrial estate and the flushing of solid wastes from river Owo into Ologe lagoon (Adebola 2011). Epe Lagoon was selected as a control because it is relatively unpolluted, given the minimal number of commercial and industries around the lagoon, compared to Lagos and Ologe Lagoon. In each of the lagoons, three sampling points were chosen for the study, namely; Afuye, Epe Jetty and Epe Bridge at Epe lagoon, Makoko, Iddo and Lekki at Lagos lagoon and Otto Jetty, Egbede and Ibiye at Ologe lagoon. The sampling points were chosen because of ease of accessibility. They also represent a source of pollution to the lagoons.

Sample collection

A total of ninety samples of silver catfish, *Chrysichthys nigrodigitatus* (Lacépède: 1803), i.e. thirty per lagoon were collected between May and July, 2012. No sex selection was made. Fishes were purchased live from catches of local fishermen at Afuye, Makoko and Otto Jetty which were the fish landing sites of Epe, Lagos and Ologe lagoons respectively. Fishes with no external abnormalities were selected. The fish were sacrificed by a pre-occipital severance of the spinal cord. The weight in grams (g) of each specimen was taken using a digital weighing balance, which was wiped dry between samples. Standard length and total length was measured in centimeter (cm) using a meter ruler. They were then dissected, the liver, tissues and gills excised, weighed and then stored at -10 °C prior to analysis.

Surface water and bottom sediment samples were collected once monthly between May and July 2012 at each sampling site. The water and sediments from the lagoons were mixed together to form a composite sample for analysis. Water samples were collected by dipping four liter plastic bottles straight into the water. The containers were rinsed three times with the site water prior to collection. All samples were collected in triplicate. Bottom sediment samples were collected using a grab sampler and transferred into polyethylene bags. Samples were transported to the laboratory within 4 h for heavy metal analysis.

Analytical procedures

Water temperature, pH, electrical conductivity, dissolved

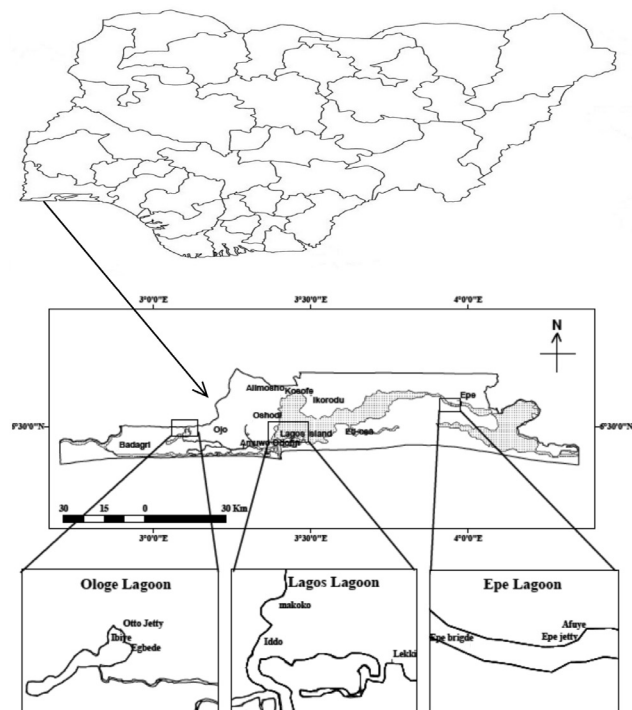


Fig. 1. Map of Nigeria, Lagos State showing the Lagoons and sampling areas.

oxygen (DO), and total dissolved solids (TDS) were measured in situ using appropriate portable meters: HM Digital COM 100 for temperature and TDS, DO meter (DO5519) and Hanna pH tester.

The concentrations of lead, nickel cadmium, and zinc were determined using an atomic absorption spectrophotometer (Analyst Perkin-Elmer).

For analysis, 5 mL of concentrated hydrochloric acid was added to 250 mL of water samples and evaporated to 25 mL. The concentrate was transferred to a 50 mL flask and diluted to mark with distilled water for the determination of the heavy metals.

Samples (5 g) of sediment were transferred into 150 mL conical flasks containing 50 mL 0.1 M HCl. The flask was agitated on an orbital shaker for 30 min and then filtered into 50 mL standard flask and made up to mark with 0.1 M HCl for the determination of the heavy metals.

Tissues and organs were defrosted for 2 h. Two g each of liver and gill sample as well as 5 g of tissue was digested using nitric acid (10 mL). The samples were heated until brown fumes disappeared and then allowed to cool. Distilled water was added to make up to 50 mL in a standard volumetric flask. The filtrates were filtered off and then the heavy metal concentrations were determined.

For each lagoon, nine liver samples were analysed for antioxidant activity and lipid peroxidation. The liver of the fish were rinsed in buffered saline. Liver samples (1 g) were homogenized with 9.0 mL 4.0m phosphate buffer pH 8.0. Superoxide dismutase (SOD) activity was determined by measuring the inhibition of auto-oxidation of epinephrine at pH 10.2 at 30 °C (Magwere et al. 1997). One unit of SOD activity was defined as the amount of SOD necessary to cause 50% inhibition of epinephrine auto-oxidation. The assay was performed in 3.0 mL 50mM Na₂CO₃ buffer to which 0.02 mL of the sample was added. Epinephrine stock solution (0.03 mL) was added to the above before taking absorbance readings at 480 nm for 3 to 5 min. The activity of SOD was expressed as units per min per mg protein.

Catalase (CAT) was assayed colorimetrically at 620 nm and expressed as μmoles of H₂O₂ consumed per min per mg protein (Sinha 1972). The reaction mixture (1.5 mL) contained 1.0 mL 0.01 M pH 7.0 phosphate buffer, 0.1 mL liver homogenate and 0.4 mL 2 M H₂O₂. The reaction was stopped by the addition of 2.0 mL dichromate acetic acid reagent (5% potassium dichromate and glacial acetic acid were mixed in 1:3 ratio). The unit of expression of CAT activity was μmol H₂O₂ per min per mg protein.

Glutathione peroxidase (GPOx) activity was measured by the method described by Ellman (1959). Reaction mixture contained 0.2 mL 0.4 M phosphate buffer pH 7.0, 0.1 mL 10 mM sodium azide, and 0.2 mL liver homogenate. The contents were incubated at 37 °C for 10 min. The reaction was stopped by adding 0.4 mL 10% trichloroacetic acid, and centrifuged. Concentration of reduced glutathione in the reaction mixture was measured as described further.

The unit of expression of GPOx activity was μmol per mL.

Reduced glutathione (GSH) was determined by the method of Ellman (1959). To the liver homogenate 10% trichloroacetic acid was added and centrifuged. Supernatant (1.0 mL) was treated with 0.5 mL of Ellmans reagent (19.8 mg 5,5-dithio-bisnitro benzoic acid in 100 mL 0.1% sodium nitrate) and 3.0 mL phosphate buffer (2M pH 8.0). The absorbance was read at 412 nm. The unit of expression was μmol GSH per mL.

Lipid peroxidation as indicated by the formation of thiobarbituric acid-reacting substances (TBARS) was determined by the method of Nichens and Samuelson (1968). Liver homogenate (0.1 mL) was treated with 2 mL (1:1:1 ratio) TBA-TCA-HCl reagent (thiobarbituric acid 0.37%, 0.25M HCl and 15% trichloroacetic acid) and placed in water bath for 15 min, cooled and centrifuged at room temperature for 10 min at 3000 rpm. The absorbance of clear supernatant was measured against a blank at 535 nm. The unit of expression of TBARS was nmol per mL.

Bio accumulation factor (BAF) and biota-sediment accumulation factor (BSAF) were determined by the following equations.

$$\text{BAF} = \frac{\text{mean concentration of heavy metal in fish (mg kg}^{-1}\text{)}}{\text{mean concentration of heavy metal in water (mg L}^{-1}\text{),}}$$

$$\text{BSAF} = \frac{\text{mean concentration of heavy metal in fish (mg kg}^{-1}\text{)}}{\text{mean concentration of heavy metal in sediment (mg kg}^{-1}\text{).}}$$

Thirty fishes per lagoon were used to evaluate the condition factor of the fishes. The condition factor (CF) was calculated according to the following equation (Busacker et al. 1990):

$$CF = \frac{W}{L^3} \times 100$$

where *W* is fish wet weight (g), *L* is fish total length (cm).

Nine liver samples per lagoon were examined for tissue damage. Liver samples were cut into thin slices of about 0.3 to 0.5 cm with a scalpel blade, fixed in 10% formal saline for 6 h and then dehydrated in graded alcohol; 70% alcohol for 1 h, 90% alcohol I for 1 h, 90% alcohol II for 1 h, 90% alcohol III for 2 h, absolute alcohol I for 2 h, and absolute alcohol for 3 h. The dehydrated specimens were transferred into xylene I for 1, and then to xylene II for 2 h, followed by wax impregnation and embedding in paraffin for histopathological examination. The resulting sections were mounted on glass microscope slides and air dried prior to staining using hematoxylin and eosin stain, and cover slipped (Luna 1992). Stained sections were then examined using light microscopy.

Data analysis

The mean values of the of heavy metal concentrations in the gill, liver and muscle of the fish and the mean SOD and CAT activity, and GSH, TBARS and GPOx concentrations

Table 1. Physicochemical parameters and fish biometrics in three lagoons. The results of fish biometrics are mean \pm SD for 30 fishes per lagoon. Same letter indicate significant difference of the parameter between the lagoons ($p < 0.05$). * above WHO guideline for Pb (0.01 mg L⁻¹), # above the WHO guideline for Ni (0.02 mg L⁻¹), + below the WHO guideline for Zn (3 mg L⁻¹)

	Parameter	Epe	Lagos	Ologe
Water	pH	7.4 \pm 0.4	7.7 \pm 0.5	7.3 \pm 0.3
	TDS (mg L ⁻¹)	144 \pm 26	245 \pm 128	75 \pm 5
	DO (mg L ⁻¹)	7.10 \pm 0.15	6.90 \pm 0.04	7.10 \pm 0.25
	Temperature (°C)	26.8 \pm 1.3	27.4 \pm 1.0	27.4 \pm 0.8
	Pb (mg L ⁻¹)	0.009 \pm 0.001	0.015 \pm 0.01*	0.011 \pm 0.01*
	Ni (mg L ⁻¹)	0.011 \pm 0.001#	0.010 \pm 0.01#	0.016 \pm 0.002#
	Zn (mg L ⁻¹)	0.13 \pm 0.03a+	0.29 \pm 0.07a+	0.14 \pm 0.04+
Sediment	Pb (mg kg ⁻¹)	0.03 \pm 0.03	0.06 \pm 0.02	0.05 \pm 0.04
	Ni (mg kg ⁻¹)	0.02 \pm 0.01	0.03 \pm 0.01	0.04 \pm 0.02
	Zn (mg kg ⁻¹)	0.58 \pm 0.05	1.23 \pm 0.03	0.32 \pm 0.03
Fish biometrics	Total length (cm)	22.2 \pm 2.1ab	19.7 \pm 1.58ac	17.3 \pm 2.2bc
	Minimum total length (cm)	18.0	16.0	14.0
	Maximum total length (cm)	27.0	23.0	21.0
	Standard length (cm)	17.0 \pm 1.4	15.3 \pm 1.3	13.3 \pm 1.6
	Minimum standard length	14.0	12.0	11.0
	Maximum standard length	21.0	18.0	17.0
	Weight (g)	118.2 \pm 31.6	79.1 \pm 14.8	55.2 \pm 18.5
	Condition Factor	1.10 \pm 0.13	1.04 \pm 0.14	1.04 \pm 0.12

in liver from the different lagoons was compared using ANOVA while Tukeys post hoc test was used to obtain the specific significant differences among the lagoons. Analysis was computed with Statistical Package for Social Sciences (SPSS) version 19.

Results

Physicochemical parameters of the lagoons and fish biometrics

The result of the physicochemical parameters of the lagoon

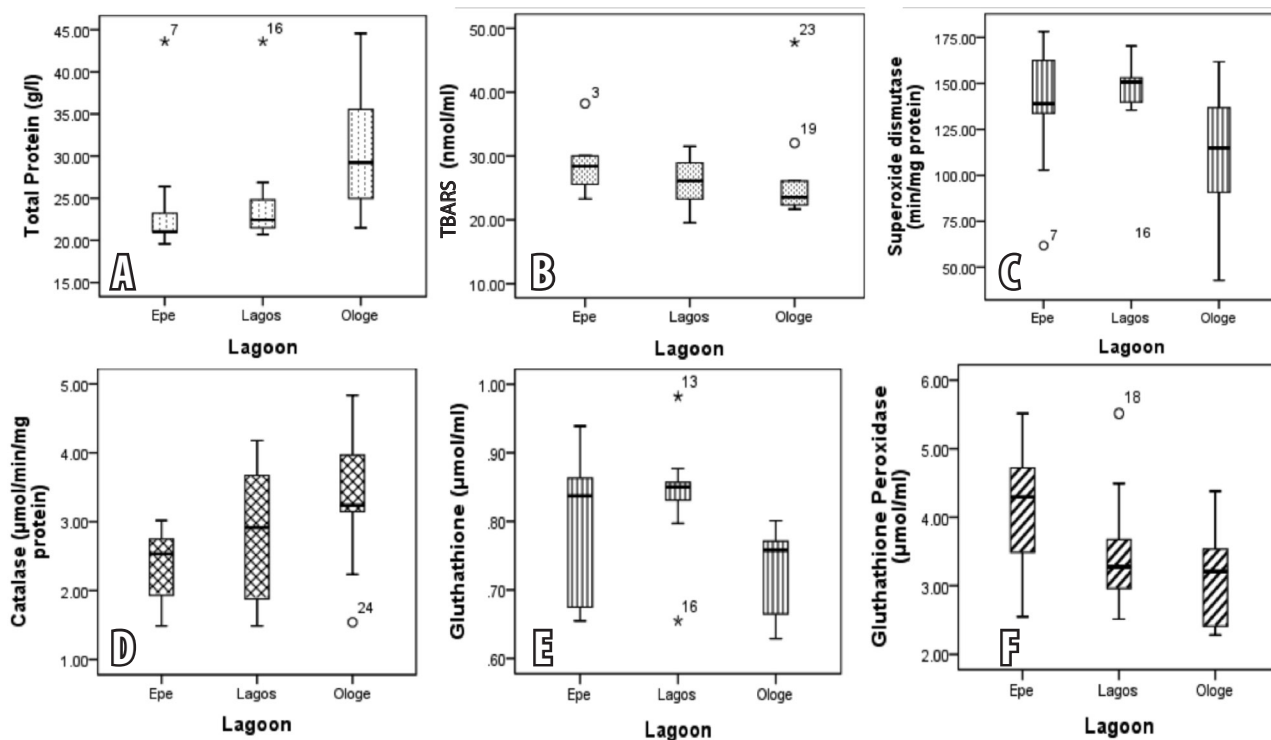


Fig. 2. Comparison of total protein concentration (A), TBARS concentration (B), superoxide dismutase activity (C), catalase activity (D), glutathione concentration (E), glutathione peroxidase activity (F) in liver of fish samples from different lagoons.

and fish biometrics is presented in Table 1. Zn had the highest concentration, while Cd was not detected in both water and sediments from the lagoons. Lagos lagoon had the highest concentration of Pb and Zn in water and sediment, while Ni was highest in water and sediment samples from Ologe. Epe lagoon had the lowest concentration of these metals in water and sediments, except compared with Zn concentration in sediments from Ologe lagoon. Zn was found to be significantly higher in water samples from Lagos lagoon compared to Epe lagoon.

Lower total length, weight and condition factor of *C. nigrodigitatus* were observed in Ologe and Lagos lagoon compared to Epe Lagoon, but these differences were not statistically significant. The trend of the condition factor of the silver catfish was Epe (1.10) > Lagos (1.04) = Ologe (1.04).

Total protein, antioxidant activity and lipid peroxidation in *C. nigrodigitatus*

The activities of antioxidant enzymes in liver of *C. nigrodigitatus* from the lagoons are presented in Fig. 2A to F. No statistically significant difference was observed in the level of total protein, activity of superoxide dismutase, catalase, glutathione peroxidase and level of lipid peroxidation in the liver of *C. nigrodigitatus* sampled from the three lagoons. The trend of total protein level of silver catfish was Ologe > Lagos > Epe lagoon, while the following trend was observed for antioxidant activities: Epe > Lagos > Ologe (SOD); Ologe > Lagos > Epe lagoon (CAT); Epe > Lagos > Ologe lagoon (GPOx) and Epe > Lagos > Ologe lagoons (TBARS). However, glutathione concentration in liver of samples from Lagos lagoon was higher ($p < 0.05$) than in Ologe lagoon and the trend observed was Lagos > Epe > Ologe lagoon.

Bioaccumulation of heavy metals, BAF and BSAF in *C. nigrodigitatus*

A similar trend of accumulation of heavy metal concentration (liver > muscle > gill, liver > gill > muscle, liver > gill > muscle, for Pb, Ni, and Zn, respectively) was observed in *C. nigrodigitatus* samples from Epe and Ologe lagoon, while for samples from Lagos lagoon the trend differed (gill > muscle > liver, liver > muscle > gill and gill > muscle > liver for Pb, Ni and Zn, respectively) (Table 2). Cd accumulation was similar in the three lagoons, liver > muscle > gill. There were no significant difference in the level of Pb, Ni, Cd, and Zn in the liver, gills and muscle of *C. nigrodigitatus* sample from Lagos and Ologe lagoon compared to Epe lagoon ($p > 0.05$). However, Pb in liver of fishes from Lagos lagoon was found to be significantly lower compared to fishes sampled from Epe lagoon. Ni concentration in the liver of fishes from Ologe lagoon was also significantly higher compared to samples from Lagos lagoon, while Zn in liver of the fishes across the three lagoons differed significantly and the trend was

Ologe > Epe > Lagos. BAF and BSAF, which estimate metal concentrations in fish relative to water and sediments, were highest for liver samples obtained from Epe and Ologe lagoon, unlike Lagos lagoon where BAF and BSAF were highest for gills, except for Ni, which accumulated more in tissue relative to water and sediments.

Table 2. Mean heavy metal concentration (mg kg⁻¹) in gill, muscle and liver of *Chrysichthys nigrodigitatus*, BAF and BSAF. +, indicates significantly different from gill and muscle; *, significantly different from liver and tissue. ND, not determined; a, significantly different from Lagos and Ologe Lagoon; b, significantly different from Epe and Lagos lagoon; c, significantly different in all three lagoons ($p < 0.05$); z, indicates above the Food and Agriculture Organisation (FAO) maximum allowable limits; Pb (0.5 mg kg⁻¹), Cd (0.05 mg kg⁻¹) and Ni (0.1 mg kg⁻¹) (FAO 1983)

Lagoon	Metal	Gill	Muscle	Liver
Epe	Pb	0.33 ± 0.26	0.43 ± 0.34	1.77 ± 0.47+a
	BAF	37.0	47.5	196.9
	BSAF	11.1	14.3	59.1
	Ni	0.63 ± 0.49	0.48 ± 0.39	2.95 ± 0.64+
	BAF	60.0	43.7	268.2
	BSAF	12.5	49.6	59.0
	Zn	1.25 ± 0.92	0.92 ± 0.88	4.32 ± 1.79+c
	BAF	9.7	7.1	33.2
	BSAF	2.2	7.5	7.5
	Cd	0.02 ± 0.04	0.03 ± 0.05	4.32 ± 1.79+c
	BAF	ND	ND	ND
	BSAF	ND	ND	ND
Lagos	Pb	2.80 ± 2.49*	0.64 ± 0.75z	0.21 ± 0.19*
	BAF	138.7	42.7	14.6
	BSAF	34.7	10.7	13.7
	Ni	0.89 ± 0.49	1.24 ± 1.04z	2.04 ± 1.60
	BAF	87.9	123.7	204.3
	BSAF	22.0	30.9	22.0
	Zn	5.30 ± 4.28	2.89 ± 2.43	2.22 ± 1.13c
	BAF	18.1	9.9	7.6
	BSAF	4.3	2.4	1.8
	Cd	0.022 ± 0.04	0.032 ± 0.05	0.04±0.07
	BAF	ND	ND	ND
	BSAF	ND	ND	ND
Ologe	Pb	0.12 ± 0.12	0.23 ± 0.19	1.16 ± 1.42+
	BAF	10.6	20.7	105.9
	BSAF	12.3	4.6	23.3
	Ni	0.79 ± 0.81	0.57 ± 0.68z	3.43 ± 1.09+b
	BAF	49.8	35.9	214.4
	BSAF	19.9	14.4	85.7
	Zn	1.93 ± 1.93	1.33 ± 1.49	9.92 ± 2.30+C
	BAF	13.9	9.5	71.4
	BSAF	6.1	4.1	31.0
	Cd	0.27 ± 0.06	0.06 ± 0.09z	0.01 ± 0.02
	BAF	ND	ND	ND
	BSAF	ND	ND	ND

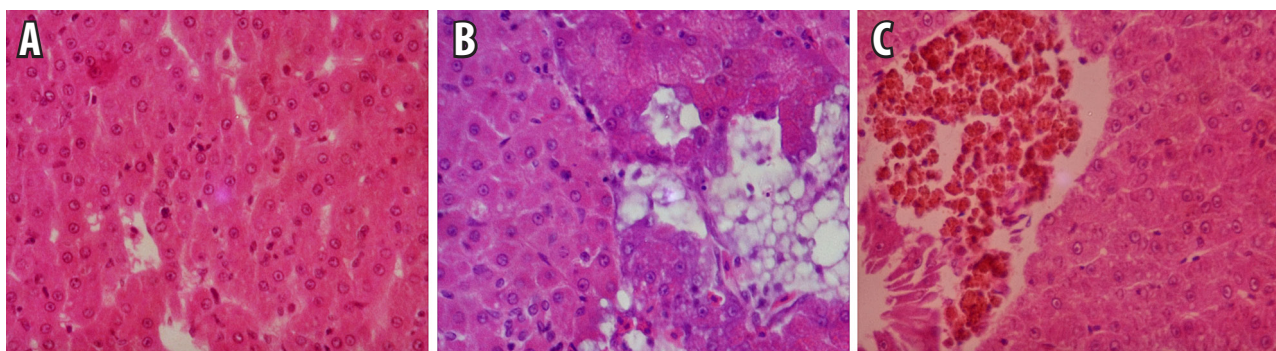


Fig. 3. A, liver histology of *Chrysichthys nigrodigitatus* showing no alteration, minimal vacuolation, sparse biliary duct numbers, and normal arrangement of hepatic cords. B, vacuolar degeneration of hepatocytes in liver tissue of *C. nigrodigitatus*. C, bile stains in liver tissue of *C. nigrodigitatus*.

Histopathology of liver of *C. nigrodigitatus*

Microscopic examination of liver of *C. nigrodigitatus* from Epe Lagoon revealed no alteration in liver ultrastructure (Fig. 3A). Liver of *C. nigrodigitatus* from Lagos Lagoon showed vacuolar hepatocellular degeneration in two samples (Fig. 3B), while the examination of liver of *C. nigrodigitatus* from Ologe Lagoon indicated bile stains in two samples (Fig. 3C).

Discussion

Chrysichthys nigrodigitatus has nutritional and commercial importance in Nigeria; therefore it is essential to assess the influence of water contamination on the health of the fish species. The final sink for many contaminants is the aquatic environment (Stegeman, Hahn 1994) and in this environment, contaminants are partitioned between water column, bottom sediments and biota. In this study, the low level of heavy metals in water compared to sediments and fish tissues is consistent with previous reports (Obasohan et al. 2006; Olowu et al. 2010). Heavy metals were present in water samples from Epe and Ologe lagoon in the concentration order Zn > Ni > Pb. Pb in water samples from Lagos and Ologe lagoon and Ni in samples from the three lagoons exceeded the WHO recommended water quality guidelines (UNEPGEMS 2006). Sediments have been reported to form the major sink of heavy metals in aquatic system (Olowu et al. 2010) and this may make the sediments hazardous to benthic organisms. The order of heavy metals in sediments was Zn > Pb > Ni. *C. nigrodigitatus* is a bottom dwelling fish and a benthic feeder and may be at more risk of exposure to heavy metals in sediments than in water. Fish have the ability for uptake and accumulation of heavy metals in their muscles and it is important to screen tissue levels to ensure that these metals are not transferred to man through food.

The concentrations of Pb and Cd in muscle of silver catfish samples from Lagos and Ologe lagoon respectively and concentration of Ni in fish samples from both lagoons were higher than the Food and Agriculture Organisation

(FAO) maximum allowable limits; Pb 0.5 mg kg⁻¹, Cd 0.05 mg kg⁻¹ and Ni 0.1 mg kg⁻¹ (FAO 1983). One may conclude that consuming the fish samples analyzed may constitute a health hazard, since the fishes contained trace metals above the FAO limits.

The condition factor (CF) of a fish, often used to depict the well-being of a fish, can also serve as a first-level screening test to identify pollutant exposure and effect (Van der Oost et al. 2003). It was observed that the size (length and weight) of *C. nigrodigitatus* caught by fishermen at Ologe Lagoon were smaller than in Lagos lagoon while at Epe Lagoon the quantity and size were bigger. The mean condition factor of 1.10 (Epe lagoon) and 1.04 (Lagos and Ologe lagoon) obtained for samples of *C. nigrodigitatus* were lower than those reported by Atobatele and Ugwumba (2011; 2.76 to 3.03), but higher than the values reported by Offem et al. (2009; 0.996) for silver catfish sampled from Aiba Reservoir Iwo and Cross River respectively in Nigeria. Poor environmental conditions may affect the condition factor of fish (Haruna, Bichi 2005). The low condition factor values recorded for Lagos and Ologe Lagoon suggest that the fish may be stressed by the deteriorating water quality caused by influx of a complex mixture of domestic and industrial wastes containing heavy metals. Decrease in the condition factor has been linked to loss of appetite and feeding behaviour of fish. Heavy metals have been suggested to affect the condition factor of fishes (Authman 2008).

Cd was reported to cause loss of appetite in rainbow trout (Mcgeer 2000) while Naz et al. (2013) reported decrease in average weight, fork and total lengths, condition factor and feed intake in *Catla catla*, *Labeo rohita*, *Cirrhina mrigala*, *Ctenopharyngodon idella* and *Hypophthalmichthys molitrix* exposed to sub-lethal concentrations of Zn, Pb, and Mn mixture.

Once absorbed, heavy metals are localized by binding with biologically active constituents like lipids, amino acids and proteins in tissues and organs. Higher concentration of heavy metals in liver and gill compared to muscle tissue of *C. nigrodigitatus* from the three lagoons were in agreement

with earlier reports (Canli, Kalay 1998; Dural et al. 2006; Alhas et al. 2008; Ayotunde et al. 2012). Uptake of heavy metals in fish occurs through diffusion facilitated absorption in gills, which are in direct contact with water (Oguzie 1996). Cd was present in the fishes analyzed although it was not detected in water and sediments. This suggests that the fishes would have been exposed to the metal some time in the past and shows the importance of incorporating fish biomonitoring in the assessment of water quality. The BAF and BSAF showed that liver had higher metal load than other organs, relative to water and sediments. In fish, liver is the organ most commonly involved in the detoxification of foreign compounds (Van der Oost et al., 2003) and metals like Zn, Cu, and Cd to bind to metallothioneins in the liver during the detoxification process (Das 2006). Low levels of metals in tissues may be due to little blood supply to the muscular tissue (Shenouda 1992).

Metals can induce oxidative stress and assessment of antioxidant activities in fishes can indicate exposure to heavy metals in the aquatic environment (Livingstone 2003). TBARS concentration, and SOD and CAT activity in liver of *C. nigrodigitatus* obtained from Lagos and Ologe lagoon did not differ significantly from these in samples from Epe Lagoon, however GSH concentration in liver specimens from Lagos lagoon was higher compared to specimens from Ologe lagoon. The depletion of GSH concentration in liver of *C. nigrodigitatus* samples from Ologe and Epe Lagos lagoon may be linked to the Pb, Ni and Zn in the liver. Pb, Cd and Ni have electron-sharing affinities that could result in covalent attachment between them and sulfhydryl groups of GSH, which could result in GSH depletion, leading to the production of reactive oxygen species (Bondy 1996; Meister 1988; Quig 1998). Most heavy metals facilitate oxidative stress, yet zinc appears to act as a membrane stabilizer and prevents the formation of reactive oxygen species through protection of sulfhydryl groups against oxidation and displacement of redox metal ions from site-specific loci (Bray, Bettger 1990; Stohs, Bagchi, 1995). Hence, given that the highest concentration of zinc was found in water and sediments from Lagos lagoon, it is probable that GSH concentration in liver of fishes obtained from the lagoon was least depleted due to the protective effects of zinc.

Histopathological biomarkers are valuable indicators of the general health of fish and mirror the effects of exposure to pollutants (Hinton et al. 1992). Heavy metals have been suggested to cause histopathological alterations in liver of fishes. The results of microscopic examination of liver specimens from Lagos and Ologe Lagoon were consistent with the findings of Olanrinmoye et al. (2009) in which liver of *C. nigrodigitatus* from Lagos lagoon showed several alterations including vacuolar hepatocellular degeneration and hepatic necrosis. Liver degeneration and necrosis due to exposure to Ni and Cd was observed in oriental sole (*Euryglossa orientalis*) and deep flounder (*Psettodes*

erumei) caught from the north coast of the Persian Gulf (Khoshnood et al. 2010).

Conclusions

The study showed the negative effects of contaminants containing heavy metals discharged into the lagoons and accumulation of Pb, Cd, Ni and Zn by *C. nigrodigitatus* relative to water and sediments. Low condition factor, GSH depletion and histology alterations in liver may be linked to the bioaccumulation of heavy metals by *C. nigrodigitatus*. The biological responses of *C. nigrodigitatus* may be useful indicators of aquatic pollution and further research on the possible use of *C. nigrodigitatus* as a model organism for routine monitoring of aquatic ecosystem is recommended.

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