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Heavy Metals and the Condition Factor of *Farfantepenaeus notialis* in a Tropical Brackish Water

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Abstract

This study investigated the concentration of six metals in the cephalothorax and abdomen of *Farfantepenaeus notialis* in relation to its condition factor. The metal concentrations were determined using Atomic Absorption Spectrophotometer. The relationship between heavy metals and condition factor was determined through correlation and regression analyses while T test was used to compare the metal concentration in abdomen and cephalothorax. Allometric growth patterns were observed in the species, with K factors from 0.47 to 0.57. The bio-accumulation of metals was found to be in the following order: Zn>Fe>Mn>Cu>Pb>Cd. Cd, Pb, Cu, and Mn had higher concentrations in the abdomen, while Zn and Fe had higher concentrations in the cephalothorax. In addition, the Fe and Mn level was significantly higher than the Federal Environmental Protection Agency's recommended limit. In both seasons, Pb in the abdomen was the only element that had a significant relationship with shrimp's condition factor, but Manganese in the abdomen and Zinc in the cephalothorax had a significant relationship with shrimp condition factor in the wet season. Thus, the study area should be closely monitored in order to reduce the risks posed to the aquatic ecosystem and human population that relies on it for water and fish supplies.

Introduction

Pollution influences the accumulation of chemical compounds in fish, and the effects varies for different aquatic animals residing in the similar ecosystem (Akinola et al., 2019 & 2020). Heavy metals also have different patterns of accumulation in organs, which can have a variety of negative effects on organisms' health, causing physiological, cognitive, and behavioral changes in those who are exposed. High metals concentrations in water can stifle fish growth and development, especially during the developmental stages, resulting in size alterations. Heavy metals have also been linked to neurological disorders in fish, particularly in the early stages, which can result in behavioural changes, poor performance, or a physiological disorder (Olawusi-Peters et al., 2017 and El-Batrawy et al., 2018).

Toxicology is the most serious concern linked with heavy metals, aside from accumulation through the food chain (Josephine, 2022). Essential metals must be absorbed from food, water, or sediment for normal metabolism in fish (Olusegun et al., 2021), whereas essential metals can cause hazardous consequences if consumed in excess, according to Younis et al., (2015). There are different mechanisms of metal toxicity in fish hence; it is difficult to determine the probable effect of a particular concentration of a metal. Younis et al., (2015) observed that metals decreased Hepatosomatic

Index (HIS) in *Clarias gariepinus* and associated it to loss of energy reserves in liver. Martínez-Gómez et al., (2012) observed that Gonadosomatic Index (GSI) decreased in *Mullus barbatus* under the effect of Hg, Pb and Ar, possibly due to structural deformation of DNA and an increase in liver EROD (ethoxyresorufin- O deethylase) activity.

Furthermore, heavy metals had a deleterious impact on gonad growth in *Leuciscus cephalus*, probably due to a decrease in 11-ketotestesteron, EROD, and vitelline levels (Olawusi-Peters and Adejugbagbe, 2020). Despite these information, there are no established relationships between the size or condition factor of fish and heavy metal concentration.

Many organisms such as plants, crustaceans, protozoans, fish and insect have been used as aquatic bio-indicators (Omobepade et al., 2020; Ibrahim et al., 2018; Esilaba et al., 2020; Ahmed et al., 2022; Fajemila et al., 2020; Olawusi-Peters and Akinola, 2017). Shrimps are important components of the aquatic food chain. Thus, their metal concentrations can serve as environmental indicator (Esilaba et al., 2020). Moreover, Olawusi-Peters et al., (2014a & 2017) reported that *Farfantepenaeus notialis* is an important component of artisanal catches from estuaries and coastal waters while Chindah et al., (2004) and Ajibare et al., (2017) reported that *F. notialis* has a higher proclivity to bio-accumulate some metals in the ecosystem more than others, suggesting that the species could be used as a biological-indicator for the monitoring of heavy metal pollution.

In addition, Olawusi-Peters et al., (2014b) and Ajibare et al., (2017) indicated that pollution from anthropogenic activities was responsible for the low K values of shrimps in the Ondo state coastal waters, which empties into the Atlantic Ocean, as well as some other regions of Nigeria. This implies that its pollution poses ecological and health problems on a global and national scale. As a result, the concentrations of Cd, Cu, Pb, Fe, Zn, and Mn in the cephalothorax and abdomen of *F. notialis* was evaluated in order to determine the consequences on the shrimps' overall health (condition factor) and the ecosystem.

Research Methodology

Study Area

The research was carried out between April 2014 and March 2016 in the Ilaje LGA, Ondo State, Nigeria, which is located in an equatorial evergreen swamp forest. The climate of the study area is divided into two distinct seasons which are dry and wet seasons. The dry season lasts from November to April with a high temperature, sometimes reaching above 30°C while the wet season lasts from May to late October with an average temperature of 30°C (Ajibare et al., 2022). This study covered two complete cycles of dry and wet seasons. As indicated in Table 1, the underlisted coastal towns were chosen based on their accessibility, large shrimp fishing activities, and human impacts such as transportation, farming, and discharges.

Collection and Identification of Shrimps

Shrimps were captured monthly with the assistance of artisanal fishermen and were sorted and identified according to Olawusi-Peters et al., (2014a) and Ajibare et al., (2022). The samples were kept in ice chest and transported to the laboratory for analysis. The total number of shrimps sampled was 1435 and 1413 in the wet and dry season respectively.

Determination of Length and Weight

Each shrimp's total length and weight (to the nearest 0.01g) were measured using a graduated measuring board (to the nearest 0.01cm) and a top loading sensitive weighing balance (Model BL100001) according to Ajibare et al., (2017).

Determination of LWR and K

The length-weight relationship of shrimps was determined by the equation:

$$W = aL^b$$ (Pauly, 1983; Ajibare et al., 2017)

Where *W* - Weight (g), *L* - Length (cm), *a* - Constant (intercept), *b* - Length exponent (slope)

‘*a*’ and ‘*b*’ were obtained from a linear regression of the logarithm of L and W according to the formula: $logW = \log a + blog\ L$ using Minitab 14.

Also, the condition factor (K) was calculated according to:

$$K = \frac{100\mathrm{W}}{\mathrm{L}^3}$$ (Gayanilo and Pauly, 1997; Ajibare et al., 2017)

Table 1: Study Area

Town	Station	Coordinate
Ayetoro	I	06°06’N 04°46’E
Idiogba	II	06°05’N 04°47’E
Bijimi	III	06°04’N 04°49’E
Asumogha	IV	06°03’N 04°39’E

Determination of Heavy Metals

The cephalothorax and abdomen of the shrimp samples were separated using dissection. The tissues (200g each) were oven dried for 48 hours at 60°C. The shrimps were homogenized and powdered. 0.2g was then placed in a 50ml digestion tube. 2.5ml of the H_2SO_4/selenium mixture was added, and the solution was heated to around 200°C until it fumed. After that, each tube was taken off the hot plate and allowed to cool for 10 minutes. In addition, 1ml of 30% H_2O_2 was added to each tube. After the reaction had died down, each tube was given 2ml of H_2O_2. After that, each tube was placed on a hot plate and cooked to 330°C for about two hours (usually until clear). As the digest progressed, the yellow tint of the solution faded. The resultant solution was then placed into a centrifuge tube, which was then filled to the 30ml mark with distilled water. This was centrifuged for 10 minutes at 3000 rpm. For analysis, the supernatant was put into sample vials. The ACCUSYS 211 Atomic Absorption Spectrophotometer was used to determine the concentration of heavy metal (Edward et al 2013).

Quality Control / Assurance

AnalaR (BDH, England) reagents were prepared for the various analyses, and distilled water was used for the solution preparation. Quality control (QC)/ assurance (QA) protocol as described by Ajibare and Ayeku (2024) was used. In this study, analytical precision from the Natural Research Council, Canada through the use of certified standard reference material and replicate runs were employed.

Statistical Analysis

The relationship between the minerals (heavy metals) and condition factor was determined through correlation and regression analyses using SPSS 20.0. The concentration of heavy metals in the abdomen and cephalothorax were compared with T test to evaluate significant difference between the parts. The probability threshold of less than 0.05 was considered significant for estimating the figures and standard deviations.

Results

Length and Weight Frequency Distributions of *F. notialis*

According to Table 2, majority (60.58% in wet season and 56.13% in dry season) of the examined shrimps had length ranging between 8.5cm and 10.4cm while the minimum frequency of 1.08% (wet) and 4.03% (dry) were recorded in the range of 4.5-6.4cm. Moreover, the weight frequency distribution (Table 3) showed that 39.60% of the shrimps (in the wet season) weighed between 5.0-5.99g while 35.93% weighed between 2.0-3.9g in the dry season.

Size, Length-Weight Relationship (*b*) and Condition Factor (K) of *F. notialis*

The sizes, K factor and LWR of *F. notialis* (as presented in Table 4) showed no seasonal variation throughout the study. The Table further revealed that the mean total length (9.41±1.29cm) and weight (4.37±1.19g) recorded in the wet season had exponential (b) values of 2.00 (a= -3.03) while similar values were recorded for length (9.43±1.40cm), weight (4.49±1.17g) and exponential (*b*=1.64; a= -2.20) in the dry season. Furthermore, the condition factor 'K' (0.52) recorded for the 1435 specimens in the wet season was similar to the 0.54 recorded for 1413 specimens in the dry season.

Table 2. Length frequency distribution of *F. notialis*

Range	Station I		Station II		Station III		Station IV		**Mean**	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	**Wet**	**Dry**
4.5-6.4cm	0.00	4.60	4.30	7.00	0.00	0.30	0.00	4.20	**1.08**	**4.03**
6.5-8.4cm	20.70	16.70	22.90	17.80	10.00	10.00	0.00	46.00	**13.40**	**22.63**
8.5-10.4cm	47.50	48.90	52.90	54.30	71.00	71.60	70.90	49.70	**60.58**	**56.13**
10.5-11.4cm	20.20	18.80	13.80	15.40	15.90	13.80	20.50	0.00	**17.60**	**12.00**
>11.4cm	11.60	11.00	5.90	5.40	3.10	4.30	8.60	0.00	**7.30**	**5.18**

Table 3. Weight frequency distribution of *F. notialis*

Range	Station I		Station II		Station III		Station IV		**Mean**	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	**Wet**	**Dry**
<2g	3.30	8.60	8.40	8.60	2.00	1.40	0.00	10.10	**3.43**	**7.18**
2.0-3.99g	32.70	36.30	37.90	27.50	27.00	23.20	5.30	56.70	**25.73**	**35.93**
4.0-4.99g	35.50	28.30	25.90	25.40	25.90	26.70	34.60	30.20	**30.48**	**27.65**
5.0-5.99g	28.50	26.90	27.80	38.40	42.00	42.90	60.10	3.10	**39.60**	**27.83**
6.0-7.99g	0.00	0.00	0.00	0.00	3.20	5.70	0.00	0.00	**0.80**	**1.43**

Heavy metal concentration in Abdomen and Cephalothorax of *F. notialis*

The concentration of heavy metals (Figure 1) shows that the mean concentration of Cd in the abdomen and cephalothorax was 0.001±0.00mg/kg in both wet and dry seasons, and that the concentration of Cd in the abdomen was not significantly different from the concentrations recorded in the cephalothorax while the concentration of Pb in the abdomen and cephalothorax in the wet season was 0.020±0.004mg/kg and 0.016±0.006mg/kg respectively while in the dry season, it was 0.019±0.004mg/kg and 0.018±0.003mg/kg respectively. This demonstrates that in both seasons, the Pb concentration in the abdomen was considerably greater (P<0.05) than the concentrations in the cephalothorax, and there was no seasonal fluctuation (P>0.05) in the Pb concentrations in the abdomen and cephalothorax.

Similarly, Figure 2 showed that the concentration of Cu in the abdomen and cephalothorax was 1.931±0.487mg/kg and 1.774±0.329mg/kg and

Table 4. Size, Length/Weight Relationship (*b*) and Condition Factor (K) of *F. notialis*

Season	Station	n	Length (cm)	Weight (g)	Equation	R^2	K
Wet	Station I	352	9.71±1.36	4.33±1.09	$LogW = -2.73 + 1.84LogL$	0.85	0.47
	Station II	370	9.22±1.48	4.10±1.24	$LogW = -3.13 + 2.03LogL$	0.91	0.52
	Station III	352	9.61±0.97	4.75±1.20	$LogW = -4.22 + 2.54LogL$	0.81	0.53
	Station IV	361	9.13±1.20	4.33±1.13	$LogW = -2.80 + 1.92LogL$	0.70	0.57
	Mean	**1435**	**9.41±1.29**	**4.37±1.19**	$\boldsymbol{LogW = -3.03 + 2.00LogL}$	**0.80**	**0.52**
Dry	Station I	346	9.53±1.56	4.19±1.14	$LogW = -2.26 + 1.63LogL$	0.87	0.48
	Station II	361	9.29±1.43	4.42±1.12	$LogW = -2.04 + 1.57LogL$	0.73	0.55
	Station III	348	9.57±0.99	4.97±1.16	$LogW = -2.92 + 1.99LogL$	0.73	0.57
	Station IV	358	9.35±1.54	4.39±1.13	$LogW = -1.97 + 1.53LogL$	0.64	0.54
	Mean	**1413**	**9.43±1.40**	**4.49±1.17**	$\boldsymbol{LogW = -2.20 + 1.64LogL}$	**0.71**	**0.54**

n= number of individuals; R^2 = Regression Coefficient; K= Condition Factor.

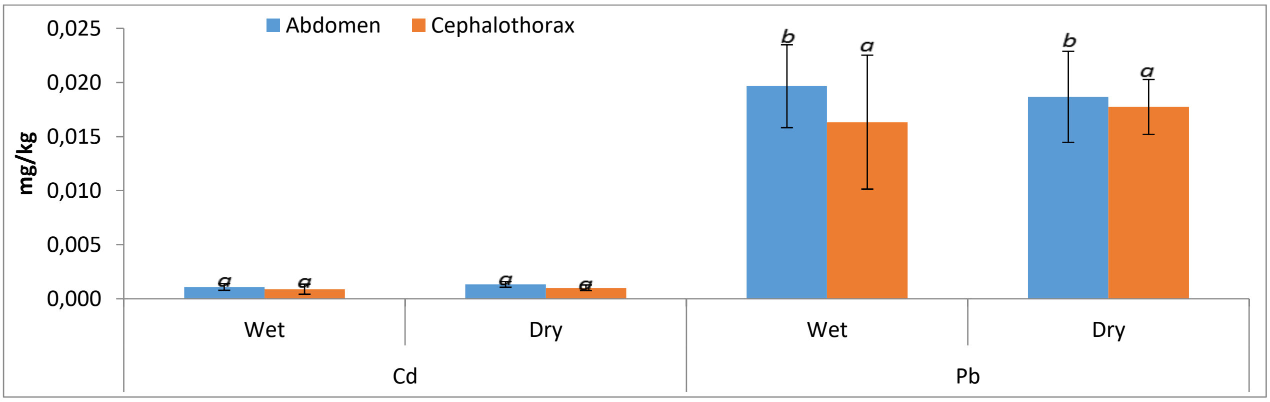

Figure 1. Concentration of Cd and Pb in Abdomen and Cephalothorax of *F. notialis.*

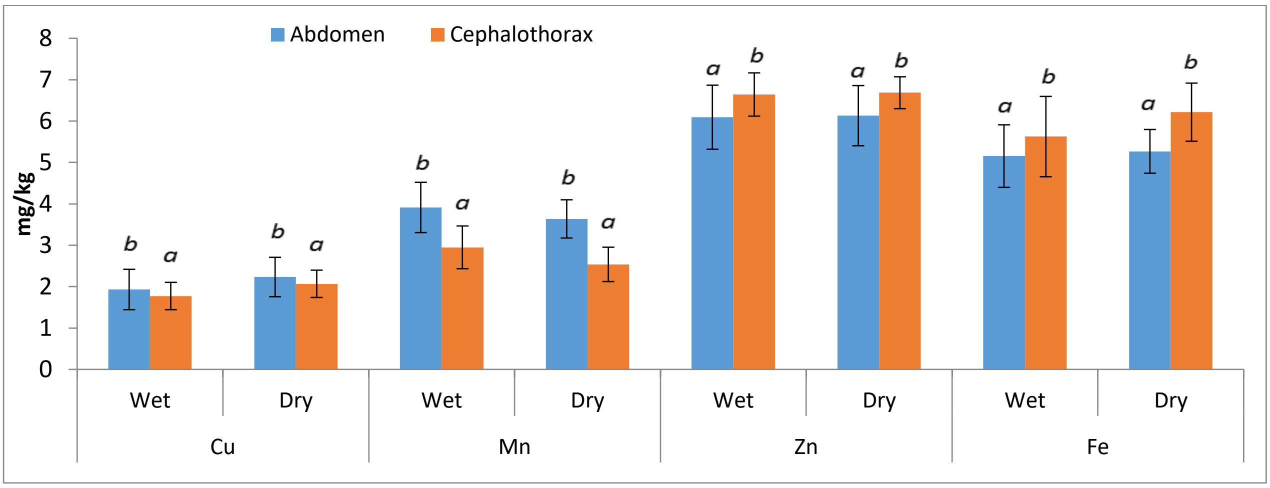

Figure 2. Concentration of Cu, Mn, Zn and Fe in Abdomen and Cephalothorax of *F. notialis.*

2.233±0.476mg/kg and 2.068±0.329mg/kg in wet and dry seasons respectively. Also, the concentration of Mn in the abdomen and cephalothorax was 3.913±0.607mg/kg and 2.950±0.516mg/kg in the wet season and 3.637±0.462mg/kg and 2.538±0.415mg/kg in the dry season respectively. This revealed that the concentration of Cu and Mn in the abdomen was significantly higher than the concentration recorded in the cephalothorax in both seasons.

The concentration of Zn in the abdomen and cephalothorax was 6.094±0.774mg/kg and 6.643±0.522mg/kg respectively (in the wet season), while it was 6.132±0.727mg/kg and 6.686±0.385mg/kg respectively (in the dry season). Also, in the wet season, the mean concentration of Fe in the abdomen and cephalothorax was 5.154±0.756mg/kg and 5.626±0.970mg/kg respectively while it was 5.269±0.528mg/kg and 6.215±0.702mg/kg respectively in the dry season. This showed that the concentrations of Zn and Fe in the abdomen were significantly lower than the concentrations observed in the cephalothorax. However, there was no seasonal variation in the concentrations of all examined minerals.

The correlation coefficient (R) and the significance levels (P) for the relationships between heavy metals, condition factor (K), length (TL) and weight (TW) of *F. notialis* examined in this study is presented in Table 5 which revealed that TL (0.34), Pb in Abdomen (0.42), and Mn in Abdomen (-0.40) had significant relationship ($P<0.05$) with the condition factor of the shrimp while Pb in Cephalothorax had significant correlation (0.21) with TW whereas TW had a strong, positive and significant correlation (0.89) with TL in the wet season. The Table further showed that the concentration of Pb in Abdomen was the only mineral that had significant correlation (-0.30) with condition factor in the dry season. Furthermore, Mn in Abdomen and Cephalothorax had negative correlation with TL and TW in wet season while Fe in Abdomen and Cephalothorax had negative correlation with TL in the wet season. Also, Cd, Pb and Mn in the cephalothorax had negative correlation with TL and TW in the dry season while Fe in Abdomen had negative correlation with TW in the dry season.

The regression of condition factor (K) and concentration of heavy metals in the wet and dry seasons is presented in Table 6 which showed that Pb in Abdomen (b=0.32, R^2=0.18), Mn in Abdomen (b=-0.30, R^2=0.17) and Zn in Cephalothorax (b=-0.39, R^2=0.07) had significant relationship ($P<0.05$) with the condition

Table 5. Correlation Coefficient (R) and Significance Level (P) for the relationships between Size, Heavy Metals and Condition Factor of *F. notialis* in the Coastal waters of Ondo State

	WET SEASON			DRY SEASON		
Parameter	*K*	*TL*	*TW*	*K*	*TL*	*TW*
Condition Factor (K)	1.00			1.00		
Total Length (TL)	0.34*	1.00		-0.10	1.00	
Total Weight (TW)	0.26	0.89*	1.00	-0.01	0.82*	1.00
Cd in Abdomen	-0.23	0.03	0.14	0.03	0.13	0.10
Cd in Cephalothorax	0.02	0.10	0.09	-0.24	-0.06	-0.07
Pb in Abdomen	0.42*	0.10	0.11	-0.30*	0.08	0.04
Pb in Cephalothorax	0.16	0.15	0.21*	0.12	-0.03	-0.02
Mn in Abdomen	-0.40*	-0.13	-0.16	0.18	0.10	0.02
Mn in Cephalothorax	0.10	-0.01	-0.11	0.10	-0.06	-0.16
Cu in Abdomen	-0.01	0.04	0.14	-0.16	0.10	0.08
Cu in Cephalothorax	-0.09	0.07	0.08	0.06	0.10	0.08
Zn in Abdomen	-0.17	0.03	0.05	0.26	0.11	0.04
Zn in Cephalothorax	-0.24	0.01	0.04	-0.08	0.16	0.10
Fe in Abdomen	-0.02	-0.04	0.03	0.03	0.02	-0.07
Fe in Cephalothorax	-0.10	-0.04	0.07	-0.06	0.02	0.02

Values with asterisk '*' are significantly correlated at $P<0.05$

Table 6. Regression of Condition Factor (K) and Heavy Metals in *F. notialis* in the Wet and Dry Seasons

	Wet Season					Dry Season				
Parameter	a	b	R	R^2	P	a	b	R	R^2	P
Cd in Abdomen	-1.38	-0.11	0.24	0.06	0.10	-0.51	0.02	0.03	0.00	0.85
Cd in Cephalothorax	-0.48	0.02	0.08	0.01	0.60	-1.56	-0.14	0.26	0.07	0.07
Pb in Abdomen	0.60	0.32*	0.42	0.18	0.00	-1.12	-0.12*	0.35	0.12	0.02
Pb in Cephalothorax	-0.75	-0.02	0.16	0.03	0.28	-0.22	0.10	0.09	0.01	0.53
Mn in Abdomen	-0.23	-0.30*	0.41	0.17	0.00	-0.86	0.18	0.17	0.03	0.26
Mn in Cephalothorax	-0.72	0.07	0.10	0.01	0.50	-0.76	0.14	0.12	0.02	0.40
Cu in Abdomen	-0.65	-0.01	0.02	0.00	0.91	-0.53	-0.12	0.19	0.04	0.21
Cu in Cephalothorax	-0.61	-0.07	0.10	0.01	0.49	-0.64	0.02	0.02	0.00	0.88
Zn in Abdomen	-0.31	-0.19	0.19	0.04	0.19	-1.34	0.38	0.25	0.06	0.08
Zn in Cephalothorax	0.09	-0.39*	0.26	0.07	0.03	-0.28	-0.18	0.08	0.01	0.59
Fe in Abdomen	-0.62	-0.02	0.01	0.00	0.95	-0.78	0.10	0.07	0.01	0.65
Fe in Cephalothorax	-0.44	0.12	0.11	0.01	0.44	-0.39	-0.12	0.08	0.01	0.57

Parameters with asterisk '*' are significantly related with Condition Factor (K) at $P<0.05$

factor in the wet season, while the concentration of Pb in Abdomen was the only mineral with significant relationship (b=-0.12, R^2=0.12) with condition factor in the dry season. The Table further shows that Cd in Abdomen (-0.11), Pb in cephalothorax (-0.02), Mn in Abdomen (-0.30), and Cu in Abdomen (-0.01) and Cephalothorax (-0.07), Zn in Abdomen (-0.19) and Cephalothorax (-0.39) and Fe in Abdomen (-0.02) had negative relationship with condition factor of the shrimps in the wet season while Cd in Cephalothorax (-0.14), Pb in Abdomen (-0.12), Cu in Abdomen (-0.12) Zn in Cephalothorax (-0.18) and Fe in Cephalothorax (-0.12) had negative relationship with condition factor of the shrimps in the dry season.

Discussion

The sizes of shrimps recorded in both seasons falls within the range 4.0-13.5cm recommended by Food and Agricultural Organization (FAO, 2007), Lawal-Are & Akinjogunla, (2012) and Olawusi-Peters et al., (2014a) for *F. notialis* in coastal/brackish waters. The constancy in length and weight suggests a consistent habitat that provides a consistent environment for the shrimps. However, the slight variation observed across the stations may be due to variability of the sampling size, length interval within different areas, food availability, habitat suitability, sex and maturity (El-Batrawy et al., 2018; Ajibare et al., 2022; Nieto-Navarro, 2010; Olawusi-Peters et al., 2014a). The length-weight relationship (*b*) obtained in this study (2.00 and 1.64 in wet and dry seasons respectively) was less than three (3) implying that the shrimps exhibited negative allometric growth. This means that *F. notialis* did not increase in weight as it increased in length. This is similar to the observations of Lawal-Are & Akinjogunla, (2012); Olawusi-Peters et al., (2014a); Oluboba, (2015) in Lagos lagoon and coastal waters of Ondo state. Yakubu and Ansa, (2007) however observed positive allometry for *F. notialis* in Buguma Creek and this could be attributed to differences in locality and season (Lawal-Are & Owolabi, 2012).

Also the differential length and weight frequency implies that *F. notialis* has heterogenous groups in the waterbody. Moreover, higher variations in the proportionality constant (*a*) than in the exponents (*b*) in all length and weight group of this study echoes Ajibare et al., (2017) that values of (*a*) vary with environmental factors, while *'b'* (which represents the body form) remains constant during a particular life phase. The Condition Factor of *F. notialis* in this study corroborates the view of Olawusi-Peters & Aguda, (2015) that allometric fishes usually have 'K' of less than one (K<1). It is also within the values recorded by Oluboba, (2015) for both sexes of *F. notialis* from Lagos lagoon, Nigeria. Although this low Condition factor may be due to environmental factors as earlier reported by Ajibare et al., (2017) that condition factor of fish is influenced by several environmental conditions and seasons. Moreover, reduced or low condition factor indicates unfavourable ecological conditions or stress from low food availability or reproduction. Other school of thought like Abowei, (2009); Lawal-Are & Owolabi, (2012); George et al., (2013); Ajibare (2024) opined that the 'K' of fish are influenced by stomach fullness, length-weight relationship, sampling size, data pulling, sorting into classes, decrease in water volume, feeding activities, sex difference, gonad maturity level as well as habitat suitability.

The shrimps contained all of the heavy metals that were tested. The metal bioaccumulation in the shrimps was in the sequence Zn > Fe > Mn > Cu > Pb > Cd, which was comparable to the trend described in *M. macrobrachion* and *M. vollenhovenii* by Adedeji & Okocha (2011). Also, the concentration of Zn, Cu, Pb and Cd found in this study were low in comparison to the maximum limit in fish/shrimps recommended by World Health Organisation, (2003), Federal Environmental Protection Agency, (2003) & FAO, (2007). The observed concentrations of minerals were also low when compared to the observations of Adedeji & Okocha, (2011), Jimoh et al., (2011); Edward et al., (2013) for organisms in Epe Lagoon, Asejire reservoir and Odo Ayo river respectively.

However, the Mn and Fe concentrations in the shrimps' abdomen and cephalothorax exceeded the 0.5mg/kg stated by FEPA, (2003) and WHO, (2003), but were lower than the concentrations found in prawns and shrimps obtained from Nigeria (Epe lagoon and Asejire River) and India (Kolaba market of Mumbai) by Adedeji & Okocha, (2011) and Zodape, (2014), respectively. As previously stated by Adegbole et al., (2021) and Olawusi-Peters et al., (2014b & 2017), the high amount of Mn and Fe in water may well be attributable to human activities such as washing, swimming, bathing, transportation, agriculture, and waste disposal, which continuously increase the amount of heavy metals in water.

In both seasons, Pb, Cu, and Mn concentrations were higher in the abdomen than the cephalothorax, while Zn and Fe concentrations in the cephalothorax were higher than the corresponding abdomen. This is similar to the findings of Khalil & Faragallah (2008), who found higher concentrations in the gill and theorized that metals can become reabsorbed onto to the gills surface, which is the first contact point. Although the concentration of heavy metals as observed in this study did not exhibit seasonal variation, the result of the correlation and regression analyses revealed that Pb in abdomen was the only element that had significant relationship with condition Factor/well-being of the shrimps in both seasons. This showed that the bio-accumulation of Pb in the abdomen of *F. notialis* is not seasonally induced and that Pb has the most significant effect on the condition factor of the shrimp. The accumulation of Mn in the abdomen and Zn in the cephalothorax only had significant effect on the condition factor of shrimps in the wet season.

This supports the findings of Olawusi-Peters et al., (2014b), who found that fertilizers contain relatively high amounts of Mn and Zn, which may eventually build in agricultural soils and be released to the aquatic environment via run-offs, especially during the rainy season. In most cases, there were positive relationships between shrimp sizes (TL and TW) and concentration of metals while negative relationships were found in the concentrations of Mn in Abdomen and Cephalothorax, Fe in Abdomen and Cephalothorax in wet season and Cd, Pb and Mn in Cephalothorax in the dry season. These corroborate several studies that have determined the association of size (weight, length, age, etc.) and metal concentration (FilipovićMarijić & Raspor, 2006). Pierron et al., (2007) reported that fish tissues tend to accumulate more minerals with increase in sizes and ages. Metals in *Lethrinus lentjan* exhibited positive correlation with size (Al-Yousuf et al., 2000). Olawusi-Peters and Adejugbagbe, (2020) also observed that *Branchiostoma belcheri* had a positive correlation between Cd and Size (length and weight). Metal concentration in *F. notialis* were positively correlated with size (TL and TW) and Condition Factor (K), which indicates that the increased concentration of essential metals in the shrimps reflects increased size and condition factor.

Increase in condition factor with metal exposure (positive correlation) can be explained by the stimulation of detoxification mechanisms which prevented metabolic reactions to be effected by heavy metals (Pierron et al., 2007). El-Batrawy et al. (2018), however, argued that some metal concentrations do not increase with size/age due to homeostatic control. Thus, the positive correlation between some metals and shrimps' size in this study can be linked to loss of homeostatic capacity of *F. notialis* leading to bioaccumulation under chronic metal exposure. The negative correlation that exist between Cd, Mn, Cu, Zn, Fe (in Abdomen), Cu, Zn, Fe (in Cephalothorax) and the condition Factor shows that the concentration of the minerals in the tissue of the shrimps reduced the well-being of the shrimps. The decrease in condition factor under the effect of heavy metals (negative correlation) might be a result of reduced appetite or The negative association between the metals and the condition factor, according to Ajibare et al., (2022), is a sign of tissue lipid depletion. excessive utilization of reserved energy (Pierron et al., 2007; Josephine, 2022). However, the non-significant positive correlation indicates that the minerals may either improve or not have effect(s) on the condition factor of the shrimps. This may be due to the low concentration observed in this study or to the contributions of essential minerals (such as Zn, Fe, Mn etc.) on the health of the shrimps (Zodape, 2014). This study therefore recommends that further laboratory studies be done to determine the effect of these metals on other aspects of the shrimp's biology.

Conclusion

This study concludes that abdomen bioaccumulated more Pb, Cu and Mn than cephalothorax while Zn and Fe were higher in the cephalothorax than the abdomen even though the metal concentrations did not exhibit seasonal variation. Moreover, Pb was the most significantly bio-accumulated mineral in the shrimp as it significantly affected the condition factor of the shrimps throughout the study period. This study also suggests that Cd, Mn, Cu, Zn and Fe will also influence the size and condition factor negatively at concentrations above the permissible limits. Hence, anthropogenic activities are to be regulated in the environment.

Ethical Statement

Not applicable.

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Author Contribution

All of the authors worked together to complete this project. The study was created by AOA. The protocol was written by AOA and POO. The statistical analysis was carried out by AOA. The study's analyses and literature searches were handled by all of the writers. The original draft of the manuscript was written by AOA and OOO. The final manuscript was read and approved by all writers.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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