

# Trace Elements in Mollusks, Crustaceans and Fish Commonly Consumed by the Catfish *Chrysichthys nigrodigitatus* Lacépède, 1803 from the Lake Togo-Lagoon of Aného Hydrosystem (Southern Togo)

Kamilou Ouro-Sama<sup>1\*</sup> , Komlan Mawuli Afiademanyo<sup>2</sup>, Hodabalo Dheoulaba Solitoke<sup>1</sup>, Gnon Tanouayi<sup>1</sup>, Tchaa Ezzo-Essinam Badassan<sup>1</sup>, Koudjo Adje<sup>1</sup>, Sadikou Agbere<sup>1</sup>, Kissao Gnandi<sup>1</sup>

<sup>1</sup>Laboratoire de Gestion, Traitement et Valorisation des Déchets, Département de Géologie et Environnement, Faculté des Sciences, Université de Lomé, Lomé, Togo

<sup>2</sup>Laboratoire d'Ecologie Animale et d'Ecotoxicologie, Département de Zoologie et Biologie Animale, Faculté des Sciences, Université de Lomé, Lomé, Togo

Email: \*ouro\_kamilou@yahoo.fr

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## Abstract

The omnivorous fish species, *C. nigrodigitatus* feeds mainly on benthic organisms and may therefore consume contaminated food throughout its food web. This can lead to the bioaccumulation of contaminants such as trace elements in their tissues. However, fish consumption is a major pathway of human exposure to contaminants which may cause public health problems. The aim of the present study is to assess trace elements contamination in some species from the food web of *C. nigrodigitatus*. For this, 10 main food items of the silver catfish were collected at two sites from February to July 2017 and analyzed using an Atomic Absorption Spectrometer coupled with a hydride and cold vapour generator. The concentrations of trace elements varied greatly from one species to another and within each species. These values ranged from 0.007 mg/kg for Hg in *C. hippos* to 354.84 mg/kg for Mn in *P. fusca*. The most contaminated species by trace elements were benthic organisms: *M. perna* (Cd, Pb, Hg), *Pagurus* sp. (Cr, Ni, Cu, Zn), *G. paradoxa* (As) and *P. fusca* (Mn). The average concentrations of trace elements found in species were, for the most part, above WHO standards except Hg in *M. perna* and *G. paradoxa*. The water-based bioconcentration factors (BCF<sub>w</sub>) reach 92.58 for Cd, 44.72 for Pb, 382.49 for Hg and 1514.34 for As in *M. perna*. It is therefore necessary to pay particular attention to this ecosystem and to put in place a better management plan.

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## Keywords

*C. nigrodigitatus* Preys, Trace Elements, Contamination, Lake Togo, Aného Lagoon

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## 1. Introduction

Most parts of terrestrial and aquatic ecosystems are now affected in one way or another by anthropogenic activities such as the rapid industrialization and demographic pressure during the last decades which lead to continental and aquatic ecosystems contamination by trace elements. Indeed, in aquatic environments, significant amounts of trace elements are introduced by industries, mining, fossil fuel combustion, run-off from agricultural lands, house hold sewages, atmospheric deposition and rocks weathering. These metals pose high environmental risks due to their longtime persistence in nature and possible bioaccumulation and biomagnification [1]-[6]. These inputs have greatly altered the biogeochemical cycles of trace metals and enhanced their bioavailability [7]. Consequently, it follows permanent disturbances in aquatic ecosystems leading to environmental and ecological degradation and which constitute a potential risk to a number of flora and fauna species, including human through food web [8] [9].

Aquatic organisms have been reported to contain higher concentrations of trace element in their tissues compared to the levels in the surrounding environment [10] [11]. Coastal aquatic ecosystems are of considerable ecological and socio-economic importance [12]. They are the habitats and nurseries for many larval and juvenile stages of fish species [13] [14]. Thus, trace element contamination of these ecosystems includes that of the fish food web species presenting a serious public health issue because these fish are finally consumed by humans.

The Silver Catfish *C. nigrodigitatus* from the Lake Togo-Lagoon of Aného hydrosystem is highly appreciated as protein source by local populations and contributes to their socio-economic well-being [15] [16]. It is well established that this hydrosystem and its basin includes the most contaminated coastal areas in Togo. Several workers reported the presence of harmful pollutants in waters, soils, sediments, biota and vegetables from the basin mainly due to phosphorites mining in the region [1] [4] [5] [17] [18] [19] [20] [21]. The Silver catfish which is known to be omnivorous feeding mainly on benthic organisms may therefore consume contaminated food throughout its food web. This can lead to the bioaccumulation of contaminants such as trace elements in its tissues. Knowing that fish consumption is the major pathway of human exposure to contaminants [22], human health may be highly threatened. The aim of the present study is to assess trace element contamination levels in some species from the food items of *C. nigrodigitatus*.

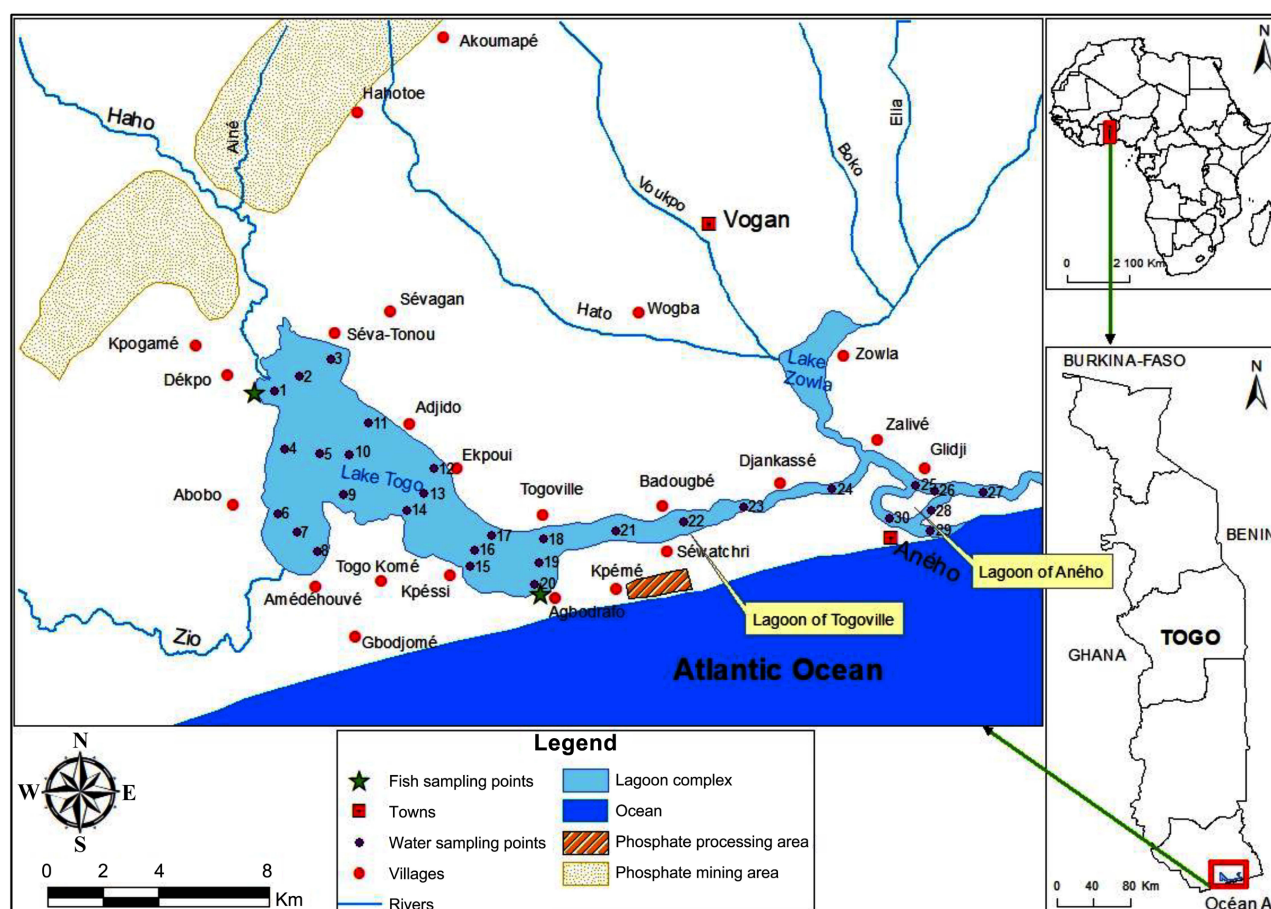
## 2. Materials and Methods

### 2.1. Study Area

The study area is represented by the Lake Togo-Lagoon of Aného hydrosystem (**Figure 1**). It is a continuous body of water along the Togolese coast between the phosphorite mining area in the North and the phosphorite processing plant on the beach in the south. It is located between the North latitudes ( $6^{\circ}17'37''$ ;  $6^{\circ}14'38''$ ) and the East longitudes ( $1^{\circ}23'33''$ ;  $1^{\circ}37'38''$ ) and is composed of three lagoons: Lake Togo (46 km<sup>2</sup>), between the village of Dékpo in the North and Agbodrafo in the South, is 13 km long in its largest diagonal (NW-SE) and 6 km in its smaller diagonal (NE-SW), the Togoville lagoon (13 km long and 150 to 900 m wide) which is parallel to the coast between the villages of Togoville and Zalivé and the Aného lagoon which is a network of narrow channels from Zalivé to its mouth at Aného [23].

### 2.2. Sampling and Laboratory Analysis

Based on the work of Ouro-Sama *et al.* [24], the main species composing the diet of *C. nigrodigitatus* in the Lake Togo-Lagoon of Aného hydrosystem were collected from two sites during the months of February to July 2017 in collaboration



**Figure 1.** Location map of the study area and sampling points.

with fishermen from the lagoon complex [25]. The samples were wrapped in batches of species in sterile polyethylene bags and placed in coolers in the presence of a refrigerating equipment and then transported to the laboratory where they were stored at  $-20^{\circ}\text{C}$  [26]. Due to their small size, five batches of composite samples of 4 to 10 individuals for each species were carried out according to Pascal *et al.* [27] (the smallest making at least 75% of the largest). After identification, the samples were dried at  $65^{\circ}\text{C}$  in an oven, finely ground in an agate mortar. The grinding equipment has always been cleaned before and after each sample. These samples were then digested using a mixture of reagents composed of 30% hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and 67% nitric acid ( $\text{HNO}_3$ ) in the proportions of 1  $\text{H}_2\text{O}_2$ : 3  $\text{HNO}_3$  at  $90^{\circ}\text{C}$  on a hot plate [28] [29] [30] [31] [32]. For the determination of mercury, the samples were digested at room temperature for 72 - 96 hours while stirring them regularly in order to allow good attack by the reagents. Simultaneously, the blanks were prepared and processed under the same conditions as the two series of samples. Then, each solution from the digestion was filtered, completed to 20 ml with distilled water and stored at room temperature. Trace elements were determined in these solutions, by atomic absorption spectrometer (AAS) with flame (Thermo Electron S. Series type), for Cd, Pb, Cr, Ni, Cu, Zn, Mn and by the same AAS coupled to a hydride and cold vapour generator (Thermo Scientific VP100 type), with flame for As and without flame for Hg. The reagents used for this purpose are analytical grade from Sigma-Aldrich for  $\text{H}_2\text{O}_2$  and  $\text{HNO}_3$  and from SCPScience for trace element standards.

### 2.3. Accuracy and Quality Control

The quality of the analytical methods has been verified by internal control. A procedural blank was prepared with the same reagents and the same experimental conditions as the main samples. The blank allowed zeroing the device and was analyzed after each 10 samples batch during the analysis. This allowed to determine possible contaminations and eliminate the quantization errors. The standard solutions prepared for each trace element were also analyzed at regular intervals in order to verify the accuracy of the results. In addition, the repeatability of the results was checked by the analysis of duplicates which were randomly incorporated among the samples.

### 2.4. Bioconcentration Factors of Trace Elements

In order to assess the level of transfer of trace elements from the medium to the organism, bioconcentration factors (BCF) were calculated in relation to both water and sediment. These BCF are expressed according to the following equation [3] [10] [33] [34].

$$\text{BCF} = \frac{C_{\text{tissue}}}{C_{\text{water/sediment}}}$$

where  $C_{\text{tissue}}$  is the concentration of the trace element in the tissue and  $C_{\text{water/sediment}}$  is the concentration of the same trace element in water or sediment.

Trace element concentrations in waters and sediments (**Table 1**) used for the calculations were from simultaneous studies in the same hydrosystem [4] [5].

## 2.5. Statistical Analysis

The analysis of variances (ANOVA) followed by the Newman-Keuls test made it possible to evaluate the interspecies variations in trace element contamination of the prey species of *C. nigrodigitatus* [3] [10] [31]. Principal Component Analysis (PCA) was carried out to assess the typology of trace element contamination [35] [36] [37]. Pearson's correlation analysis demonstrated the links between trace elements [34]. These analyses were performed using the STATISTICA 6.1 software.

## 3. Results

### 3.1. Bioaccumulation of Trace Elements in *C. nigrodigitatus*' Preys

#### 3.1.1. Trace Element Contents in *C. nigrodigitatus*' Preys

**Table 2** indicates that all trace elements are highly concentrated by the species studied except Hg. In addition, it is generally noted that the lowest levels of trace elements were recorded at the level of fish species. Cadmium (Cd) concentrations ranged from 0.04 mg/kg obtained in *Tilapia zillii* to 3.98 mg/kg in *Callinectes amnicola*. The Pb contents of the preys are between 0.02 mg/kg observed in *C. amnicola* and 7.42 mg/kg found in *Mytilus perna*. The lowest Cr content (0.02 mg/kg) is obtained in *T. zillii* while the highest content (5.17 mg/kg) is recorded in *Pagurus* sp. The crustacean species *Farfantepenaeus notialis* has the lowest Ni content (0.27 mg/kg) while the highest is recorded in the hermit crab *Pagurus* sp. with a value of 42.44 mg/kg. As for Cu contents, they vary from 0.25 mg/kg in *T. zillii* to 78.25 mg/kg obtained in *F. notialis*. The Hg contents vary from 0.006 mg/kg recorded in *Caranx hippos* to 0.183 mg/kg in *M. perna*. The As contents vary between 0.18 mg/kg in *T. zillii* and 4.66 mg/kg observed in *Galatea paradoxa*. The species with the lowest Zn content (4.47 mg/kg) was *T. zillii* and the highest Zn content was obtained from *Pagurus* sp. (152.60 mg/kg). Mn concentrations, are between 0.78 mg/kg in *T. zillii* and 494.16 mg/kg in *Pachymelania fusca*. The levels of trace elements in these species are generally above WHO standards for consumption with the exception of Hg concentrations which are above standards only in *G. paradoxa* and *M. perna*.

**Table 1.** Trace elements in waters and sediments from the hydrosystem.

	Cd	Pb	Cr	Ni	Cu	Hg	As	Zn	Mn
<b>Waters (µg/l)</b>									
<b>Dry season</b>	39.28	216.82	197.00	100.06	105.00	0.58	2.97	11.48	38.86
<b>Rainy season</b>	92.30	348.35	396.90	185.40	126.93	0.96	4.86	35.40	67.80
<b>Sediments (mg/kg)</b>									
<b>Dry season</b>	0.75	13.26	50.63	36.05	10.90	0.04	3.88	47.38	766.74
<b>Rainy season</b>	0.46	9.50	27.43	21.36	9.61	0.05	5.23	39.21	910.08

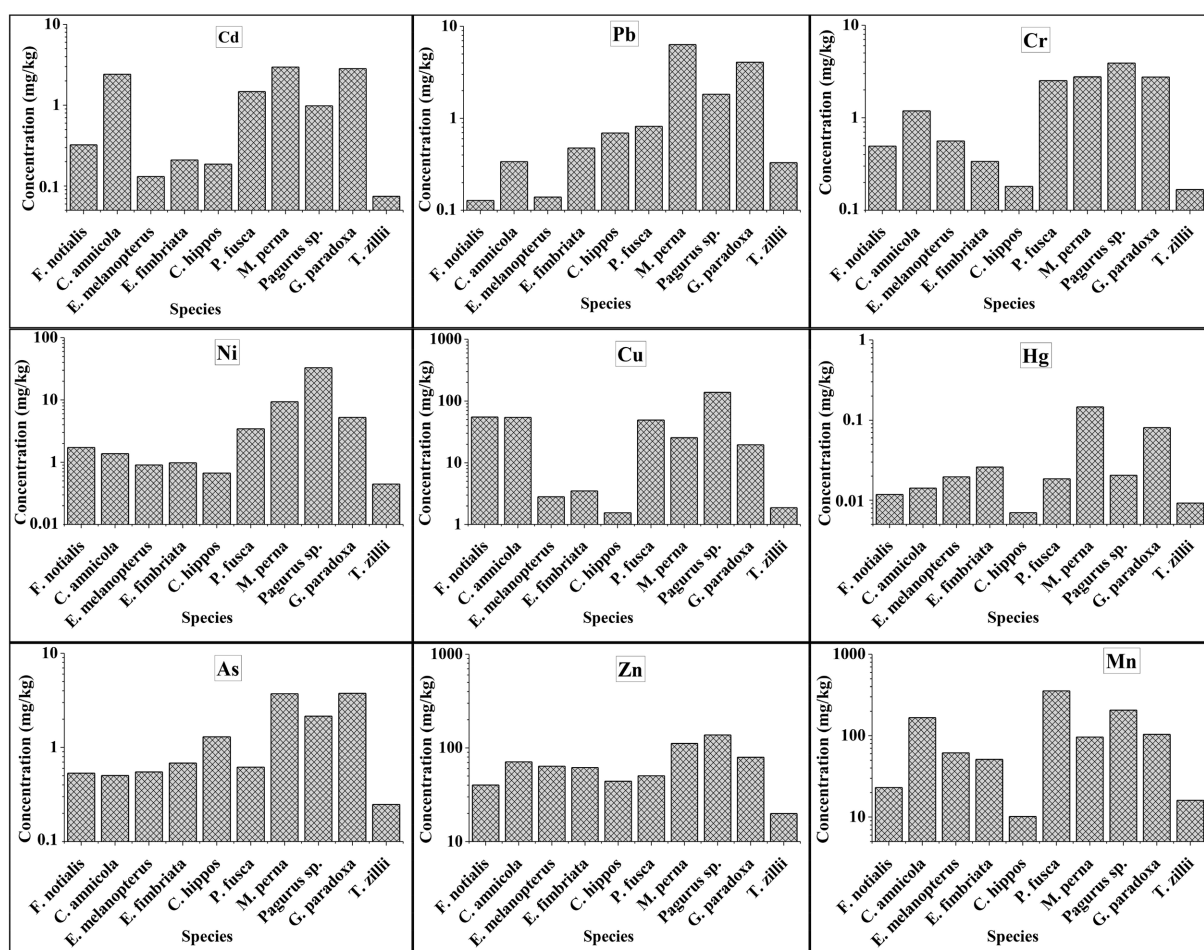
**Table 2.** Statistical values of the trace element contents of *C. nigrodigitatus*' preys.

Species	Concentrations of trace elements (mg/kg)									
	Cd	Pb	Cr	Ni	Cu	Hg	As	Zn	Mn	
<i>F. notialis</i>	0.08 - 0.59	0.04 - 0.18	0.07 - 0.69	0.27 - 5.93	10.54 - 78.25	0.008 - 0.013	0.48 - 0.67	12.01 - 48.05	6.90 - 42.67	
	0.32 ± 0.20	0.13 ± 0.06	0.50 ± 0.24	1.72 ± 2.37	55.05 ± 26.45	0.012 ± 0.002	0.53 ± 0.08	40.14 ± 15.76	23.10 ± 14.72	
<i>C. amnicola</i>	1.84 - 3.98	0.02 - 0.64	0.83 - 1.64	0.86 - 1.69	36.01 - 71.71	0.011 - 0.017	0.44 - 0.55	67.38 - 75.49	119.88 - 189.8	
	2.41 ± 0.90	0.34 ± 0.31	1.19 ± 0.40	1.37 ± 0.34	54.32 ± 13.41	0.014 ± 0.002	0.50 ± 0.05	71.12 ± 3.62	166.24 ± 27.85	
<i>E. melanopterus</i>	0.06 - 0.22	0.06 - 0.22	0.41 - 0.85	0.84 - 0.99	2.45 - 3.28	0.011 - 0.028	0.49 - 0.60	59.35 - 71.71	49.78 - 76.36	
	0.13 ± 0.06	0.14 ± 0.08	0.56 ± 0.17	0.90 ± 0.07	2.81 ± 0.37	0.020 ± 0.006	0.55 ± 0.04	63.92 ± 5.40	61.39 ± 11.43	
<i>E. fimbriata</i>	0.10 - 0.32	0.29 - 0.64	0.05 - 0.65	0.69 - 1.25	1.10 - 5.21	0.023 - 0.028	0.62 - 0.75	56.98 - 72.64	40.95 - 60.79	
	0.21 ± 0.08	0.48 ± 0.15	0.34 ± 0.22	0.98 ± 0.23	3.49 ± 1.77	0.026 ± 0.002	0.68 ± 0.06	61.80 ± 6.46	51.22 ± 8.42	
<i>C. hippos</i>	0.08 - 0.24	0.30 - 1.32	0.09 - 0.27	0.51 - 0.82	0.31 - 2.55	0.006 - 0.008	1.02 - 1.41	8.96 - 64.34	1.57 - 13.35	
	0.19 ± 0.06	0.69 ± 0.40	0.18 ± 0.08	0.67 ± 0.13	1.55 ± 0.93	0.007 ± 0.001	1.30 ± 0.16	44.10 ± 21.25	10.15 ± 4.90	
<i>P. fusca</i>	1.28 - 1.69	0.57 - 1.49	1.43 - 4.56	1.36 - 5.35	45.03 - 51.42	0.013 - 0.029	0.55 - 0.80	46.58 - 54.36	283.3 - 494.16	
	1.47 ± 0.17	0.82 ± 0.39	2.52 ± 1.22	3.43 ± 1.42	49.24 ± 2.68	0.018 ± 0.007	0.62 ± 0.10	50.38 ± 3.32	354.84 ± 84.21	
<i>M. perna</i>	1.58 - 3.72	4.18 - 7.42	1.29 - 4.79	6.48 - 14.43	21.78 - 27.71	0.064 - 0.183	3.50 - 4.01	95.05 - 130.76	69.90 - 119.88	
	2.96 ± 0.92	6.33 ± 1.26	2.77 ± 1.52	9.38 ± 3.21	25.46 ± 2.29	0.146 ± 0.048	3.72 ± 0.21	111.65 ± 14.61	96.29 ± 18.16	
<i>Pagurus sp.</i>	0.64 - 1.27	1.14 - 3.12	3.27 - 5.17	28.23 - 42.44	127.28 - 143	0.014 - 0.024	1.79 - 2.36	127.25 - 152.6	193.2 - 216.46	
	0.98 ± 0.24	1.83 ± 0.75	3.90 ± 0.81	32.82 ± 5.91	137.41 ± 6.18	0.020 ± 0.004	2.15 ± 0.23	137.80 ± 9.95	206.33 ± 9.60	
<i>G. paradoxa</i>	1.87 - 3.75	2.82 - 6.16	1.85 - 3.47	4.04 - 6.27	17.30 - 22.69	0.056 - 0.095	2.96 - 4.66	55.34 - 102.53	61.17 - 150.65	
	2.83 ± 0.84	4.07 ± 1.37	2.76 ± 0.64	5.27 ± 0.82	19.54 ± 2.05	0.081 ± 0.015	3.75 ± 0.75	79.55 ± 16.99	104.18 ± 35.9	
<i>T. zillii</i>	0.04 - 0.12	0.20 - 0.60	0.02 - 0.38	0.30 - 0.73	0.25 - 3.76	0.007 - 0.011	0.18 - 0.33	4.47 - 26.73	0.78 - 24.41	
	0.07 ± 0.03	0.33 ± 0.16	0.17 ± 0.13	0.45 ± 0.15	1.88 ± 1.34	0.009 ± 0.002	0.25 ± 0.06	19.95 ± 8.0	16.09 ± 8.20	
WHO Standard	0.05	0.2	0.5	0.5	0.5	0.05	0.1	30	0.5	

### 3.1.2. Interspecific Variations in Trace Element Concentrations in Fish's Preys

**Figure 2** indicates that the trace element contents are unevenly distributed in the prey species. These interspecific variations in trace element levels are confirmed by analysis of variances (ANOVA) which were found to be significant at the 5% level for all elements (**Table 3**). However, this ANOVA is followed by the Newman-Keuls test which revealed several significant differences between the prey species considered in pairs and allowed them to be classified into homogeneous groups according to their levels of trace element accumulation. Thus, species bearing the same letter indices form a homogeneous group (**Table 3**).

In accordance with the trace element contents, the decreasing order of contamination of the prey species for each trace element is presented as indicated in **Table 4**. It is observed that the lowest levels are found most often in the fish species (*C. hippos* and *T. zillii*) while the highest levels are more recorded in species of Bivalves (*M. perna*) and Crustaceans (*Pagurus sp.*).



**Figure 2.** Interspecific variations in trace element concentration of prey of *C. nigrodigitatus*.

**Table 3.** Analysis of variances (ANOVA) and Newman-Keuls test.

Species	Analysis of variances (ANOVA) followed by Newman-Keuls test								
	Cd	Pb	Cr	Ni	Cu	Hg	As	Zn	Mn
<i>F. notialis</i>	0.32 <sup>a</sup>	0.13 <sup>a</sup>	0.50 <sup>a</sup>	1.72 <sup>a</sup>	55.05 <sup>a</sup>	0.012 <sup>a</sup>	0.53 <sup>a</sup>	40.14 <sup>a</sup>	23.10 <sup>a</sup>
<i>C. amnicola</i>	2.41 <sup>b</sup>	0.34 <sup>a</sup>	1.19 <sup>a</sup>	1.37 <sup>a</sup>	54.32 <sup>a</sup>	0.014 <sup>a</sup>	0.50 <sup>a</sup>	71.12 <sup>bc</sup>	166.24 <sup>b</sup>
<i>E. melanopterus</i>	0.13 <sup>ac</sup>	0.14 <sup>a</sup>	0.56 <sup>a</sup>	0.90 <sup>a</sup>	2.81 <sup>b</sup>	0.020 <sup>a</sup>	0.55 <sup>a</sup>	63.92 <sup>bc</sup>	61.39 <sup>aij</sup>
<i>E. fimbriata</i>	0.21 <sup>a</sup>	0.48 <sup>a</sup>	0.34 <sup>a</sup>	0.98 <sup>a</sup>	3.49 <sup>bc</sup>	0.026 <sup>a</sup>	0.68 <sup>a</sup>	61.80 <sup>bdi</sup>	51.22 <sup>ai</sup>
<i>C. hippos</i>	0.19 <sup>ad</sup>	0.69 <sup>ab</sup>	0.18 <sup>a</sup>	0.67 <sup>a</sup>	1.55 <sup>bd</sup>	0.007 <sup>a</sup>	1.30 <sup>b</sup>	44.10 <sup>acdi</sup>	10.15 <sup>a</sup>
<i>P. fusca</i>	1.47 <sup>e</sup>	0.82 <sup>a</sup>	2.52 <sup>b</sup>	3.43 <sup>ab</sup>	49.24 <sup>a</sup>	0.018 <sup>a</sup>	0.62 <sup>a</sup>	50.38 <sup>acd</sup>	354.84 <sup>c</sup>
<i>M. perna</i>	2.96 <sup>b</sup>	6.33 <sup>c</sup>	2.77 <sup>bc</sup>	9.38 <sup>c</sup>	25.46 <sup>e</sup>	0.146 <sup>b</sup>	3.72 <sup>c</sup>	111.65 <sup>e</sup>	96.29 <sup>dgi</sup>
<i>Pagurus sp.</i>	0.98 <sup>cdf</sup>	1.83 <sup>bd</sup>	3.90 <sup>d</sup>	32.82 <sup>d</sup>	137.41 <sup>f</sup>	0.020 <sup>a</sup>	2.15 <sup>d</sup>	137.80 <sup>f</sup>	206.33 <sup>e</sup>
<i>G. paradoxa</i>	2.83 <sup>b</sup>	4.07 <sup>e</sup>	2.76 <sup>b</sup>	5.27 <sup>be</sup>	19.54 <sup>eg</sup>	0.081 <sup>c</sup>	3.75 <sup>ce</sup>	79.55 <sup>bg</sup>	104.18 <sup>fgi</sup>
<i>T. zillii</i>	0.07 <sup>af</sup>	0.33 <sup>a</sup>	0.17 <sup>a</sup>	0.45 <sup>bf</sup>	1.88 <sup>bh</sup>	0.009 <sup>a</sup>	0.25 <sup>a</sup>	19.95 <sup>h</sup>	16.09 <sup>a</sup>
<b>F Values</b>	27.89	41.56	17.2	94.58	98.4	37.02	130.37	43.97	59.99
<b>p Values</b>	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Values with different letters indicate a significant difference between species' concentrations.

**Table 4.** Decreasing order of prey species contamination for each trace element.

Trace elements	Decreasing order of contamination in prey species
<b>Cd</b>	Mp > Gp > Ca > Pf > Psp > Fn > Ef > Ch > Em > Tz
<b>Pb</b>	Mp > Gp > Psp > Pf > Ch > Ef > Ca > Tz > Em > Fn
<b>Cr</b>	Psp > Mp > Gp > Pf > Ca > Em > Fn > Ef > Ch > Tz
<b>Ni</b>	Psp > Mp > Gp > Pf > Fn > Ca > Ef > Em > Ch > Tz
<b>Cu</b>	Psp > Fn > Ca > Pf > Mp > Gp > Ef > Em > Tz > Ch
<b>Hg</b>	Mp > Gp > Ef > Psp > Em > Pf > Ca > Fn > Tz > Ch
<b>As</b>	Gp > Mp > Psp > Ch > Ef > Pf > Em > Fn > Ca > Tz
<b>Zn</b>	Psp > Mp > Gp > Ca > Em > Ef > Pf > Ch > Fn > Tz
<b>Mn</b>	Pf > Psp > Ca > Gp > Mp > Em > Ef > Fn > Tz > Ch

Fn: *F. notialis*; Ca: *C. amnicola*; Em: *E. melanopterus*; Ef: *E. fimbriata*; Ch: *C. hippos*; Pf: *P. fusca*; Mp: *M. perna*; Psp: *Pagurus sp.*; Gp: *G. paradoxa*; Tz: *T. zillii*.

### 3.1.3. Intraspecific Variations in Trace Elements Concentration in Fish's Preys

**Figure 3** shows that the lowest element accumulated in all species is Hg. Its levels vary from 0.007 mg/kg observed in *C. hippos* to 0.146 mg/kg obtained in *M. perna*. The highest levels of trace elements recorded are those of Cu in *F. notialis*, of Zn in the species *Eucinostomus melanopterus*, *E. fimbriata*, *C. hippos*, *M. perna* and *T. zillii* and of Mn in *C. amnicola*, *P. fusca*, *Pagurus sp.* and *G. paradoxa*. It therefore emerges that there is a variation in the levels of accumulation of trace elements in all the species studied. The order of accumulation of trace elements in each species was therefore established and presented in **Table 5**.

### 3.1.4. Bioconcentration Factors Relative to Water (BCF<sub>w</sub>)

With the exception of Pb in the species *F. notialis* (BCF<sub>w</sub> = 0.90) and *E. melanopterus* (BCF<sub>w</sub> = 0.99), the other bioconcentration factors (BCF<sub>w</sub>) obtained are all greater than 1 and vary from 1, 26 for Cr in *T. zillii* to 12342.19 for Mn in *P. fusca* (**Table 6**). The species which have accumulated more trace elements are those that lead a benthic life in direct contact with the sediments and are sedentary. These are the species *P. fusca*, *M. perna*, *Pagurus sp.*, *G. paradoxa*. The least accumulators are exclusively composed of fish species (*E. melanopterus*, *E. fimbriata*, *C. hippos*, *T. zillii*).

### 3.1.5. Bioconcentration Factors Relative to Sediments (BCF<sub>sed</sub>)

The bioconcentration factors of trace elements relative to sediment (BCF<sub>sed</sub>) are presented in **Table 7**. They vary from 1.02 for Zn in *C. hippos* to 13.40 for Cu in *Pagurus sp.* Zn accumulation was observed in 80% of species with BCF<sub>sed</sub> between 1.02 obtained in *C. hippos* and 3.18 found in *Pagurus sp.* In addition, 60% of the species exhibited Cu BCF<sub>sed</sub> ranging from 2.48 in *M. perna* to 13.40 in *Pagurus sp.* Cd is accumulated by 50% of species with BCF<sub>sed</sub> varying from 1.63 in *Pagurus sp.* to 4.90 obtained in *M. perna*. Hg BCF<sub>sed</sub> greater than 1 were only

found in *M. perna* (BCF<sub>sed</sub> = 3.33) and *G. paradoxa* (BCF<sub>sed</sub> = 1.84). Accumulation of Ni was observed only in *Pagurus* sp. with a BCF<sub>sed</sub> = 1.14.

### 3.2. Correlation Matrix between Trace Elements

Pearson's correlations between trace elements in *C. nigrodigitatus* prey are shown in Table 8. It indicates that all significant correlations between trace elements are positive. Thus, Cd is significantly correlated with Pb, Cr, Hg, As, Zn and Mn. As for Pb, it is significantly correlated with Cr, Hg, As and Zn. In addition,

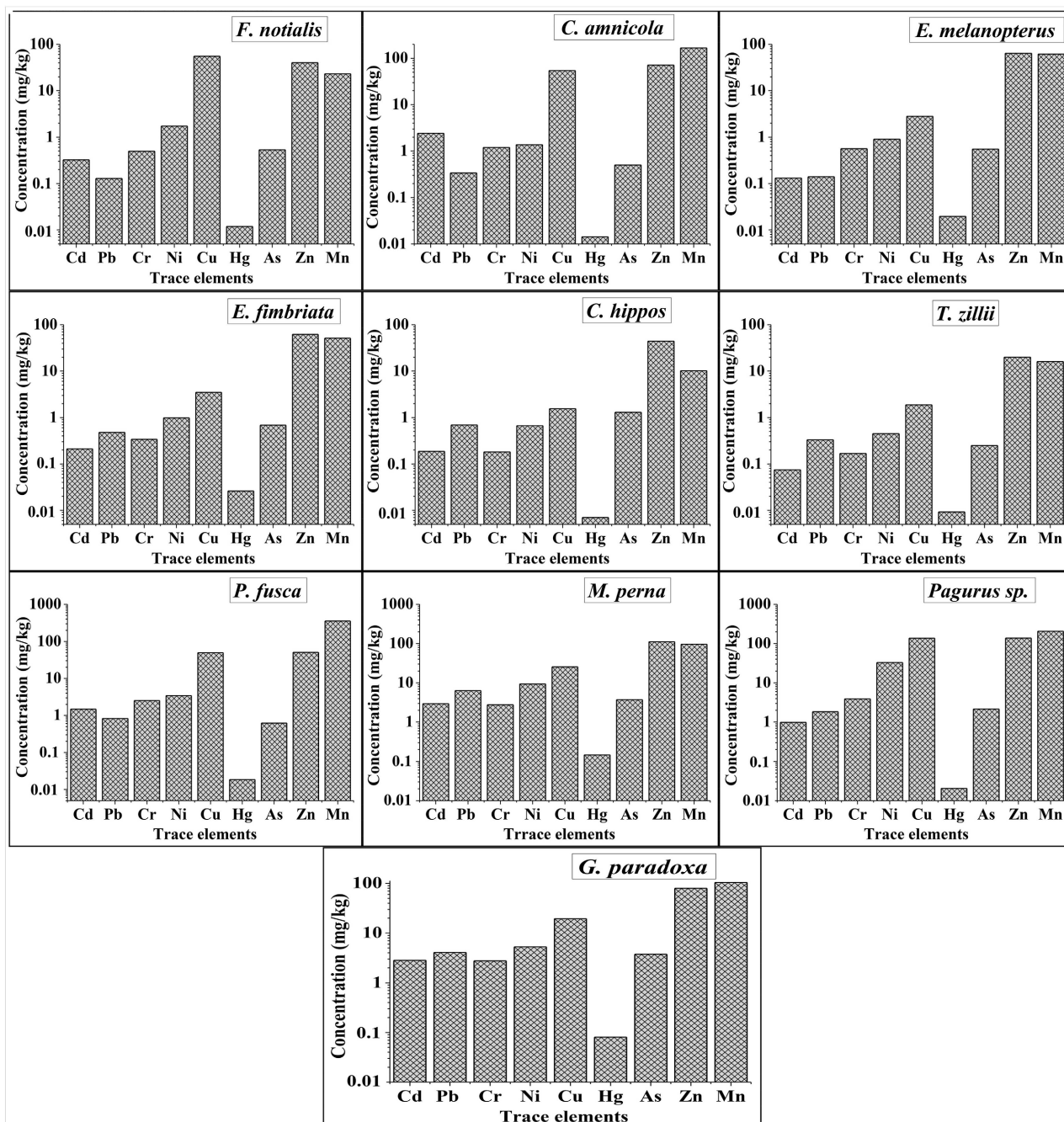


Figure 3. Intraspecific variations in trace element levels in preys of *C. nigrodigitatus*.

**Table 5.** Order of accumulation of trace elements in each prey species.

Species	Descending order of accumulation of trace elements
<i>F. notialis</i>	Cu > Zn > Mn > Ni > As > Cr > Cd > Pb > Hg
<i>C. amnicola</i>	Mn > Zn > Cu > Cd > Ni > Cr > As > Pb > Hg
<i>E. melanopterus</i>	Zn > Mn > Cu > Ni > Cr > As > Pb > Cd > Hg
<i>E. fimbriata</i>	Zn > Mn > Cu > Ni > As > Pb > Cr > Cd > Hg
<i>C. hippos</i>	Zn > Mn > Cu > As > Pb > Ni > Cd > Cr > Hg
<i>P. fusca</i>	Mn > Zn > Cu > Ni > Cr > Cd > Pb > As > Hg
<i>M. perna</i>	Zn > Mn > Cu > Ni > Pb > As > Cd > Cr > Hg
<i>Pagurus sp.</i>	Mn > Zn > Cu > Ni > Cr > As > Pb > Cd > Hg
<i>G. paradoxa</i>	Mn > Zn > Cu > Ni > Pb > As > Cd > Cr > Hg
<i>T. zillii</i>	Zn > Mn > Cu > Ni > Pb > As > Cr > Cd > Hg

**Table 6.** Bioconcentration factors of trace elements relative to water (BCFw).

Species	Bioconcentration factors relative to water (BCFw)								
	Cd	Pb	Cr	Ni	Cu	Hg	As	Zn	Mn
<i>F. notialis</i>	10.13	0.90	3.73	20.66	646.72	30.91	216.13	2044.17	803.53
<i>C. amnicola</i>	75.37	2.39	8.92	16.41	638.18	37.16	204.16	3621.97	5782.26
<i>E. melanopterus</i>	4.09	0.99	4.22	10.84	33.06	51.27	222.68	3255.38	2135.42
<i>E. fimbriata</i>	6.58	3.36	2.54	11.80	41.00	68.18	277.67	3147.45	1781.72
<i>C. hippos</i>	5.83	4.89	1.36	8.01	18.20	18.34	527.99	2245.87	353.07
<i>P. fusca</i>	46.05	5.80	18.97	41.23	578.44	48.36	250.65	2565.61	12342.19
<i>M. perna</i>	92.58	44.72	20.80	112.63	299.06	382.49	1514.34	5686.45	3349.21
<i>Pagurus sp.</i>	30.76	12.89	29.36	394.16	1614.35	53.58	873.40	7017.84	7176.64
<i>G. paradoxa</i>	88.46	28.74	20.74	63.22	229.55	211.37	1524.26	4051.25	3623.69
<i>T. zillii</i>	2.33	2.32	1.26	5.37	22.04	24.09	101.00	1016.17	559.66

**Table 7.** Bioconcentration factors of trace elements relative to sediments (BCFsed).

Species	Bioconcentration factors relative to sediments (BCFsed)								
	Cd	Pb	Cr	Ni	Cu	Hg	As	Zn	Mn
<i>F. notialis.</i>	0.54	0.01	0.01	0.06	<b>5.37</b>	0.27	0.12	0.93	0.03
<i>C. amnicola</i>	<b>3.99</b>	0.03	0.03	0.05	<b>5.30</b>	0.32	0.11	<b>1.64</b>	0.20
<i>E. melanopterus</i>	0.22	0.01	0.01	0.03	0.27	0.45	0.12	<b>1.48</b>	0.07
<i>E. fimbriata</i>	0.35	0.04	0.01	0.03	0.34	0.59	0.15	<b>1.43</b>	0.06
<i>C. hippos</i>	0.31	0.06	0.00	0.02	0.15	0.16	0.29	<b>1.02</b>	0.01
<i>P. fusca</i>	<b>2.44</b>	0.07	0.06	0.12	<b>4.80</b>	0.42	0.14	<b>1.16</b>	0.42
<i>M. perna</i>	<b>4.90</b>	0.56	0.07	0.33	<b>2.48</b>	<b>3.33</b>	0.82	<b>2.58</b>	0.11
<i>Pagurus sp.</i>	<b>1.63</b>	0.16	0.10	<b>1.14</b>	<b>13.40</b>	0.47	0.47	<b>3.18</b>	0.25
<i>G. paradoxa</i>	<b>4.68</b>	0.36	0.07	0.18	<b>1.91</b>	<b>1.84</b>	0.82	<b>1.84</b>	0.12
<i>T. zillii</i>	0.12	0.03	0.00	0.02	0.18	0.21	0.05	0.46	0.02

**Table 8.** Pearson correlation matrix between preys' trace elements.

	Cd	Pb	Cr	Ni	Cu	Hg	As	Zn	Mn
Cd	1								
Pb	<b>0.64<sup>a</sup></b>	1							
Cr	<b>0.59<sup>a</sup></b>	<b>0.53<sup>a</sup></b>	1						
Ni	0.16	0.25	<b>0.69<sup>a</sup></b>	1					
Cu	0.19	0.03	<b>0.58<sup>a</sup></b>	<b>0.81<sup>a</sup></b>	1				
Hg	<b>0.67<sup>a</sup></b>	<b>0.91<sup>a</sup></b>	<b>0.46<sup>b</sup></b>	0.11	-0.10	1			
As	<b>0.63<sup>a</sup></b>	<b>0.88<sup>a</sup></b>	<b>0.61<sup>a</sup></b>	<b>0.42<sup>b</sup></b>	0.13	<b>0.80<sup>a</sup></b>	1		
Zn	<b>0.45<sup>b</sup></b>	<b>0.53<sup>a</sup></b>	<b>0.63<sup>a</sup></b>	<b>0.78<sup>a</sup></b>	<b>0.63<sup>a</sup></b>	<b>0.45<sup>b</sup></b>	<b>0.63<sup>a</sup></b>	1	
Mn	<b>0.37<sup>b</sup></b>	0.06	<b>0.53<sup>a</sup></b>	<b>0.35<sup>c</sup></b>	<b>0.53<sup>a</sup></b>	0.02	0.06	<b>0.33<sup>c</sup></b>	1

Figures in bold show significant correlations with a:  $p < 0.001$ ; b:  $p < 0.01$ ; c:  $p < 0.05$ .

significant correlations were obtained between Cr and other trace elements except Cd and Pb. Significant correlations were recorded between Ni and each of Cu, As, Zn and Mn. Cu shows a good correlation with Zn and Mn. Also, significant correlations were obtained between Hg and the elements As, Zn and between As and Zn.

### 3.3. Principal Components Analysis of Trace Element in *C. nigrodigitatus*' Preys

**Table 9** shows that the first 3 components explain 88.31% of the total variance with F1: 52.95%; F2: 24.97%; F3: 10.39%. However, the two components (F1  $\times$  F2) alone explain 77.92% of the total variance. Thus, this map can explain most of the information contained in the data regarding the distribution of trace elements in the different prey species of *C. nigrodigitatus*.

The component F1 (52.95%) is determined in its negative part by the elements Cd, Pb, Cr, Ni, Hg, As and Zn with correlation coefficients presented in **Table 8**. Component F1 therefore indicates, from right to left, a contamination gradient in trace elements (Cd, Pb, Cr, Ni, Hg, As and Zn). The component F2 (24.97%) is determined in its negative part by the Cu ( $r = -0.77$ ) and the Mn ( $r = -0.51$ ) indicating, from top to bottom, a contamination gradient in Cu and Mn (**Figure 4(a)**).

Four groups of species can be distinguished in **Figure 4(b)**. The first group (G1) is essentially composed of fish (*E. melanopterus*, *E. fimbriata*, *C. hippos* and *T. zillii*) and shrimps (*F. notialis*). This group is characterized by the lowest levels of trace elements with Ni and Cu concentrations obtained in *F. notialis* which are much higher than those recorded in fish. The second group (G2) includes crabs (*C. amnicola*) and gastropods (*P. fusca*) which are characterized by fairly high levels of trace elements. However, the average Ni content of *P. fusca* is higher than that of *C. amnicola*. As for Cu contents, they are rather higher in *C. amnicola* than in *P. fusca*. The third (G3) and fourth (G4) groups have the high-

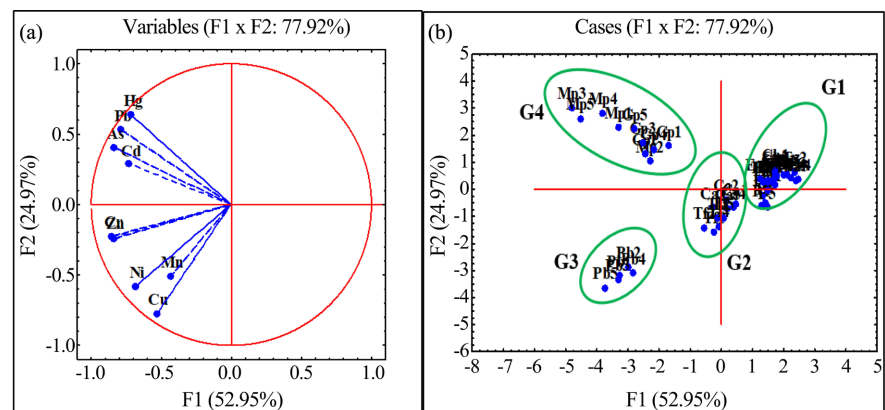
est levels of trace elements. The G3 group is formed from *Pagurus* sp. and presents the highest contents of Cr, Zn, Ni and Cu while group (G4) consists of *M. perna* and *G. paradoxa* characterized by the highest contents of Cd, Pb, Hg and As.

#### 4. Discussion

The preys of *C. nigrodigitatus* in the Lake Togo-Lagoon of Aného hydrosystem are diverse and includes fish, gastropods, crustaceans, bivalves, plants etc. [24]. However, it is known that the accumulation of trace elements in the tissues of aquatic organisms, such as fish, also depends on their feeding behavior [10] [34] [38]. Thus, a few individuals from each taxon were assessed for their metallic contents. In fish species, the average concentrations recorded are higher than the quality standards of fishery products for Cd, Pb, Ni, Cu, As, Zn, Mn with the exception of Zn and Ni in *T. zillii* and Pb at *E. fimbriata* [39] [40] [41] [42] [43].

**Table 9.** Correlation between components and variables.

Variables	Components		
	F1	F2	F3
Cr	<b>-0.86</b>	-0.22	-0.13
Zn	<b>-0.84</b>	-0.24	0.28
As	<b>-0.84</b>	0.40	0.19
Pb	<b>-0.79</b>	0.54	0.07
Cd	<b>-0.73</b>	0.29	-0.45
Hg	<b>-0.71</b>	0.64	-0.02
Ni	<b>-0.69</b>	-0.58	0.38
Cu	-0.53	<b>-0.77</b>	0.07
Mn	-0.44	-0.51	<b>-0.67</b>
Eigenvalues	4.77	2.25	0.93
% Total variance explained	52.95	24.97	10.39
% Cumulated variances	52.95	77.92	88.31



**Figure 4.** Projection of variables (a) and cases (b) in the plan F1 × F2.

However, the average concentrations of Cr and Hg in fish are within quality standards [39] [42] [43]. With regard to shrimps (*F. notialis*) and crabs (*C. amnicola*), their average trace element contents do not meet quality standards with the exception of Hg for both species and Pb and Cr for *F. notialis*.

It appears that all species accumulated high concentrations of trace elements in their tissues with variations depending on the species. Indeed, the highest concentrations of trace elements were recorded in species of sedentary benthic macroinvertebrates such as molluscs and crustaceans *P. fusca*, *Pagurus* sp., *M. perna*, *G. paradoxa* and in another crustacean (*C. amnicola*) while the lowest concentrations were mainly observed in fish species which are more mobile and benthopelagic. This strong accumulation of trace elements in molluscs and crustaceans compared to fish has also been observed by Ali and Fishar [44] in Lake Qarun (Egypte), by Ouro-Sama *et al.* [45] in the Togolese lagoon system and by Zhang *et al.* [34] in marine environment in China. The difference in trace element accumulation between fish and benthic macroinvertebrates was demonstrated by principal component analysis (PCA). This confirms that the accumulation of trace elements varies widely depending on the species, food habits and lifestyle [10] [34]. Thus, these interspecific variations in the accumulation of trace elements may be due to differences in their physiology (absorption, bio-transformation and excretion) and their feeding behavior in the ecosystem. Indeed, in most cases, the concentration of trace elements in organisms depends on the physiological properties and biological functions of the trace elements [46]. Among other things, bivalves are benthic, fixed or free and live buried or on the surface of sediments which are considered as reservoirs of pollutants such as trace elements in aquatic ecosystems [47] [48]. In addition, being microphagous and filterers of large quantities of water, bivalves and certain crustaceans have the capacity to accumulate at high concentrations, numerous trace elements present in their immediate environment, both from water and from the particulate phase [44] [49] [50]. These toxic trace elements can be accumulated in their tissues at high concentrations and without harmful effects [51] [52]. The high accumulation of all trace elements is due to the fact that mollusks have a poor ability to discriminate between elements which are similar in certain characteristics such as the valence of ions [53]. However, these mollusks have effective detoxification mechanisms that reduce the toxicity of the trace elements absorbed despite their high concentrations [44].

The intraspecific variations of the recorded element contents can be explained by the fact that the accumulation of trace elements in the tissues of aquatic organisms depends not only on the species but also on the chemical nature of the element concerned (molecular size, speciation chemical, bioavailability, etc.) and the physicochemical characteristics of the medium (temperature and pH, salinity) [33]. Indeed, whatever the route of entry of pollutants into the body, the intensity of absorption is extremely variable from one pollutant to another. This has been attributed to the characteristics of the membrane barriers in contact

with the external environment (branchial epithelium, digestive wall) and to those of the pollutants themselves [54] [55].

Results also indicate that bioconcentration factors relative to water (BCF<sub>w</sub>) are significantly higher than those relative to sediments (BCF<sub>sed</sub>). It can be inferred that, trace elements accumulated in the tissues of these aquatic organisms come mainly from water. These results corroborate those of other authors who believe that the levels of trace elements in tissues are largely influenced by their concentrations in water [3] [10] [56]. Overall, the BCF values were higher for Cu, Zn As and Mn. These high accumulations may be due to physiological needs since these elements are essential for the unfolding of biological processes [34] [57] [58] [59]. The significant correlations recorded between the trace elements indicate that these elements come from the same source and that their absorption, distributions and accumulations in each individual would respect the same physicochemical and biological processes [3] [60]. The correlations between the different trace elements were confirmed by the results of the PCA thus indicating their common accumulation processes.

Contamination of these species is a threat to their consumers in general and to *C. nigrodigitatus* in particular. Thus, the consumption of these species can contribute to the accumulation of trace elements in their tissues leading to problems of toxicity and survival of the species and a perturbation of the ecological balance [61]. Furthermore, humans at the end of the food chain cannot be spared the toxic effects of these trace elements.

## 5. Conclusion

It emerges from this study that most of the species overall present concentrations higher than the WHO standards for all trace elements with the exception of Hg. Nevertheless, only *M. perna* and *G. paradoxa* recorded levels higher than the standard for Hg. The species most contaminated by trace elements are: *M. perna* (Cd, Pb, Hg), *Pagurus* sp. (Cr, Ni, Cu, Zn), *G. paradoxa* (As) and *P. fusca* (Mn) while the least contaminated are mainly composed of fish species notably *T. zillii* (Cd, Cr, Ni, As, Zn) and *C. hippos* (Cu, Hg and Mn). The concentrations of trace elements varied greatly from species to species and within species. Bioconcentration factors relative to water (BCF<sub>w</sub>) showed that these species strongly accumulated trace elements in their tissues with BCF<sub>w</sub> that reached 92.58 for Cd, 44.72 for Pb, 382.49 for Hg and 1514.34 for As in *M. perna*. This contamination of preferred prey by catfish exposes the species and humans being to contamination by trace elements following its consumption. It is therefore imperative to pay particular attention to this ecosystem and to put in place a better management plan.

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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