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Consumption of the Clam, *Galatea paradoxa* (Born 1778) in Ghana: Human Health Implications with Reference to Heavy Metals

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Abstract This study was carried out over a 7-month period at two active clam fishing locations, Ada and Aveglo at the Volta estuary in Ghana, to assess the levels of some heavy metals: Mn, Zn, Fe and Hg in whole soft tissue of *Galatea paradoxa* and their suitability for human consumption. The clam, *Galatea paradoxa* (Born 1778) is a commercially important bivalve species exploited mainly for its flesh. In Ghana, it constitutes an important and affordable protein source and is consumed by the riparian communities and beyond the Volta estuary. For each sampling location 30 clams were obtained and grouped into three size classes of 10 individuals, each based on shell lengths. The categorization was as follows: small (25–40 mm), medium (41–55 mm), and large (above 55 mm). The groupings were chosen based on the three dominant size groups in the natural population to give a broad and representative range of metal concentrations in the clams. The concentrations of zinc, iron and manganese were determined using a flame Atomic Absorption Spectrophotometer (AAS) and mercury concentrations were determined using an Atomic Mercury Analyzer. The results were expressed as total concentrations (μg/g dry weight (dw)). There were no significant differences ($p > 0.05$) in Mn, Fe and Zn concentrations among the different size classes except for Hg concentration in clams from Ada, indicating a similar bioavailability of Mn, Fe, Zn at both locations and, possibly, an efficient metabolism to keep the concentrations of Mn, Fe and Zn relatively similar in the tissues of the different clam sizes. Spatial variations in metal concentrations (i.e., Ada small vs. Aveglo small, Ada medium vs. Aveglo medium, and Ada large vs. Aveglo large) were not significant for Mn, Zn and Hg for all the size classes. However, variations in Fe concentration in the large-sized clams was significant ($p < 0.05$).

Heavy metal concentrations in the tissues of the clams were found to be suitable for human consumption based on the WHO Safety Reference Standards for Bivalves and a human health risk assessment methodology.

Keywords Freshwater clam · Galatea paradoxa · Heavy metal · Human health implications · Consumption · Volta estuary

Introduction

Bivalves are known to accumulate heavy metals in their tissues at concentrations in excess of the ambient water and sediment levels (El-Shenawy 2002). The accumulation of heavy metals in bivalves has direct consequences to the ecosystem and humans. Symptoms of zinc toxicity in humans are slow reflexes, anaemia, metabolic disorder, teratogenic effects and increased mortality (Klaassen 1996). Zinc has a prominent role in determining the outcome of pregnancies and supporting neurobehavioral development (Hotz et al. 2003). Mercury has caused more problems to consumers of fish than any other inorganic contaminant. In extreme cases, consumption of mercury-tainted fish has led to the onset of a serious neurological disease, termed Minamata disease. Victims of the disease are diagnosed as having a degeneration of their nervous systems. Numbness occurs in their limbs and lips, their speech becomes slurred, and

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their vision constricts (Järup 2003). Some people have serious brain damage, while others lapse into unconsciousness or suffer from involuntary movements. Other symptoms are memory loss, shortfall in attention and Alzheimer's disease (Zahir et al. 2005). In some cases, entire fisheries have been either restricted or significantly curtailed because of mercury contamination (Moore 1991).

Symptoms of the manganese toxicity include dullness, weak muscles, headaches and insomnia. High iron concentrations affect vital organs in humans, including the liver, cardiovascular system and kidneys (Alabaster and Lloyd 1980).

The clam, *Galatea paradoxa* (Born 1778) is a commercially important bivalve species exploited mainly for its flesh and is consumed boiled or fried. It is a filter-feeding organism with a wide distribution extending from the Gulf of Guinea to the Congo (Moses 1990). Limited information about the prevalence and commercial exploitation of this clam is available from only a few countries, including Ghana, Nigeria and Cameroon, despite its extensive distribution in the wider West African region.

In Ghana, the Volta estuary represents the main fishing grounds of *G. paradoxa*. Clam fishing represents a viable source of income and livelihood for the local people. Furthermore, it constitutes an important and affordable protein source to the riparian communities along the Volta estuary and beyond (Amador 1997). On dry matter basis, the average protein content of the smoked clam is 46.5% (Kwei 1965). The shell of the clam has various uses, notably as the main source of calcium in poultry feeds and lime manufacturing industries. One interesting use to which the clam shells have been put in the southern parts of the Volta region is in the construction industry. The shells are used as an alternative to stone chippings in concrete. Additionally, it is used as a pavement material to overcome muddy conditions in village compounds.

Anecdotal information suggests that the Volta basin might be receiving a considerable range of polluting effluents, particularly heavy metals from metal fabrication and agricultural industries along the basin. Many of the agricultural products used on these agricultural lands, especially inorganic fertilizers, contain metals such as manganese and zinc, which eventually accumulate in the soils and become exposed to the estuary and the organisms present in them through run-off during the rainy season. Higher levels of iron and zinc might as well be due to import from the metal fabrication industries sited in the cachement of the estuary and the galvanized iron roofing sheets mostly used by the inhabitants of the estuary, most of which are presently rusty.

This study was, therefore, conducted to investigate the levels of some heavy metals in the soft tissues of the clams at the Volta estuary and to determine the suitability of the clams for human consumption.

The studies on heavy metals were limited to manganese (Mn), zinc (Zn), iron (Fe) and mercury (Hg) because a preliminary study on seven selected metals, including the above-listed ones and copper, lead and cadmium indicated that the concentrations of the excluded metals (copper, lead and cadmium) were in concentrations below the detection limits of the Atomic Absorption Spectrophotometer (AAS) used for the analysis and registered as None Detected (ND).

Materials and Methods

Study Area

The study was carried out in Ada and Aveglo, at the Volta estuary, in Ghana, from March 2008 to September 2008 to coincide with the clam fishing season. Ada, located at Latitude 05°49′18.6″N and 00°38.46′1″E, and Aveglo, 05°53′28.2″N and 00°38′24.7″E, represent the most active clam fishing grounds of the Volta estuary (Fig. 1).

Collection and Processing of Clam Samples

Clam samples were obtained from fishermen's catch from the two sampling stations at monthly intervals for 7 months and transported to the laboratory, submerged in river water, in insulated chests within 12 hours for processing and storage for heavy metal analyses. In the laboratory, clam samples were cleansed to remove the mud and any debris and then washed with double distilled water. For each site, clams of various sizes were obtained and grouped into three size classes of 10 individuals, each based on shell lengths. The categorization was as follows: small (25–40 mm), medium (41–55 mm), and large (above 55 mm). The various clam size classes were purged of ingested organic and inorganic particles before being analyzed for heavy metal accumulation by keeping each size class in distilled water for a 24-hour depuration. After the depuration process, a sterile stainless steel knife was used to dislodge and remove the soft tissue of each clam from the shell (Chiu et al. 2000). The flesh of each subsample was oven-dried to a constant weight at 60°C for 48 hours. Each dry clam sample was weighed on a Sartorius BP 210 S micro balance to the nearest 0.0001 g. Individuals of each size class were ground together into fine powder using a porcelain pestle and mortar. Homogenized subsamples were stored in airtight, acid-washed (0.1 M HCl) snap-top glass vials for heavy-metal analyses (Environmental Agency 2008).

Digestion of the Samples

About 0.5 g of the homogenized clam subsamples were weighed into a 50 ml digestion tube and 1 ml of distilled

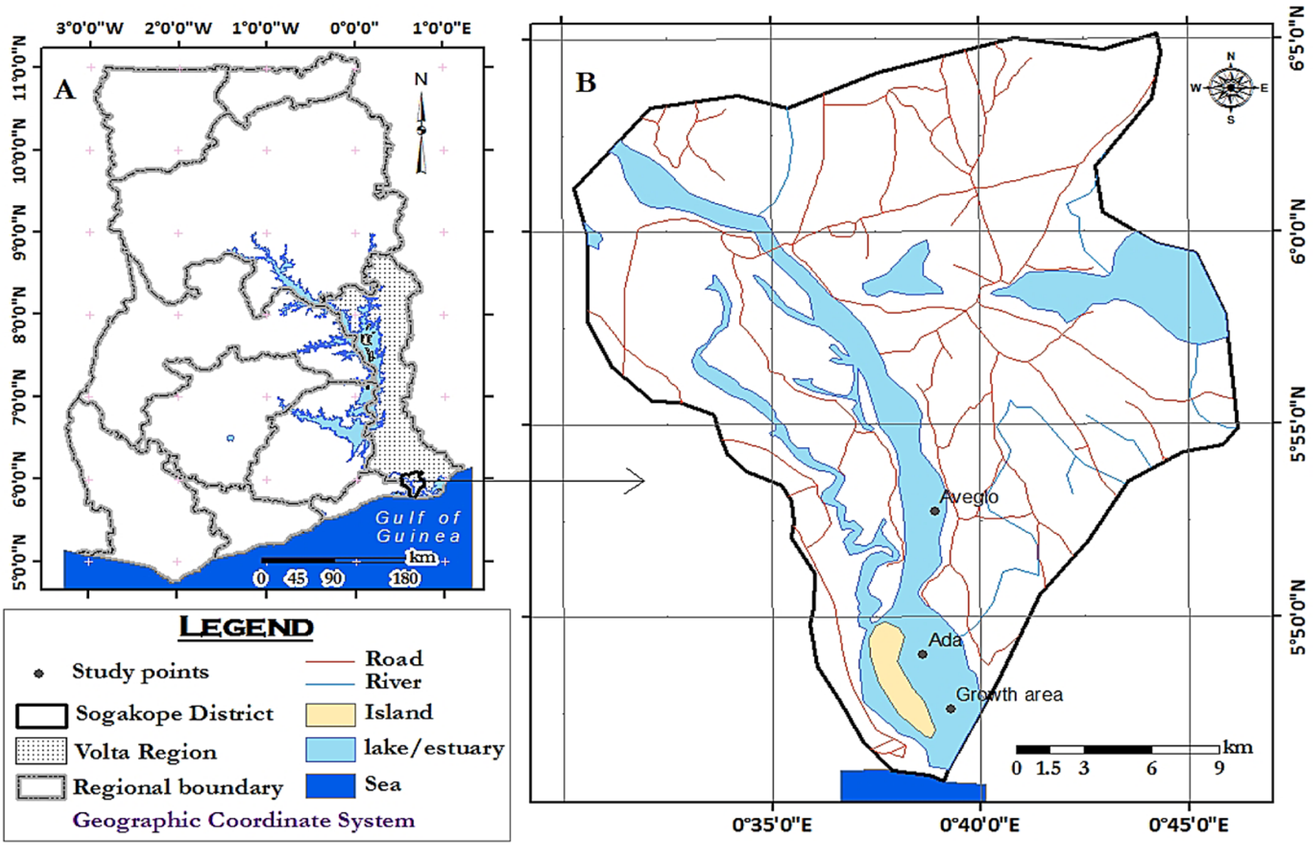


Fig. 1 Map showing the clam sampling locations at Ada and Aveglo in the Volta estuary in Ghana

water, 2.0 ml perchloric acid (HNO_3–$HClO_4$) (1:1 vv) and 5.0 ml sulphuric acid (H_2SO_4) were added. Each mixture was refluxed at 200°C for 30 minutes in a clean fume chamber. The completely digested subsamples were allowed to cool at room temperature, and the undigested portions were filtered off through a Whatmann Glass Microfibre filter paper (GF/C) to obtain a clear solution and diluted to 50 ml in volumetric flasks with double distilled water (Jin et al. 1999; Sastre et al. 2002; Otchere 2003).

Determination of Manganese, Zinc and Iron

Concentrations of manganese, zinc and iron were determined using a Buck Scientific Model VGP flame Atomic Absorption Spectrophotometer (AAS). All tissue analytical batches were accompanied by blanks at a minimum rate of one blank per 20 samples. Replicate analyses were conducted on 10% of the samples to evaluate precision of the analytical techniques. The data were expressed as total concentration (μg/g dry weight (dw)).

Determination of Total Mercury

The Atomic Mercury Analyzer (Model HG 5000) equipped with a mercury lamp at a wavelength 253.7 nm was used for the determination of total mercury in the clam soft tissue samples. Responses were recorded on strip chart recorders as sharp peaks. The peak heights were used for computation of the total mercury concentrations in the clam and expressed as microgram per gram dry weight (μg/g dw). Total mercury concentrations were validated according to standard procedures described for Mercury Analyzer Model HG 5000 to check for precision and accuracy.

Table 1 Wavelengths and detection limits for manganese, zinc and iron

Element	Slit	Wavelength	Detection Limit
Manganese	0.7	385.2	0.001
Zinc	0.7	213.9	0.005
Iron	0.7	248.3	0.03

Determination of the Human Risks Associated with Clam Consumption

Comparing to Fung et al. (2004), this work assessed the environmental health risk associated with the consumption of *G. paradoxa* by making a comparison between environmental status (represented by the concentrations of heavy metals in the clam) and threshold values which may cause adverse effects in human consumers.

Risk quotient (RQ) was calculated as the ratio between concentration of heavy metal in the clam and the level of concern (LOC) for that metal (Fung et al. 2004). A level of concern (LOC), which is a threshold concentration of a chemical above which a hazard to human health may exist, was calculated as the ratio of Tolerable Daily Intake (TDI) and the Rate of Shellfish Consumption (RSC) (Fung et al. 2004). For the purpose of this calculation, it was assumed that total trace metal exposure was derived solely from shellfish consumption.

Data on average national rate of shellfish consumption (RSC) of Ghana was calculated from the Daily Food Supply per capita from Fish and Fishery Products of the FAO (FAOSTAT 2004; http://apps.fao.org) which estimates the daily food supply from fish and fishery products in Ghana to be 62.6 g/person/day for the year 2002. The total fishery production for the same year was approximately 380,000 metric tons, of which 5,794 metric tons constituted mollusks (Directorate of Fisheries 2005). The daily rate of shellfish consumption for the Ghanaian population was calculated to be 0.95 g/person/day using simple proportion. This value however reflects the national and not local shellfish consumption levels as there is no documented data on the shellfish consumption levels of the riparian communities where the study was conducted. This was used to calculate the levels of concern (LOCs) for the average shellfish consumption group.

In the absence of a health criteria in Ghana, the Tolerable Levels of Intake (TDI) and Estimated Safe and Adequate range of Daily Dietary Intake Levels (ESAADI) for the studied heavy metals were provided either by the US Food and Drug Administration (http://vm.cfsan.fda.gov), FAO/WHO, or the National Research Council (NRC) of the US National Academy of Sciences (NAS) for the calculation of the relevant level of concern for each metal. Results of the evaluation of the risks to human health associated with consumption of the clams containing trace metals are summarized in Table 3.

For cases where $RQ < 1$, the heavy metals involved are unlikely to cause harm to human consumers (Fung et al. 2004).

Analysis of Results

Results of the heavy metal analyses were subjected to a one-way analysis of variance (ANOVA) to test for significant differences ($p < 0.05$) in the concentrations of the heavy metals in the tissues of the different size classes of the clams. The Mann–Whitney test ($p < 0.05$) was applied in order to compare the metal concentrations in clams from the two sampling stations.

Results of the heavy metal concentrations in the tissues of the clams were compared to the WHO Safety Reference Standards for Bivalves to determine whether or not they were within permissible ranges suitable for human consumption. A further evaluation of the risks to human health associated with consumption of clams from the two sampling stations was conducted based on the methodology of Fung et al. (2004).

Descriptive statistics and graphs were performed using the GraphPad Prism 5 Software.

Results

Heavy Metal Concentrations in the Whole Tissues of the Clams

Results of the mean heavy metal concentrations of Mn, Zn, Fe and Hg in clam tissues (March to September, 2008) are summarized in Fig. 2.

Ada Sampling Station

Manganese (Mn) concentration in the whole soft tissue of the small-size clams (shell lengths of 25–40 mm) at Ada varied from 73 µg/g in June to 867 µg/g in July. The medium-size clams (shell lengths of 40–50 mm) recorded Mn values between 68 µg/g in May 2008 and 336 µg/g in August. Mn content in the tissues of the large-size clams (shell length over 55 mm) ranged from 49 µg/g in June to 212 µg/g in July.

The highest concentration of zinc (Zn) in the tissue of the small-size clams (42 µg/g) at Ada was recorded in May and June with the lowest concentration of 19 µg/g recorded in August. Concentrations of 13 and 27 µg/g were the lowest and highest concentration of Zn recorded for the medium-size clams in March and June respectively. In the large-size clams, Zn concentration varied between 16 µg/g in March and 43 µg/g in July.

The results obtained for Fe in the tissues of the small-size clams indicated a highest value of 209 µg/g in August and a lowest value of 139 µg/g in June. The medium-size clams recorded 79 and 316 µg/g in April and September respectively while the large-size clams recorded values ranging between 121 µg/g in May and August and 154 µg/g in September.

Total mercury (THg) concentration for the small-size clams ranged between 0.028 µg/g in April and 0.042 µg/g in August. The medium-size clams recorded a THg value of 0.049 µg/g in March and September and 0.035 µg/g in April. THg concentrations ranged between 0.044 µg/g and 0.059 µg/g in July and September in the large-size clams.

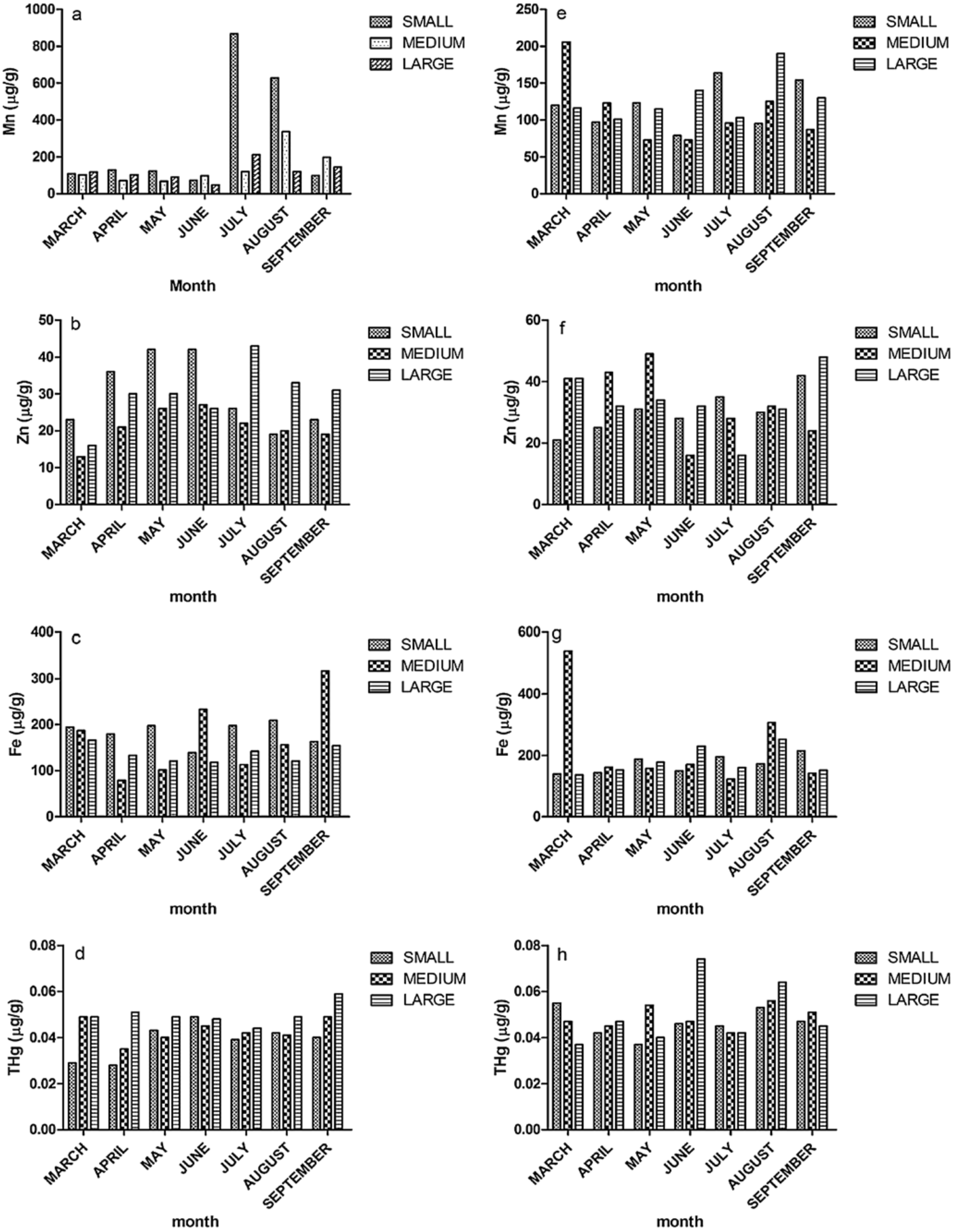
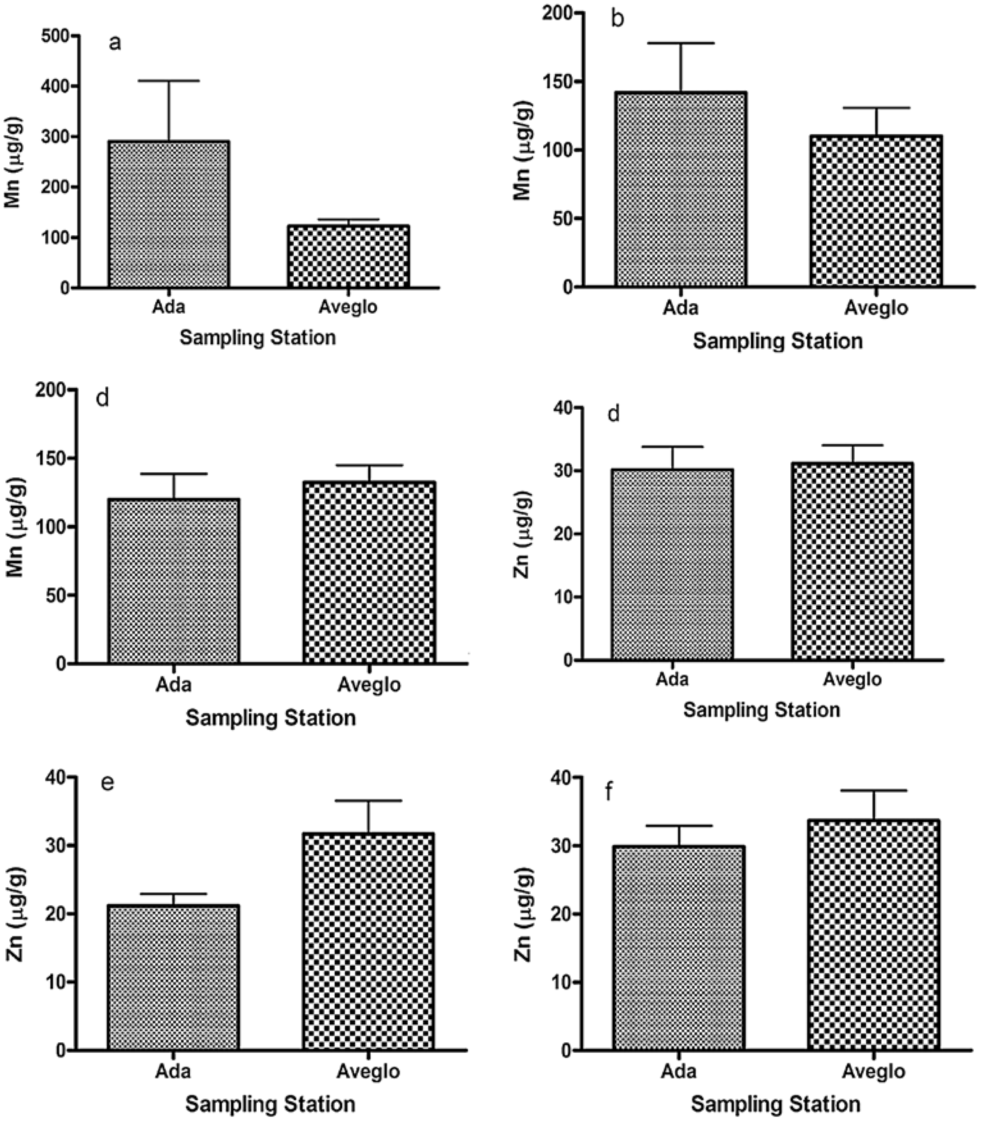


Fig. 2 Concentrations of Mn, Zn, Fe and THg in the tissues of the three clam size classes (small, $n = 10$; medium, $n = 10$; large, $n = 10$) from Ada (**a**–**d**) and Aveglo (**e**–**h**)

Fig. 3 Means ± SD of Mn and Zn concentrations in the different clam sizes from Ada and Aveglo. (**a**) Mn small, (**b**) Mn medium, (**c**) Mn large, (**d**) Zn small, (**e**) Zn medium, (**f**) Zn large



Aveglo Sampling Station

Manganese concentration was highest in the small-size clams at Aveglo in July (164 μg/g) and lowest in June (79 μg/g). The medium-size clams recorded concentrations varying between 73 μg/g in May and June and 206 μg/g in March. The large-size clams recorded values ranging between 103 μg/g in July and 19 μg/g in August.

Zinc concentration for the small-size clams ranged from 21 μg/g in March to 42 μg/g in September. Values of 16 μg/g and 49 μg/g in June and May respectively were recorded for the medium-size clams. The large-size clams recorded zinc concentrations between 16 μg/g in June and 48 μg/g in September.

Results from the analysis of iron in the tissues of the small-size clams indicated a lowest value of 139 μg/g in March and a highest value of 214 μg/g in September. The medium-size clams had iron concentrations ranging between a low of 123 μg/g and a high of 539 μg/g in July and March. The large-size clams had concentrations varying between 136 μg/g and 252 μg/g in March and August respectively.

THg concentrations in the tissues of the small-size clams at Aveglo ranged between 0.037 μg/g and 0.055 μg/g in May and March respectively. For the medium-size clams, the concentrations ranged between 0.042 μg/g in July to 0.056 μg/g in August. The large-size clams had a lowest THg concentration of 0.037 μg/g in March and a highest concentration of 0.074 μg/g in June.

Spatial Variations in Heavy Metal Concentrations in Clam Samples from Ada and Aveglo

Comparing the different clam size classes (small vs. small, medium vs. medium, and large vs. large) from the two sampling stations, no significant differences in concentrations

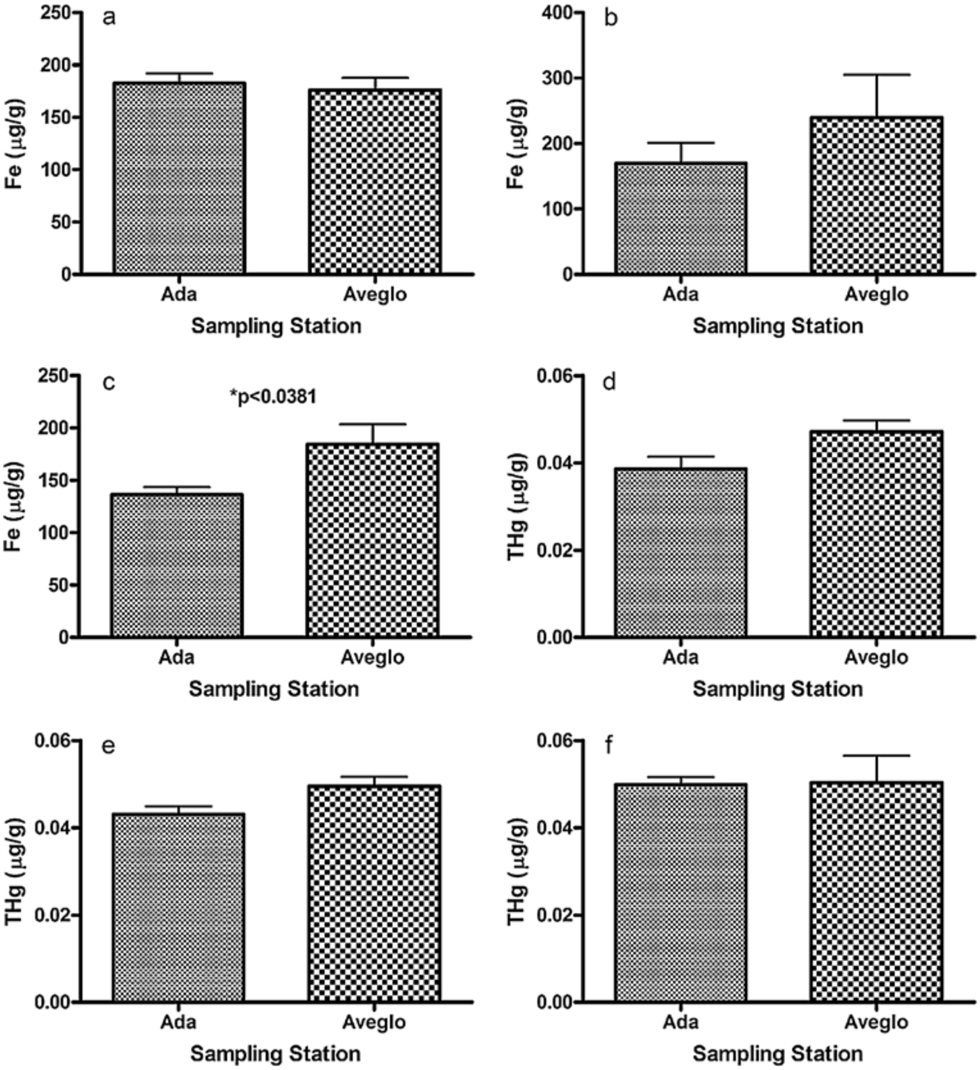


Fig. 4 Means ± SD of Fe and THg concentrations in the different clam sizes from Ada and Aveglo. (**a**): Fe small, (**b**): Fe medium, (**c**): Fe large, (**d**): THg small, (**e**): THg medium, (**f**): THg large. $^*p < 0.05$

($p > 0.05$) were observed for Mn, Zn and Hg for all the size classes over the sampling period. Spatial variations in iron concentrations in the large-size clams from Ada and Aveglo were however significant ($p < 0.05$), Fig. 3(a–f) and Fig. 4(a–f). The graphs are presented as means of monthly concentrations ± SD.

Variations in Heavy Metal Concentrations in Relation to Clam Size

Variations in the mean heavy metal concentrations in the tissues of the different size classes of clams from the two sampling stations over the sampling period were not significant ($p > 0.05$) except for total mercury concentrations in clams from Ada (Fig. 5(a–h)).

Table 2 presents and overview of trace metal concentrations in other bivalves in Ghana and on the African continent. Trace metal burdens are higher in bivalves harvested from water bodies with significant anthropogenic impacts.

Implications for Human Consumption of Whole Soft Tissue of Clams from the Volta Estuary

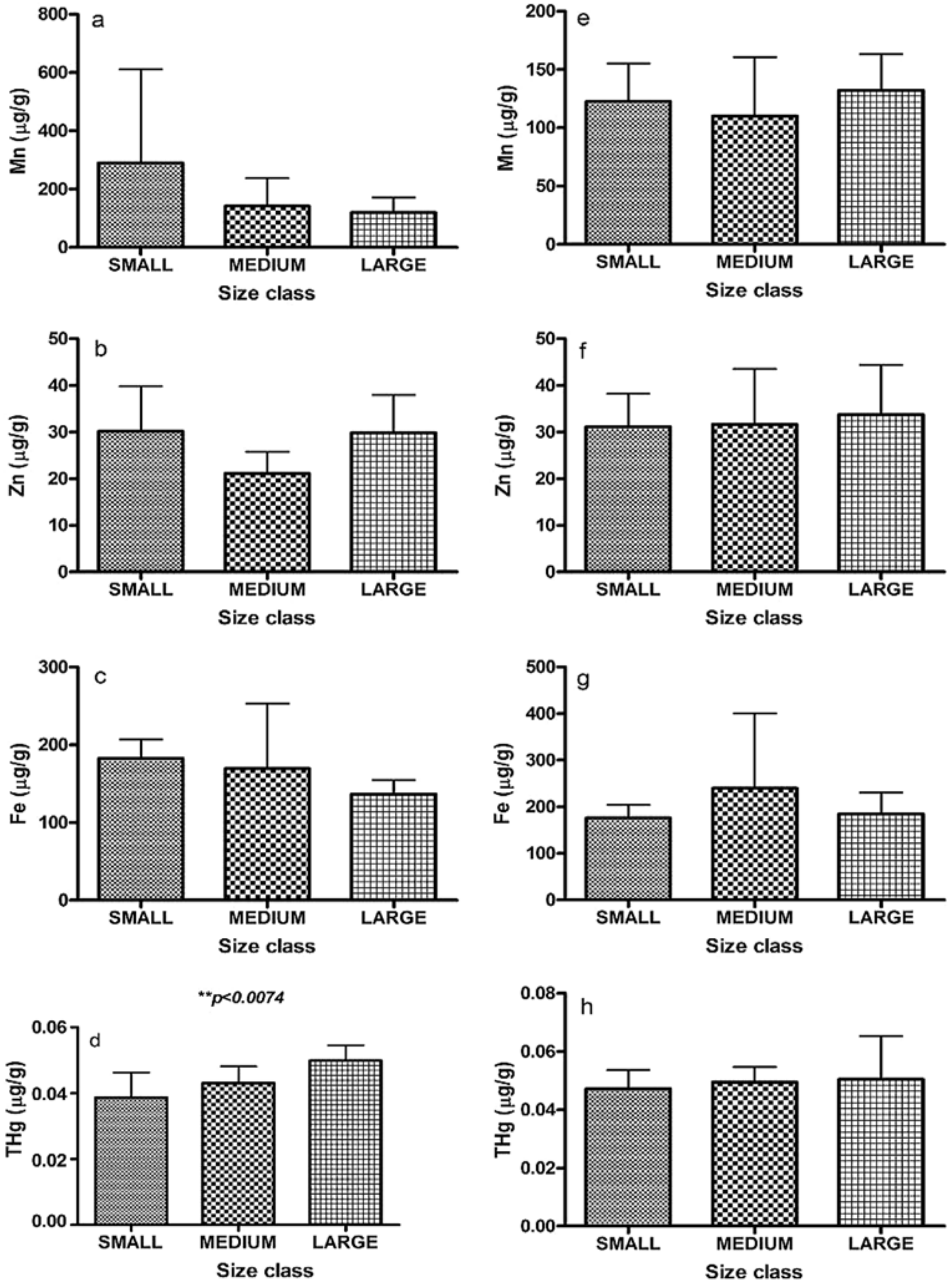
Zinc and mercury concentrations over the study period were found to be well below the WHO Guideline Values and the clams from the two sampling locations were therefore deemed safe for human consumption as far as the two metals are concerned (Table 3).

In the absence of health-based guideline values for Mn and Fe, and the possibility of bioaccumulation of heavy metals over time, the results for the heavy metal concentrations in the tissues of the clams were subjected to further analysis based on the methodology of Fung et al. (2004) to ascertain their suitability for human consumption.

Risk Assessment

Based on the maximum and minimum concentrations of the heavy metals in the tissues of the clam from Ada and Aveglo, all the calculated Risk Quotients (RQs), were 13 (Mn) to

Fig. 5 Means ± SD of heavy metal concentrations in the clam size classes from Ada (**a**–**d**) and Aveglo (**e**–**h**). Significant variations: $^{**}p < 0.01$



1613 (THg) times lower than "1", suggesting that no health-related problems might be encountered, at least not in moderate *G. paradoxa* consumers (Table 4).

Discussions

Trace metal concentrations in clams depend on numerous environmental and biological factors (Cossa 1989; Kramer 1994; Kljaković-Gašpić et al. 2007). The pattern of variation of heavy metal accumulation in whole soft tissues of the clams appears to be influenced largely by the reproductive cycle of the organism (Etim 1990). Studies by Etim et al. (1991), revealed that spawning in the clam starts in June (when the maximum mean dry tissue weight occurs) and is completed between October and November (when the minimum mean dry tissue weight occurs). Before the spawning period, proteins and carbohydrates, which have a high affinity for heavy metals, are accumulated for gonad tissue production, energetic storage and consumption (Latouche and Mix 1982; Páez-Osuna et al. 1995; Lima 1997). Galstoff (1964) and Etim et al. (1991) observed that the ripe gonad

Table 2 Overview of trace metal concentrations in the whole soft tissue of bivalve species collected in African waters (data expressed in µg/g dw)

Area	Reference	Species	Heavy metal concentration (µg/g dw)			
			Fe	Zn	THg	Mn
Volta River, Ada, Ghana	Present work	*Galatea paradoxa*	71–316	13–43	0.028–0.056	49–867
Volta River Aveglo, Ghana	Present work	*Galatea paradoxa*	123–539	16–49	0.037–0.074	73–206
Lake Timsah, Egypt	El-Shenawy (2002)	*Ruditapes decussatus*	2243.4			139.8
Cross River, Nigeria	Etim et al. (1991)	*Galatea paradoxa*		117		
Benya, Ningo and Sakumo Lagoons, Ghana	Otchere (2003)	*Crassostrea tulipa*	280–700	380–2780		11–20
Benya, Ningo and Sakumo Lagoons, Ghana	Otchere (2003)	*Perna perna*	900–1130	12–16		12–15
Benya, Ningo and Sakumo Lagoons, Ghana	Otchere (2003)	*Anadara senelis*	210–1170	6–104		5–19
Matola River, Mozambique	Böhlmark (2003)	*Meretrix meretrix*	131–4275	7.7–69.7		5.8–76.3

may comprise 31 to 41% of the total body weight. On the basis of this, Cunningham and Tripp (1975) argued that if metals were accumulated in the gonad tissues, an appreciable loss might occur during spawning. The accumulation of proteins and carbohydrates prior to spawning explains why most of the peak metal concentrations coincided with the onset of the spawning period of the *G. paradoxa*.

At the two sampling stations (Ada and Aveglo), very intense clam fishing is done at the onset of the rainy season in March, through to December. Introduction of heavy metals into the estuary during intense fishing activities could come from such sources as fuel leakages and fumes from outboard motors and from the motorized air compressors used by the divers in the their clam fishing activities. The elevated concentrations of heavy metals might also be attributed to surface run-off from the surrounding agricultural lands. In Tunisia, Chouba et al. (2007) found higher levels of heavy metals in the mullet, *Mugil cephalus*, during periods of high rainfall and intense fishing activities. Metals could also be introduced from sources such as the paints used on the boats.

The study did not observe any known point source of pollution and this provides evidence that even clams from areas with no known point-sources of contamination may have measurable body burdens of heavy metals probably due to the processes of natural weathering and supply from locations further upstream. The relatively high concentration of essential heavy metals, particularly manganese and iron, might be attributed to local hydrological conditions, weathering and the leaching of mineralized rocks in the surrounding areas during rainstorms. The activities of metal fabrication industries and use of galvanized iron sheets as the principal roofing material in the settlements surrounding the Volta estuary could also account for the high levels of Fe and Zn in the clams. According to Otchere (2003), higher wet season levels of Fe and Zn might as well be due to import from surrounding settlements as most roofing in Ghana is made of galvanized iron sheets, most of which are presently rusty. Heavy metals like Mn and Zn are also found in agricultural products such as fertilizers and pesticides. These metals may accumulate in agricultural soils and become exposed to the estuary and the organisms through run-offs during the rainy season.

Table 3 Results of the heavy metal concentrations in the tissues of the clams compared to the WHO Safety Reference Standards for Bivalves (a): Ada, (b): Aveglo

(a)

	Mn	Zn	Fe	Hg
Min. Conc. (µg/g dw)	49	13	79	0.028
Max. Conc. (µg/g dw)	867	46	316	0.059
WHO Standard (2004)	*	1000	*	0.5

(b)

	Mn	Zn	Fe	Hg
Min. Conc. (µg/g dw)	49	16	123	0.037
Max. Conc. (µg/g dw)	206	49	539	0.074
WHO Standard (2004)	*	1000	*	0.5

* No health-based guideline values were found

The non-significant variations in metal concentrations in the clams from the two sampling stations as observed by Amisah et al. (2009) could be due to similarities in bioavailability of the heavy metals to the clams at the two stations; suspended particulate matter, food sources and homogeneity in physical and chemical water parameters at the two sampling stations. The relatively consistent monthly concentrations of Mn, Fe and Zn in the whole soft tissues

Table 4 Risk analysis for the minimum and maximum concentrations of metals present in *Galatea paradoxa* from Ada and Aveglo in the Volta estuary, Ghana

Metal	Min. Conc. (µg/g)	Max. Conc. (µg/g)	TDI/ ESADDI (µg/g/d)	RSC (g/p/d)	LOC_1 (µg/g)	LOC_2 (µg/g)	1-For LOC_1	2-For LOC_2
THg	0.028	0.074	33–43[a]	0.95	34.74	45.26	0.0021	0.0016
Zn	13	49	5600–15000[b]	0.95	5894.74	15789.47	0.0083	0.0031
Fe	79	539	8000–45000[c]	0.95	8421.05	47368.42	0.0064	0.011
Mn	49	867	20000–11000[c]	0.95	2105.26	11578.95	0.41	0.075

TDI—Tolerable Daily Intake (in µg/person/day)
ESAADI—Estimated Safe and Adequate range of Daily Dietary Intake levels (in µg/person/day) for all foods set by the National Research Council of the National Academy of Sciences of the USA
RSC—Rate of Shellfish Consumption for Ghana calculated from the Daily Food Supply per capita from Fish and Fishery Products of the FAO (FAOSTAT 2004; http://apps.fao.org)
LOC_1—Level of Consumption (in µg/g) calculated from the lowest value of TDI or ESADDI range
LOC_2—Level of Consumption (in µg/g) calculated from the highest value of TDI or ESADDI range
RQwcs—Risk Quotient for worst-case scenario: 1—For lowest value of TDI or ESADDI range
2—For highest value of TDI or ESADDI range

[a] Provisional Tolerable Daily Intake of total mercury; set by FAO/WHO

[b] Dietary reference value for zinc (WHO 2001)

[c] Tolerable Daily Intake of Iron and Manganese; set by the Institute of Medicine of the USA, 2003

of the different size classes may well represent an efficient metabolism and detoxifying processes of these metals that include transportation, transformation, sequestration and/or excretion of excess metals (Connell et al. 1999; Ferreira et al. 2004).

The results further suggest that the levels of contamination of these metals in the estuary, mainly through anthropogenic activities do not exceed the clams' capacity of regulation. This could also explain the absence of any significant spatial variations in metal concentration between the two sampling stations.

Analysis of risks levels associated with the consumption of clams and comparison to WHO Safety Reference Standards for Bivalves revealed that the concentration of the heavy metals found in the clam tissues were within permissible limits. It should, however, be noted that consumption data used in the assessment are based on national average shellfish consumption rates as there is no documented data on the shellfish consumption levels of the riparian communities where the study was conducted. However, based on the calculated RQs and the national rate of shellfish consumption, it will take a daily consumption level of approximately 12–227 g of *G. paradoxa* flesh to cause manganese toxicity, 86–528 g for iron toxicity, 306–1159 g for zinc toxicity and 594–1532 g for mercury toxicity. These values are very much likely to be above the daily shellfish consumption values for the communities around the Volta estuary and thus the heavy metals studied are unlikely to cause harm to human consumers in these areas.

Conclusion

The objective of this study was to evaluate the risk implications for human consumption of the whole soft tissue of *G. paradoxa* in the light of various health standards. Analysis of risks levels associated with the consumption of clams and comparison to WHO Safety Reference Standards for Bivalves revealed that the concentrations of the heavy metals found in the clam tissues were within permissible limits using various indicators such as Tolerable Daily Intake (TDI) ESAADI, RSC, Risk Quotients and LOCs Risk (Table 3). Against this background, the clams can be said to contain acceptable levels of manganese, zinc, iron and mercury for human consumption.

However, it should be pointed out that exposure estimates for heavy metal intake from shellfish consumption are based on the national average shellfish consumption data which may not be appropriate for estimating exposures of particular subpopulations or individuals residing in specific regions and towns of the country, such as coastal settlements and locations of active shellfish production, where more shellfish is consumed.

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