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Relationship between trace element concentration and condition index in bivalves from lagoons in Ghana

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The study investigated the seasonal relationship between the Condition Index (CI) and concentrations of six trace metals in the tissues of three bivalves: Crassostrea tulipa (n = 275), Anadara (Senilia) senilis (n = 310) from two 'open' lagoons (Benya and Ningo), a 'closed' lagoon (Sakumo), and Perna perna (n = 155) from rocky shores adjacent to Benya and Sakumo. These bivalves were analyzed for their total Cu, Zn, Fe, Mn, Cd and Hg concentrations across three size classes, two seasons, and three location sites on the Ghanaian coast. When all samples were pooled together, oysters exhibited the highest CI (147, range: 35 to 446), while mussels displayed the least (124, range: 48 to 252). Overall, CI was higher in the dry season compared to the wet season. CI varied based on body size, season, level of parasitic infestation, and local environmental conditions. In this study, CI was used to assess the plumpness of bivalves, defined as the ratio between soft tissue dry weight (mg) and shell length (mm). Food availability appeared to control CI in the results, while trace metal concentrations varied with size or CI and the season of sampling.

Key words: Trace elements, bivalves, lagoons, seasonal variation, condition index.

INTRODUCTION

In the marine ecosystem, sources of trace metals typically stem from both natural and anthropogenic origins. Natural sources include: (i) Coastal supply, comprising inputs from rivers due to erosion from wave action and glaciers; (ii) Deep sea supply, involving metals released from deep sea volcanism and those extracted from particles or sediments by chemical processes; and (iii) Supply bypassing the near-shore environment, such as metal transportation through the atmosphere as dust particles or aerosols, as well as material produced by glacial erosion in polar regions and transported elsewhere by floating ice (Hossain et al., 2017; Guin and Roy, 2022; Avishek and Roy, 2023).

Anthropogenic inputs into the sea mainly occur through the atmosphere and rivers. Metal particles released into the air at ground level can mix vertically, leading to contaminants being transported over thousands of kilometers from their original release points. Variations in global climate result in uneven deposition of trace metals, with the relative absence of precipitation, scavenging, and strong atmospheric inversions contributing to the net accumulation of metals like Hg, Cd, V, and Mn in Arctic

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biota and ice. These metals are believed to originate from industrialized temperate zones, indicating significant directional transport. Comparisons between atmospheric and riverine inputs of trace metals into the sea reveal that only a small portion, such as 2% of Pb, eventually dissolves in seawater via rivers. The atmosphere is the primary source of dissolved Cd, Cu, Fe, and Zn.

At a regional level, it is estimated that 40 to 60% of the input of trace metals such as Cd, Hg, Cu, Pb, and Zn into the North Sea is through atmospheric deposition. Additionally, domestic effluent and urban stormwater runoff are significant sources of trace metal input into coastal waters (Otchere, 2019). Concentrations in the milligram per liter range can be found in domestic effluent, with contributions from metabolic waste, corrosion of water pipes (Cu, Pb, Zn, and Cd), and consumer products (e.g., detergent formulations containing Fe, Mn, Cr, Ni, Co, Zn, B, and As). It should be noted that metals are indestructible, unlike organic compounds; they are retained and accumulated within ecosystems because reactive forms bind to sediments, while non-reactive forms occur as insoluble oxides and salts. Thus, ecotoxicological effects of metals can persist for decades after pollution incidents and even when sediments and mine waste are disturbed (Hossain et al., 2017; Otchere, 2022).

The Condition Index (CI), which relates the amount of flesh to shell volume, has been widely used in scientific research and commercial fishery. Various methods exist for measuring CI (Galvao et al., 2015; Krampah et al., 2016; 2019). A commonly used index involves expressing dry flesh weight as a proportion of the internal cavity volume of the shell (that is, whole volume minus the volume occupied by the actual shell valves). Methods using wet flesh weight or volume are less sensitive, primarily due to difficulties in standardizing the degree of wetness. CI varies based on body size, season (Micklem et al., 2016), level of parasitic infestation (Galvao et al., 2015), and local environmental conditions, especially food availability. In this study, CI was utilized to assess the plumpness of bivalves, defined as the ratio between soft tissue dry weight (mg) and shell length (mm) (Hossain et al., 2017; Otchere, 2020).

MATERIALS AND METHODS

Description of the study areas

The lagoons in Ghana are primarily categorized into two types: 'open' and 'closed' lagoons. The open lagoons, such as Benya and Ningo, remain in contact with the sea throughout the year and are thus partly under tidal influence. They exhibit temperature and salinity ranges of 24 to 32°C and 10 to 40 psu (practical salinity units) respectively. In contrast, the closed lagoons are separated from the adjacent sea by a sandbar, approximately 40 m wide, for the majority of the year. Examples include Sakumo, which experiences temperature and salinity ranges of 27 to 34°C and 27 to 70 psu respectively. The rocky shores adjacent to these lagoons vary in characteristics, ranging from cliff-type to gentle sea shores with tidal markings (Otchere, 2020).

Sampling procedure and treatment

Samples of Anadara (Senilia) senilis (n = 310) and *Crassostrea tulipa* (n = 275) from three lagoons, as well as *Perna perna* (n = 155) from two rocky shores adjacent to these lagoons, were randomly collected in October 2016 and February 2017 during the wet and dry seasons, respectively. Total weights of these bivalves were determined using a weighing balance with a precision of 0.001 g. Length and width measurements were obtained using a veneer caliper with a minimum reading precision of 0.1 mm. The total flesh of the bivalves was excised, weighed, and deep frozen, with soft tissue dry weight determined after samples were freeze-dried for 24 h. The Condition Index (CI) of the bivalves was calculated as the ratio between soft tissue dry weight (mg) and shell length (mm). Element analysis, wavelengths, detection limits, and quality control and assurance procedures have been extensively described by Otchere (2003).

Data management and analysis

Correlations, simple linear regressions, and frequency distributions were employed to compare locations and seasons. Size classes were determined based on shell length, with cockles and mussels categorized as small (less than 30 mm), medium (30 to 40 mm), and large (greater than 40 mm), while oysters were classified as small (less than 40 mm), medium (40 to 50 mm), and large (greater than 50 mm). Results were compared within classes across different locations and species, as well as among classes using the Mann-Whitney-U and Kruskal-Wallis tests of significance, given the non-normal and skewed distributions. Significance levels were set at 0.05 for significance and 0.01 for high significance. Median values (min - max) were presented for the data analysis.

RESULTS

There was a correlation between total Hg concentration and CI (Figure 1). On the other hand, Figure 1 clearly illustrates the non-spatial variation in the contamination of Hg in cockles. Thus, the lower wet season concentration was not due to CI, but a real difference in contamination.

There was a significant correlation between ∑Hg concentration and CI (Figure 2). Figure 2 is a reflection of the seasonal variation in the contamination of total Hg in the mussels. Thus, the seasonal differences observed in ∑Hg concentrations could not only be due to CI/biomass effect but also a difference in contamination levels.

Total mercury concentrations in lagoons, when compared among species and between stations/ location, bivalves from Benya had the highest ∑Hg (0.36 µg/g dw) concentration in the dry season. The lowest ∑Hg concentration was recorded in Sakumo cockles (0.11 µg/g dw, wet season).

Cadmium concentrations (Table 1) in the dry season were similar for Sakumo and Benya lagoons (1 µg/g dw) and both were 3-fold more than Ningo (0.34 µg/g dw). In the wet season Cd in open lagoons were significantly higher than the closed one ($p < 0.001$). Temporally, there was a significant difference in Cd levels between dry and

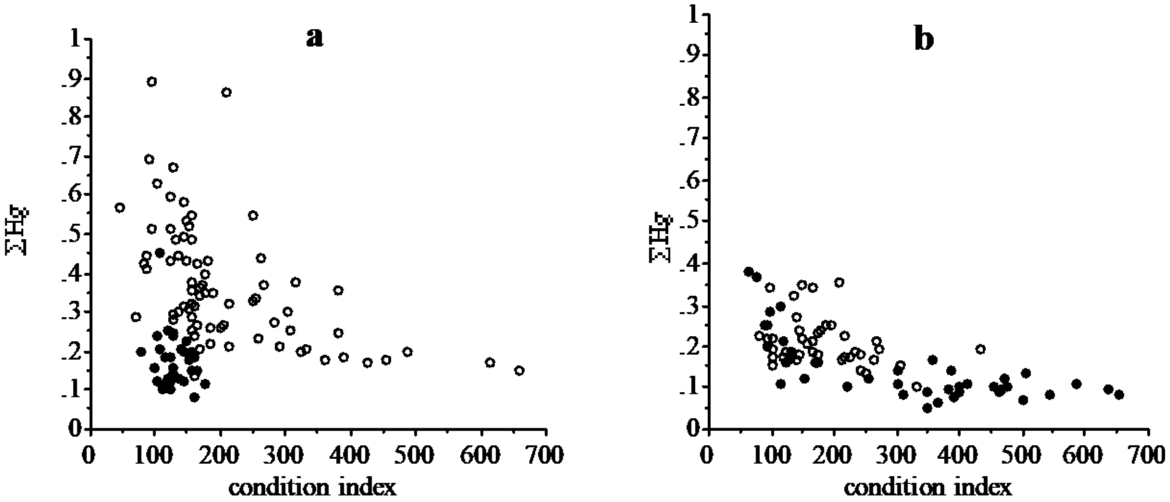

Figure 1. Relationship between CI and ∑Hg concentration (µg/g dw) in cockles (all stations pooled); dry (a) and wet (b) seasons; Benya (circles), Ningo (half shaded) and Sakumo (dots) lagoons.

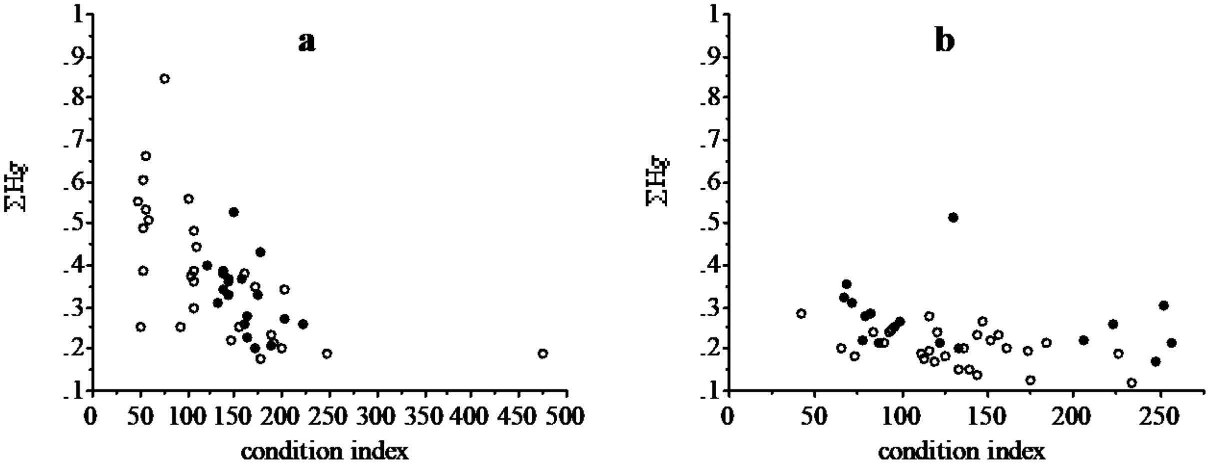

Figure 2. Relationship between CI and ∑Hg concentration (µg/g dw) in mussels (all stations pooled); dry (a) and wet (b) seasons: Benya (circles) and Sakumo (dots).

wet seasons at all locations. There is a relationship between CI and Cd concentration for the dry season cockles (Figure 3), concentration decreasing with increasing at CI. In the wet season the differences might be due to the degree of urbanization (Benya > Ningo > Sakumo). The seasonal differences were significant and could be used to explain the seasonal variation observed in Cd concentration as the season changes.

Metal concentrations in Ningo samples (dry season) were higher than Benya and Sakumo due to the relatively smaller sizes of the oysters hence no regional difference. In the wet season Cd levels in the open lagoons were significantly different from the closed one ($p < 0.001$) however, in Figure 3b the differences disappeared. There were temporal variations in Cd concentration (Figure 3), dry season values were more than the wet season values (that is, between 3 and 7-fold), reasons for these variations might be similar to those given for Hg.

Condition index (CI) for dry season Benya oysters (120) was not different from the CI for wet season (100) while Cd concentration during the wet season (0.21 µg/g dw) was 3 times lower than the dry season (0.74 µg/g dw). From Figure 4a it seemed that the seasonal differences in concentrations were entirely influenced by the differences in the availability of the metal and not the biomass of the mussels. Regional differences in the dry season were apparent due to CI but in the wet season there was no such variation (Figure 4b).

Dry season Cd concentration decreased with CI (Figure 3) resulting in apparent significant difference ($p < 0.01$)

Table 1. Seasonal and spatial variations in concentration (µg/g dw) of total Cu, Fe, Mn, Zn, Cd and Hg compared to CI in *Anadara (Senilia) senilis* from lagoons in Ghana: median values (min-max); Benya and Ningo are open lagoons and Sakumo a closed lagoon; n = number of samples.

Locations >	**Benya**	**Ningo**	**Sakumo**
Dry season	(n = 64)	(n = 32)	(n = 41)
Cu	8.2 (4.3 - 12.4)	3.0 (0.86 - 4.6)	8.2 (3 - 21.4)
Zn	36 (9.4 - 48)	36 (30.6 - 41)	6.0 (3.4 - 11.5)
Fe	790 (510 - 1190)	210 (153 - 420)	520 (360 - 850)
Mn	4.8 (2.1 - 11)	14.7 (2.4 - 39.6)	18.2 (5.3 - 30.1)
Cd	0.90 (0.3 - 1.4)	0.34 (0.31 - 0.40	1.06 (0.27 - 2.0)
Hg	0.36 (0.13 - 0.89)	0.20 (0.15 - 0.86)	0.16 (0.08 - 0.45)
C. Index	170 (100 - 290)	290 (180 - 500)	120 (60 - 300)
Wet season	(n = 46)	(n = 35)	(n = 55)
Cu	4.6 (3.6 - 5)	4.3 (4.0 - 5.75)	4.5 (3.5 - 6.40)
Zn	104 (67 - 185)	43 (36.5 - 46)	35 (20 - 40.3)
Fe	1100 (685 - 2050)	825 (640 - 930)	570 (275 - 970)
Mn	9.6 (5 - 41.7)	7.7 (7.1 - 12.5)	19.4 (10.7 - 33.3)
Cd	0.30 (0.15 - 0.50)	0.19 (0.14 – 0.25)	0.13 (0.90 - 0.20)
Hg	0.21 (0.15 - 0.36)	0.14 (0.10 – 0.19)	0.11 (0.05 - 0.38)
C. Index	140 (100 - 300)	240 (170 - 330)	280 (100 - 410)

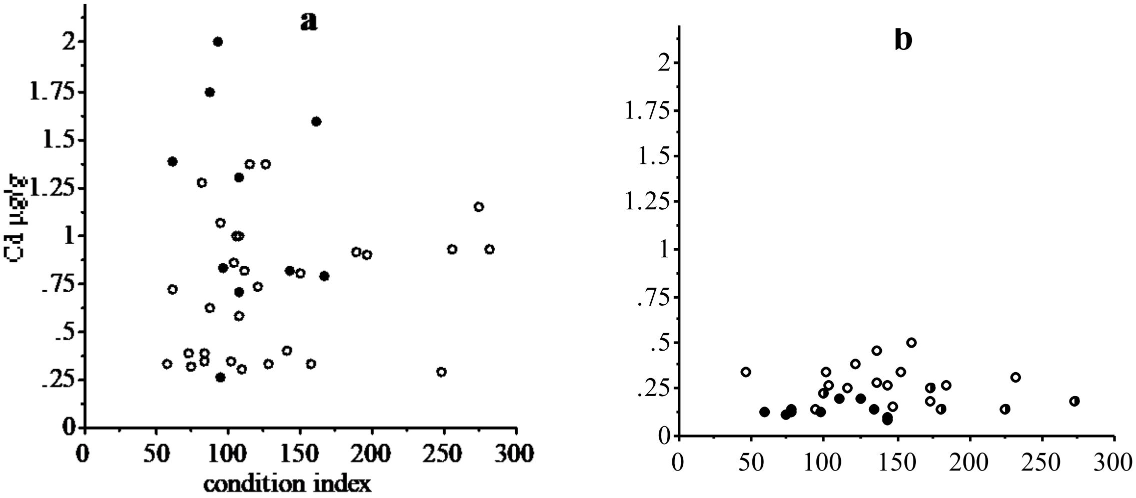

Figure 3. Relationship between total Cd concentration (µg/g dw) and CI of cockles (all stations pooled); (a) dry season and (b) wet season: Benya -circles, Ningo -half shaded and Sakumo -dots.

between Benya and Sakumo. Benya Cd concentration (wet season) was 3-fold higher (0.42 µg/g dw) than Sakumo (0.11 µg/g dw). Dry season Benya Cd levels were 3 times higher than the wet season concentrations.

Dry season Cd concentration showed a significant difference at the stations but this was apparent due to CI effect (Figure 4a). In the wet season, regional difference seems to be real (Figure 4b) compared to the dry season. From Figure 4 the seasonal differences in concentrations in the mussels were due to differences in contamination.

There is a correlation between CI and Cu concentration for dry season and no relationship in the wet season. However, there was a higher level of Cu contamination in the dry season compared to the wet season, and this variation cannot be attributed to CI effect. Zinc concentration in oyster did not show any correlation with its CI. There was a seasonal variation in Zn concentration as shown in Table 2. Regional differences in Zn concentrations were significant, e.g. Benya was 3 times more than Sakumo (660 µg/g dw) in the dry season. In

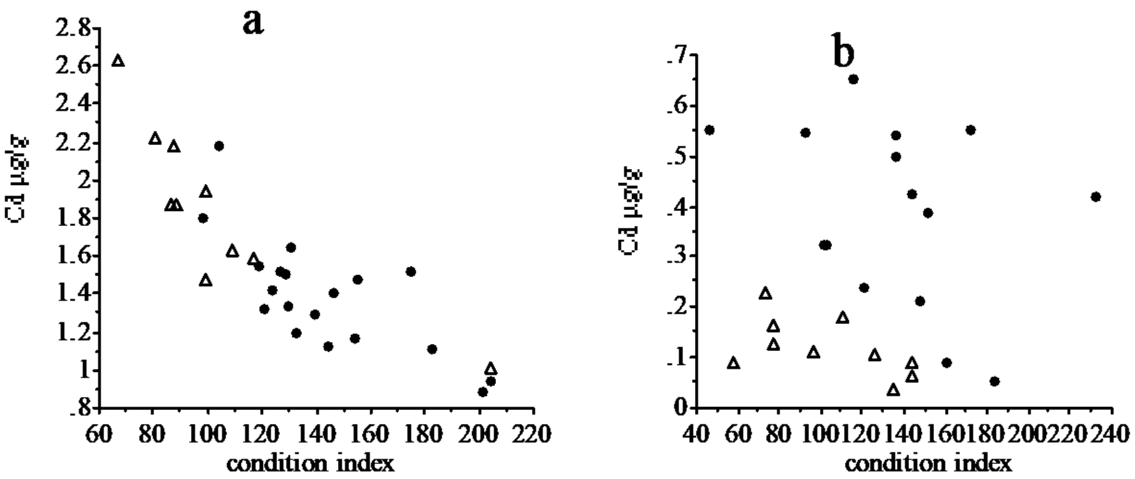

Figure 4. Relationship between total Cd concentration (µg/g dw) and CI of mussels (all stations pooled); (a) dry season and (b) wet season: Benya -dots and Sakumo -triangles.

Table 2. Seasonal and regional variations in concentration (µg/g dw) of total Cu, Fe, Mn, Zn, Cd and Hg compared to CI in *Crassostrea tulipa* from lagoons in Ghana: median values (min-max); Benya and Ningo are open lagoons and Sakumo a 'closed' lagoon; n = number of samples.

Location >	**Benya**	**Ningo**	**Sakumo**
Dry season	(n = 59)	(n = 43)	(n = 47)
Cu	17 (6.6 - 22.8)	74 (67 - 95)	40 (23.5 - 56)
Zn	2350 (1110 - 3030)	380 (270 - 470)	660 (430 - 800)
Fe	350 (207 - 580)	450 (330 - 620)	280 (134 - 540)
Mn	11 (6.1 - 17.4)	20 (15.9 - 28)	17 (10 - 28.6)
Cd	0.74 (0.38 - 1.18)	1.12 (0.83 - 1.80)	0.91 (0.59 - 1.30)
Hg	0.21 (0.10 - 0.47)	0.16 (0.03 - 0.23)	0.13 (0.08 - 0.18)
C. Index	120 (60 - 280)	90 (60 - 160)	100 (60 - 170)
Wet season	(n = 45)	(n = 26)	(n = 34)
Cu	17 (9.2 - 27)	59 (44 - 79)	33 (23.9 - 40)
Zn	2800 (2228 - 3540)	560 (458 - 780)	425 (310 - 590)
Fe	560 (300 - 830)	700 (443 - 840)	520 (148 - 620)
Mn	13 (9 - 16.7)	13 (3.57- 21.9)	20 (14.3 - 29)
Cd	0.21 (0.06 - 0.31)	0.18 (0.04 - 0.23)	0.12 (0.03 - 0.28)
Hg	0.14 (0.09 - 0.37)	0.13 (0.10 - 0.16)	0.12 (0.07 - 0.29)
C. Index	100 (80 - 300)	100 (70 - 270)	170 (90 - 310)

the wet season there were regional variations as well, Benya had the highest (2800 µg/g dw) as compared to Sakumo (425 µg/g dw) the lowest. There was no correlation between Fe concentration in oyster and its CI. A seasonal variation of Fe concentrations has no variation at the stations as shown in Table 2. There was no relationship between Mn concentration in oyster and its CI. Mn concentrations in oyster for both seasons were similar. No regional variation in Mn concentrations at the stations for both seasons.

There was no relationship between Cu concentrations in mussels and its CI for both seasons. Dry season concentrations were 2 times higher than the wet season levels. The seasonal differences in concentrations in mussels were due to differences in contaminations and not to its biomass. There was no relationship between Zn concentrations and CI for both seasons. Zn concentration in Benya mussels during the wet season (87 µg/g dw) was about 5 times higher than the dry season (16 µg/g dw) and for Sakumo the difference was about 4 times (Table 3). There was a relationship between Fe concentration and CI in the dry season but not in the wet

Table 3. Seasonal and regional variations in concentration (µg/g dw) of total Cu, Fe, Mn, Zn, Cd and Hg compared to CI in *Perna perna* from the coast of Ghana: median values (min-max); n = number of samples.

Location >	**Benya**	**Sakumo**
Dry season	(n = 30)	(n = 45)
Cu	15 (9.7 - 27)	16 (12.5 - 18)
Zn	16 (8.0 - 36.4)	12 (8.0 - 36)
Fe	895 (550 - 1400)	1130 (650 - 1720)
Mn	11.9 (7.88 - 20.9)	14.6 (9.10 - 22.4)
Cd	1.40 (0.88 - 2.23)	1.90 (1.01 - 2.63)
Hg	0.37 (0.19 - 0.84)	0.33 (0.02 – 0.53)
C. Index	130 (100- 200)	90 (70 - 200)
Wet season	(n = 25)	(n = 22)
Cu	8.4 (4.61 - 11)	7.1 (5 - 9.63)
Zn	87 (21.0 - 133)	47 (20.9 - 77)
Fe	1050 (644 - 1900)	610 (510 - 860)
Mn	18.2 (13.6 - 25.0)	5.1 (4.2 - 8.33)
Cd	0.42 (0.06 - 0.65)	0.11 (0.04 - 0.23)
Hg	0.02 (0.12 – 0.29)	0.26 (0.17 - 0.52)
C. Index	140 (50 - 230)	103 (60 - 140)

season. Benya wet season concentrations were significantly ($p < 0.01$) higher than the dry season. However, for Sakumo samples the dry season levels were higher than wet season levels. Spatial variations in the dry season were apparent due to CI but the observed difference in the wet season was real. There was a relationship between Mn concentrations and CI in the dry season and no relationship in the wet season, there were seasonal differences in concentrations, at Benya the wet season concentrations were significantly ($p < 0.01$) higher than the dry season and for Sakumo the dry season level was 3 times higher than in the wet season.

Table 4 illustrates concentration on a size class basis (all samples pooled). Variation in concentration for Cd showed no consistent size-dependent pattern for both seasons in the three species. However, when size classes were compared among the species, no difference in concentration was observed between the species. For example, in the dry season, large size mussels had the highest (1.4 µg/g dw) while large size cockles had the lowest (0.33 µ/g dw) the difference were due to size variation (41 and 49 mm respectively). This was also true for the large size in the wet season (Table 4). Seasonal variation could also be noticed in Table 4; in mussels and oysters the dry season concentrations were higher than in the wet season levels (that is, intra-species comparison on a size class basis).

DISCUSSION

Increased concentration (∑Hg) in dry season possibly resulted from rapid mobilization of reserved food during low primary production in the lagoons, at the time when metabolic demands due to gametogenesis were highest, bringing sequestered and detoxified ∑Hg into circulation. Since gonadal material contribute as much as 40 % of the dry soft tissue when completely ripe (Laporte et al., 1997; Otchere, 2020). There was an apparent increase in weight from the result of CI in the dry season; the net effect was not somatic growth but rather gonad maturation. Hence increase in weight or CI in the dry season did not reflect dilution effect in Hg concentration but rather an increase (Otchere, 2003).

These processes in turn require an accelerated filtration rate and increased phytoplankton ingestion. Joiris et al. (2000) reported that contamination of marine organisms by stable residues presents spatial and temporal variations related not only to the level of contamination of their environment, but also to biological factors such as CI, age, sex, feeding habits and physiology of the biota. Thus, increased demand in energy and oxygen consumption lead to increased phytoplankton ingestion and coupled with higher dry season temperatures making Hg relatively more available in the dry season (Otchere et al, 2003).

Using these bivalves as bioindicators for Hg levels, the observed variations in concentration would suggest that the lagoons become more polluted in the dry season than in the wet season. Metals are more bioavailable in areas of low salinity, freshwater having a higher capacity to maintain metals in the water column either in solution or in suspension than sea water (Otchere, 2019). On the other hand, high primary production during the wet season could lead to lower Hg concentrations in particulate matter. Lower wet season concentration could

Table 4. Size classes and seasonal variations in concentrations (µg/g dw) of total Cu, Zn, Fe, Mn, Cd and length (mm) of bivalves from Ghana lagoons: median values (min-max) n = number of samples.

Sampled pooled	n	Length	Cu	Zn	Fe	Mn	Cd
Dry season							
Anadara senilis							
small	88	26 (18 - 30)	8.7(6.88 - 21)	24.7(4.55 - 47)	770(381 - 950)	10.6(2.06 - 28)	0.11(0.03 - 2)
medium	33	33(31 - 40)	6.2(2.8 - 9.43)	36.3(3.4 - 48)	650(202 - 1190)	6.0(3.5 - 11)	0.13(0.07 – 0.80)
large	26	49(40 - 69)	3.1(0.86 - 6.2)	36.4(11.5 - 44)	240(145 - 640)	14.6(2.43 - 40)	0.33(0.1 – 0.40)
Crassostrea tulipa							
small	12	36(24 - 39)	8.7(6.88 - 21)	24.7(4.55 - 47)	770(381 - 950)	10.6(2.06 - 28)	0.11(0.03 - 2)
medium	54	47(42 - 49)	6.2(2.8 - 9.43)	36.3(3.4 - 48)	650(202 - 1190)	6.0(3.5 - 11)	0.13(0.07 – 0.80)
large	69	55(51 –71)	3.1(0.86 - 6.2)	36.4(11.5 - 44)	240(145 - 640)	14.6(2.43 - 40)	0.33(0.1 – 0.40)
Perna perna							
medium	12	38(35 - 40)	16.2(11.2 - 26)	12.5(2.94 - 22)	1140(649 - 1780)	15.6(10.4 - 22)	1.88(1.0 – 2.60)
large	18	41 (40 - 45)	14.7(9.7 - 27)	14.8(4.55 - 36)	860(553 - 1280)	11.7(7.89 - 21)	1.37(0.9 – 3.20)
Wet season							
Anadara senilis							
small	29	25(21 - 30)	4.6(3.9 - 6.4)	38.2(33 - 185)	650(554 - 1355)	17.9(9.1 - 33)	0.14(0.1 – 0.40)
medium	19	36(31 - 38)	4.4(3.5 - 11.5)	98.5(20 - 125)	810(275 - 1930)	9.1(5.0 - 15)	0.20(0.14 – 0.40)
large	40	43(40 - 50)	4.3(3.75 - 6)	44(23 - 116)	825(497 - 2050)	17.4(5.0 - 41)	0.23(0.10 – 0.50)
Crassostrea tulipa							
small	15	34(19 - 39)	27.1(9.0 - 66)	2230(483 - 3000)	630(317 - 840)	14.4(5.56 - 22)	0.27(0.04 – 0.30)
medium	33	47(42 - 49)	26.8(13.3 - 47)	2600(310 - 3050)	640(388 - 810)	15.0(9.0 - 29)	0.24(0.1 – 0.30)
large	41	57(54 - 71)	34(12.3 - 79)	510(390 - 3540)	440(148 - 775)	15.0(3.57 - 29)	0.14(0.04 – 0.20)
Perna perna							
small	1	30	5.5	22.7	660	4.6	0.23
medium	35	38(31 - 39)	7.8(5.0 - 10.5)	59(21 - 133)	860(514 - 1880)	8.3(4.2 - 21)	0.17(0.06 – 0.60)
large	14	42 (40 - 46)	8.5(5.5 - 11)	78(51 - 124)	970(565 - 1365)	16.7(5.6 - 25)	0.50(0.04 – 0.70)

Source: Otchere (2022).

be explained as due to the interaction of lower salinity, high primary production, lower CI and lower temperatures in the lagoons (Otchere, 2020). In addition, low temperatures during the wet season (< 25°C) could reduce uptake rate and this might have contributed to the lower levels in the wet season. Nevertheless, the decrease might as well be caused by dilution or burial due to sedimentation or transport out of the area by surface run-offs during the rainy season. Similar trends were recorded for DDTs in fish and shellfish; in oysters, cockles and mussels from Ghana lagoons for total DDT, PCBs and chlordanes (Mouneyrac et al., 1998; Otchere, 2005).

Total Cd concentrations for both seasons in the three species, from Benya, Ningo and Sakumo are shown in Tables 1 to 3. Spatial differences observed might be due to several factors among these were: the type of lagoon, the type of settlement at each station as reported by Joiris et al. (2000) and most important, size or CI distribution. Dry season concentrations for Cd (cockles) were higher than those in the wet season. In the wet season Cd levels in open lagoons were significantly different from the closed one ($p < 0.01$). The pattern of variations in oysters was identical to those observed in cockles. In mussels, dry season concentrations did show significant geographical variation though apparent; and in the wet season significant differences observed were not due to CI. The regional differences in concentration recorded during the wet season could reflect real Cd bioavailability in the regions/ locations, similar to the assertion made earlier for Hg (that is, degree of urbanization). Nevertheless, the decrease might as well be caused by dilution or burial due to sedimentation or transport out of the area by surface run-offs during the rainy season. It could as well be due to lower salinity of the water and thus making essential metals more bioavailable (e.g. Zn and Cu) to compete with Cd for binding sites (Lamptey and Armah, 2008).

The changes in metabolic rates of bivalves with age and season as well as the variation in bioavailability of Cd in the surrounding water with time are thought to be responsible for the variations in these molluscs (Reinfelder et al., 1997; Guin and Roy, 2022). On the other hand, Cd availability probably fluctuated with salinity changes at these locations during the seasonal cycle (Guin and Roy, 2022). It could also be due to concentration effects and/or depletion of essential metals in the dry season: through excessive evaporation making the essential metals taken up by plant life in the lagoons and thus making the non-essential metals more available. In the wet season the levels are low as a result of 'washed out' or dilution through surface run-off. This probably caused the higher Cd levels in the dry season. Many metals are found in agricultural products; those present in fertilizers include Cd; this may accumulate in soils and become exposed to run-offs during the rainy season (Mouneyrac et al., 1998; Otchere, 2003).

Dry season concentrations for Cu (cockles) were higher than those in the wet season. While for Zn, Fe and Mn the dry season concentrations were lower than in the wet season, both situations were statistically significant ($p < 0.05$). Probably these were due to concentration effects in the dry season (Cu) and in the wet season as a result of 'washed in' or 'import' (Fe and Zn) through surface run-off (as roofing in Ghana at mostly places are galvanized iron sheets) during the wet season. Regional differences observed might be due to the type of lagoon (i.e. open verses closed), the type of settlement at each station as reported by Joiris et al. (2000) and the most important was the CI distribution. For example, Cu concentrations in the dry season (cockles) were alike (8.2 µg/g) for Sakumo and Benya and both were 3-fold more than Ningo due to CI effect. In the wet season Fe and Mn levels in open lagoons were significantly different from the closed one ($p < 0.001$).

The patterns of variations in oysters were identical to those observed in cockles. However, a glance at Tables 1 and 2 reveal outstanding concentrations for Zn, Fe and Cu (in order of decreasing importance) in oysters as the main differences between the species. Regional and seasonal differences in Zn concentration cannot be due to size or CI effect but a real reflection of the level of contamination. In the case of mussels (marine species), dry season concentrations did not show significant geographical variation, while in the wet season significant differences were observed (apart from Cu; $p < 0.05$).

Differences in Zn, Fe and Cu; essential elements for cockles, mussels and oysters, could be due to specific internal regulatory processes. Since these three elements are essential to life, we may expect a stronger influence of species than the variations in Mn. Higher wet season concentrations in Zn, Fe and Mn in the bivalves were similar to levels recorded in the mussel *Perna viridis* from India by Rivonker and Parulekar (1998); they attributed this observation to higher content of organic matter brought in by monsoon rains. Joiris and Azokwu (1999) reported higher concentrations (Cu, Fe and Zn) in wet season in the cockle (*Anadara senilis*) from Nigeria and they attributed these variations to increased run-off water with possible increase in pollutants load. Likewise, Joseph and Srivastava (1993) and Pillai and Valsala (1995) observed increased concentrations of heavy metals during the monsoon season. Elevated levels of Zn in both seasons (2400 and 2800 µg/g dw for dry and wet seasons) in oysters from Benya (a fishing harbor) Fe in cockles and mussels might be due to treated wood used in boat construction (e.g. marine paints, etc.) and anthropogenic influx of metallic contaminants (Szefer et al., 1999; Guin and Roy 2022). These high levels might also reflect the presence of blood systems or transport medium with these metals as essential components. For example, hemoglobin in cockles (high Fe content) and haemocyte in oysters (high in Cu and Zn) (Silva et al., 2003). Similarly, Rivonker and Parulekar (1998) reported high levels of Fe in mussels from India (ranged: 200 - 4000 µg/g dw) and attributed these levels to the high uptake capacity of mussels towards this particular metal. While Vaisman et al. (2005) worked on *Crassostrea rhizohporae* found similar trends of high concentrations (Cu ranged: 0.1 - 7 mg/g dw; Zn ranged: 2 to 16 mg/g dw). They concluded that inherent variability of elements in a bivalve population depended on the particular species-metal pair considered, and also on the degree of contamination involved. Results presented above (Table 4; size class) showed that from a practical point of view when using bivalves as a quantitative indicator of metal pollution, influence of the size or CI of molluscs must be taken into account even when the shell length has been classified (Otchere, 2003, 2019).

Conclusion

In conclusion, the low levels of Hg found in this study (median value of 0.20 µg/g dw for all samples) indicate minor contamination along the coast of Ghana, likely associated with human activities, as there are no known natural sources of mercury-bearing rock or hotspots of mercury contamination in the area. The elevated levels observed in Benya (0.36 and 0.37 µg/g dw for cockles and mussels, respectively) could be attributed to various factors including domestic waste discharges, the use of mercury-containing anti-fouling marine paints, atmospheric inputs, and general harbor activities. The apparent differences in metal concentrations observed from site to site are likely influenced by factors such as the degree of urbanization, type of lagoon, hydrological differences, Condition Index (CI), and reproductive stage of the bivalves. Notably, the dry season Hg levels were significantly higher than those in the wet season across stations and among species; however, data collected during different seasons should be treated separately and not directly compared. For instance, the Cd concentration during the wet season at Sakumo was three times lower than that at Benya. Spatial differences observed in the wet season may be attributed to factors such as salinity, primary production, and the level of metallic influx from inland (anthropogenic sources and a measure of urbanization). Significant seasonal differences in concentration could be due to variations in the bioavailability of Cd.

The wet season maxima in Cu, Zn, Fe and Mn observed should reflect a higher metal availability during this season (through 'import'). This could not be reproducible (differential ability of some species to regulate more efficiently than others) and would allow one to infer that temporal variability in metal concentration from sites to sites are irregular nevertheless, it could have also depended on the amount of rainfall at each location during the season. This irregularity might also be due to varying gut content since bivalves were neither depurated nor drained prior to storage. The four essential metals which were studied, were present in similar respective concentrations to those found for other bivalves elsewhere and exhibited similar seasonal pattern in terms of their concentrations with different magnitudes. There was no influence of season and location on Mn and Cu concentrations but location played an important role in Fe and Zn concentrations while season exhibited a moderate influence. From Table 1 and Figure 1a regional variations observed in the dry season seemed to be mainly due to CI factor or size distribution. This was reflected in Sakumo having lower CI (94) compared to Benya (132) during the dry season. From the tables and figures one important factor influencing these results was CI or weight of the bivalves compared to the ecological differences at the stations (e.g. Cu concentration was lowest for Ningo due to the relatively bigger size of the cockles). Observed regional differences in both wet and dry seasons reflect the effect of CI except for Zn and Fe. Significant seasonal differences in concentration imply that there was a seasonal difference in the level of metal contamination in Cu, Cd, Hg, Zn and Fe along the coast of Ghana. Mn did not show any significant regional nor seasonal variations in the level of contamination.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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