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Assessment of the environmental conditions and benthic macroinvertebrate communities in two coastal lagoons in Ghana

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ABSTRACT

This study was conducted in Domini and Amansuri Lagoons in the Western Region of Ghana in January, 2011 with the aim of assessing their physico-chemical and ecological health conditions using ecological indices e.g. richness and diversity of macroinvertebrate fauna along environmental gradients. Lagoon ecosystems have several physiographic attributes which increase their habitat heterogeneity for diverse fauna. The data is baseline for environmental monitoring assessment since the Domini Lagoon lies at a proposed site for the establishment of a petroleum gas processing facility while the Amansuri Lagoon serves as eco-tourism site. The physico-chemical factors were determined using a Water Quality Checker. Benthic sediment samples were collected with an Ekman grab, screened in the field and examined in the laboratory. Dissolved oxygen was uniformly distributed in Domini (around 6.0 mg/l) than Amansuri 4.7-6.5 mg/l; pH range at Amansuri was 5.5 – 6.0 while Domini was 7.4–7.7; turbidity range at Amansuri 15.1–20.0 ppm and Domini was 0 to 98.3 ppm. Insects encountered belonged to the orders Diptera and Trichoptera while the worms present included Oligochaetes, leeches and Polychaetes, with hermit crab and Penaeus shrimps being rare. Invertebrate richness and diversity ranged from J'= 0.68-0.81 and H'= 0.74-1.45 respectively in Amansuri while that of Domini were J'= 0.01-0.02 and H'= 0.01-0.03 respectively. The conclusion was that the freshwater Amansuri Lagoon supports richer and diverse macrobenthic fauna than the brackishwater Domini Lagoon. Future reduction in invertebrate composition, richness and diversity would imply a change or deterioration in environmental conditions of the lagoon. Serious efforts should be made to step up environmental improvement measures in and around the Domini Lagoon in the light of the current ecological and socio-economic issues around the lagoon.

Keywords: Physico-chemical conditions; Macroinvertebrates; Coastal lagoons; Species composition; Density; Species diversity.

INTRODUCTION

Coastal lagoons are transition zones serving as ecotones between freshwater, marine and terrestrial biotopes; consequently they exhibit relatively unique habitat and species diversity [1][2]. Such transitional ecosystems represent an ideal study environment for evaluation of the significance of various potential drivers of community and guild structure at the local ecosystem level [2]. Despite the high biological productivity of lagoons, they are among the least understood wetland ecosystems in the world [1]. Lagoon ecosystems have several physiographic attributes which increase their habitat heterogeneity to provide refuge for diverse fauna [3]. Therefore, a study of the functional traits of organisms involved in making up the biodiversity of these ecosystems together with the abiotic environment gives a better understanding of the functional status and productivity of a lagoon habitat [4][5].

Benthic macroinvertebrates are very important components of aquatic biotic communities, playing several ecological roles in wetland ecosystem functions. They play significant roles in the energy pathway and nutrient cycling [6][7] and they also constitute an important link in the aquatic food chain as food resource for fishes and other animals [8][9]. Most importantly, macrozoobenthos have been extensively used for the assessment of the ecological integrity and biomonitoring of aquatic habitats [10][11]. This is because they manifest a distinct response to changes in the aquatic environment, thus serving as promising indicators of hydrologic stress and aquatic ecosystem health in general [12]. In addition, the sedentary nature of macrozoobenthos, together with their ubiquitous distribution and lifecycles of measurable duration allow for both long-term and short-term analyses, and they are easy to identify with already established diversity and monitoring indices [13].

It has been pointed out that few studies in Ghana have examined the biotic functional status of lagoons in the country from the perspective of macroinvertebrates; most studies have focused on the value of the lagoons for fish and birds [7]. In view of the increasing rate of degradation of lagoon habitats in the country through pollution and other anthropogenic disturbances [14][15], it is imperative to study their benthic macrofauna assemblages together with the abiotic conditions to broaden understanding of functional status as well as biodiversity interactions with the abiotic environments. Among others, this information would be useful in determining the ecological health of the lagoons and also facilitate their biomonitoring. Baseline data would be pertinent in the monitoring of such water bodies as the oil industry develops. Against this background, this study aimed at investigating the benthic macrofauna communities together with some prevailing physico-chemical factors in the Domini and Amansuri Lagoons in the Western Region of Ghana to provide baseline information on the macrobenthos assemblages in these lagoons relative to their environmental conditions. Specifically, the study looked at the variations in salinity, conductivity, water temperature, dissolved oxygen content, pH and turbidity across the lagoons, and benthic macroinvertebrates occurrence, composition, richness, diversity and density along the environmental gradients.

MATERIALS AND METHODS

Study area

This study was conducted in Domini and Amansuri Lagoons in the Western Region of Ghana in January, 2011. The Amansuri and Domini Lagoons located at 5° 1' N, 2° 35' W and 5° 1' N, 2° 45' W respectively, are both found in the Jomoro District (Figure 1). The Amansuri Lagoon has a surface area of about 2.5 km^2 and is open to the sea by a channel while the surface area of the Domini Lagoon is less than 1.0 km^2 and is open directly to the sea [16]. The Domini Lagoon provides important fisheries livelihood for the Bonyere community and its environs and lies at a proposed site for the establishment of a petroleum gas processing facility, while the Amansuri Lagoon is both a source of fisheries for over 5000 nearby inhabitants [16], and an important eco-touristic and recreational site in Ghana on which the Nzulezu stilt village is located.

Sampling of aquatic environmental parameters and benthic macroinvertebrates

Three replicate samples of both physico-chemical factors and benthic sediments were collected from each of three locations designated 1, 2 and 3 from each of stations A, B and C in both lagoons, where stations A, B and C were represented by the southern or mouth, middle and northern portions of the lagoons (Figure 1).

The physico-chemical parameters sampled were salinity, dissolved oxygen (DO), pH, conductivity, temperature and turbidity, which were measured using a Water Quality Checker (Model: Horiba Water quality checker U-10) and HACH water quality test kit (Model FF 2).

The benthic sediment samples were collected with an Ekman grab (15 × 15 cm) and screened in the field using a set of sieves of mesh sizes 4 mm, 2 mm and 0.5 mm. The organisms retained in the sieves were preserved in 10% formalin for detailed examination in the laboratory. Prior to sorting out the organisms, the samples were dyed with Eosin to enhance their visibility. The organisms found were identified with the aid of manuals [17][18][19][20]. Counts of the different taxonomic groups in the samples were recorded for further analysis. A given procedure was followed in computing the mean densities (number/m^2) of the benthic organisms [21]. The counts of individuals belonging to each taxon in a sample were log- transformed and their densities in each water body determined as number of counts per square metre.

The benthic macroinvertebrate communities were analyzed for species richness, diversity and species composition. Species richness was determined using Margalef index (d), given as: $d = \frac{(s-1)}{\ln N}$ where s is number of species in the sample, and N is the number of individuals in the sample (Krebs, 1999). Diversity of the communities was ascertained by the Shannon-Wiener index (H') given as: $H' = -\sum_{i=1}^{s} P_i(\ln P_i)$, where s is the number of species in the community and P_i is the proportion of individuals belonging to species i in the community [22]. The evenness or equitability component of diversity was calculated from Pielou's index given as $J' = H'/H_{max}$, where $H_{max} = \ln s$ [23]. The degree of similarity between the communities in two lagoons was determined as $C_s = \frac{2j}{a+b}$ [22], where C_s is Sorensen's index, j is the number of species common to both lagoons, and a and b are the number of species occurring in either of the lagoons.

Figure 1: Map of Ghana showing the Amansuri and Domini Lagoons

RESULTS

Environmental Conditions in the Amansuri and Domini Lagoons

Data for both physico-chemical factors and benthic macroinvertebrates collected from the three locations (1, 2 and 3) at a particular station were combined for analysis after it was ascertained that there was no appreciable difference in both environmental and macrobenthos data from the locations at a station. As presented in Table 1, salinity values of the lagoons showed that the Amansuri Lagoon is a freshwater Lagoon while the Domini Lagoon is brackish. Although the lagoons had similar dissolved oxygen (DO) levels, DO was more uniformly distributed in Domini (around 6.0 mg/l) than in Amansuri were levels seemed to decline from the mouth (station A, 6.5 mg/l) to the northern portions (station C, 4.7 mg/l). Amansuri was slightly acidic (5.5 – 6.0) while Domini was slightly alkaline (7.4 – 7.7). Unlike Amansuri where turbidity did not vary much from station A to C (range of 15.1 – 20.0 ppm), the mouth of the Domini Lagoon was highly transparent (station A) while the middle portion was the most turbid (98.3 ppm).

Table 1: Means of hydrographic parameters recorded from the different stations in the Amansuri and Domini Lagoons in the Western Region of Ghana

Parameter	**Mean (± Standard Error)**					
	Amansuri Lagoon Stations			Domini Lagoon Stations		
	A	B	C	A	B	C
Salinity (‰)	0.0	0.0	0.0	29.4 (2.2)	28.0 (3.5)	26.6 (4.1)
Conductivity (mS/cm)	0.0	0.0	0.0	46.5 (1.2)	43.6 (4.8)	42.4 (5.1)
Temperature (°C)	31.1 (1.9)	31.0 (1.6)	23.2 (1.0)	28.5 (0.1)	28.5 (0.3)	29.3 (0.1)
D O (mg/l)	6.5 (0.1)	6.4 (1.8)	4.7 (0.3)	6.1 (0.1)	6.0 (0.2)	5.9 (0.3)
pH	5.9 (0.1)	6.0 (1.4)	5.5 (0.1)	7.4 (0.2)	7.6 (0.1)	7.7 (0.3)
Turbidity (ppm)	20.0 (3.7)	17.9 (2.5)	15.1 (3.2)	0.0	98.3 (20.2)	14.7 (10.3)

Occurrence of benthic macroinvertebrates in the lagoons

The occurrence of various groups of benthic macroinvertebrates in the Domini and Amansuri Lagoons is presented in Table 2. The insects encountered belonged to the orders Diptera (families Chironomidae - genera *Chironomus* and *Tanytarsus*, Ceratopogonidae and Culicidae - genus *Culex*) and Trichoptera (family Philopotamidae - genus *Chimarra*) while the annelids were from the classes Oligochaeta, Hirudinea and Polychaeta (family Maldanidae). Crustaceans (amphipod, hermit crab and a shrimp - Penaeidae of genus *Penaeus*) were found only in the Domini Lagoon. Of the four insect families, only Chironomidae occurred in both lagoons while the other three occurred only in the Amansuri Lagoon. Similarly, oligochaete worms were present in both lagoons while the leech (Hirudinea) and the polychaetes were found in only Domini Lagoon.

Richness and diversity of benthic macroinvertebrates

Table 3 shows the estimations of richness and diversity of the macroinvertebrate communities at the different stations in the lagoons as well as the overall for the lagoons. Only one invertebrate family occurred at the mouth of the Amansuri Lagoon (station A), hence diversity index was not estimated for this station. Invertebrate richness and diversity increased from the mouth of Amansuri (station A: d= 0.58; H'= 0.74; J'= 0.68) to the northern portions (station C: d= 1.60;

H'= 1.45; *J'*= 0.81) compared to Domini where richness and diversity appeared to be slightly higher at the middle portions (station B: *d*= 0.42; *H'*= 0.03; *J'*= 0.02) than at the mouth (station A: *d*= 0.29; *H'*= 0.01; *J'*= 0.01) and northern portion (station C: = 0.14; *H'*= 0.01; *J'*= 0.01). Overall, richness and diversity of macroinvertebrates were much higher in the Amansuri Lagoon (*d*= 1.25; *H'*= 1.15) than in the Domini Lagoon (*d*= 0.74; *H'*= 0.02). The distribution of the individuals among the different families was also fairly even in the Amansuri Lagoon (*J'*= 0.65) but very poor in the Domini Lagoon (*J'*= 0.01). Moreover, the similarity value was very low (C_s = 0.31) indicating that the macrobenthos communities in the two water bodies were considerably dissimilar (the index ranges from 0 = dissimilar to 1 = completely similar).

Table 2: Occurrence of benthic macroinvertebrates in the Amansuri and Domini Lagoons in the Western Region of Ghana (+ indicates present)

Class	Order/Family	Genus	Amansuri			Domini		
			A	B	C	A	B	C
OLIGOCHAETA				+	+	+	+	+
POLYCHAETA	Maldanidae							+
HIRUDINEA							+	
UNIDENTIFIED WORM					+			
	Diptera/Culicidae	*Culex*		+	+			
	Diptera/Chironomidae	*Tanytarsus*		+	+			
INSECTA		*Chironomus*	+	+			+	
	Diptera/Ceratopogonidae				+			
	Trichoptera/Philopotamidae	*Chimarra*			+			
	Amphipoda/Hautoridae						+	
CRUSTACEA	Hermit Crab					+		
	Penaeidae	*Penaeus*				+		

Table 3: Richness and diversity indices for benthic macrofauna communities in Amansuri and Domini Lagoons in the Western Region of Ghana

Lagoon	Station	No. of invertebrate families	Margalef's Richness (*d*)	Shannon-Wiener diversity (*H'*)	Pielou's evenness (*J'*)	Sorensen's Similarity (C_s)
Amansuri	A	1	0.00	0.00	0.00	
	B	3	0.58	0.74	0.68	
	C	6	1.6	1.45	0.81	
	Overall	**6**	**1.25**	**1.15**	**0.65**	**0.31**
Domini	A	3	0.29	0.01	0.01	
	B	4	0.42	0.03	0.02	
	C	2	0.14	0.01	0.01	
	Overall	**7**	**0.74**	**0.02**	**0.01**	

Composition of Benthic Macroinvertebrates

In the Amansuri Lagoon, only one specimen of Chironomid larva (Chironomidae) was found at station A (Figure 2a). At station B, Chironomid larvae constituted 74% with Oligochaeta and Culicidae constituting 16% and 10%, respectively. The northern section (station C) was also dominated by Chironomidae (41%) followed by Oligochaeta (27%) and Ceratopogonidae (18 %), with each of Culicidae, Philopotamidae and an unidentified worm making up 4.5%. All the stations in the Domini Lagoon (Figure 2b) were highly dominated by oligochaetes (> 99 %). The remaining organisms which occurred at each station together constituted less than 1%.

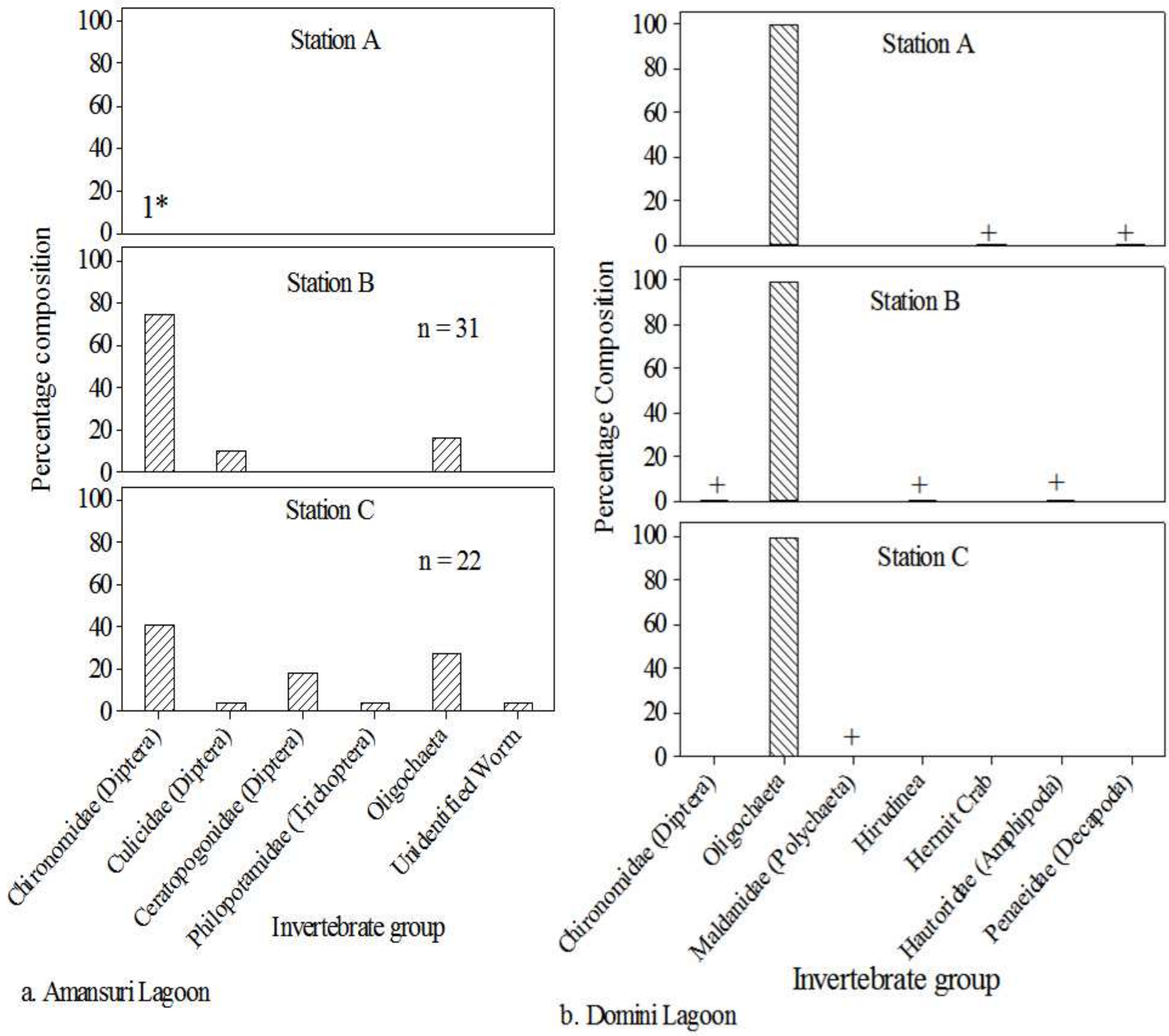

Figure 2: Percentage composition of macrozoobenthos groups at the different stations in the Amansuri and Domini Lagoons in the Western Region of Ghana (1* = 1 individual; + indicates < 1 %)

Density of benthic macrofauna

The mean density of the various invertebrate groups sampled from the Amansuri and Domini Lagoons are presented in Figure 3a and 3b respectively. In Amansuri, Chironomid larvae were far higher in density at the middle of the lagoon (B: mean = 266 individuals/m^2) than at the mouth (station A: 60 individuals/m^2) and northern portions (station C: 102 individuals/m^2) of the lagoon. Also, while the mean density of Culicidae seemed to decrease from station B (81 individuals/m^2) to C (56 individuals/m^2), oligochaete density increased towards the northern portions of the lagoon (stations B and C = 70 and 112 individuals/m^2 respectively). Other benthos which occurred at only station C were Ceratopogonidae with mean density of 89 individuals/m^2, and Culicidae, Philopotamidae and an unidentified worm which had a mean density of 56 individuals/m^2 each.

The densities of oligochaetes were extremely high in the Domini Lagoon, varying from 13,290 individuals/m^2 (station A) to 17,489 individuals/m^2 (station B) while all the other organisms (hermit crab, *Penaeus* shrimps, chironomid larvae, amphipods, leeches and polychaetes) were relatively very low in densities (< 100 individuals/m^2) at stations where they occurred.

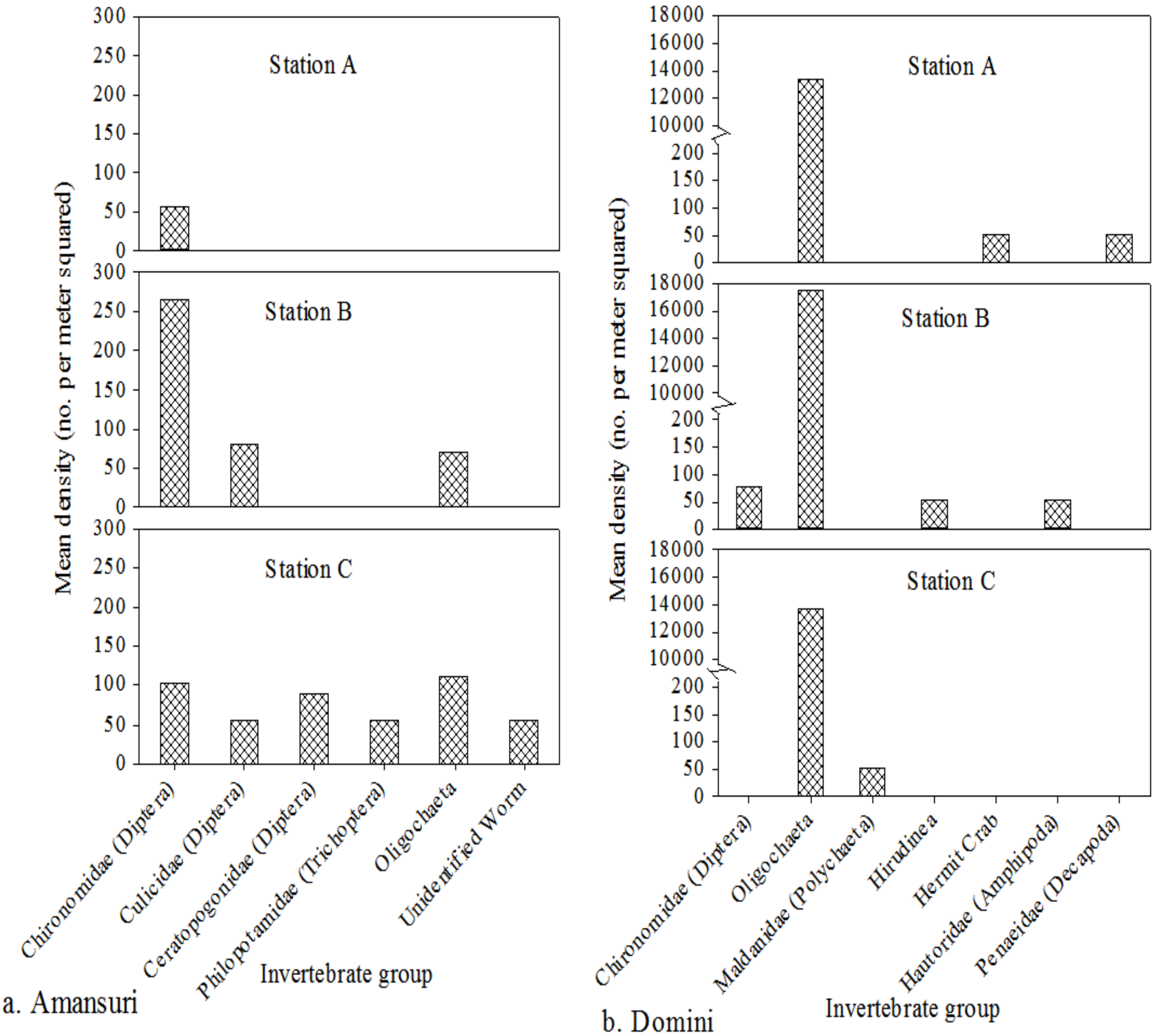

Figure 3: Mean density of macrozoobenthos groups at different stations in the Amansuri and Domini Lagoons in the Western Region of Ghana

DISCUSSION

The approximately 100 lagoons along the coastline of Ghana include brackish and freshwater types [24]. Majority of the freshwater lagoons are found mainly in the Western Region, where the underlying rocks have undergone profound leaching giving rise to extremely ion-poor waters, and the rainfall in excess of 2000 mm per annum produces conditions of high runoff and stream flow [16]. Freshwater lagoons are reportedly useful in providing water supply for domestic purposes [25]. The Amansuri (salinity of 0 ‰) is one of these freshwater lagoons while Domini Lagoon (26.6 - 29.4 ‰) is brackish.

Salinity is the major factor determining the composition, diversity and abundance of macrozoobenthic fauna in coastal lagoons in Ghana [7][26], with high macroinvertebrate diversity and abundance occurring at low salinities, and low diversity and abundance occurring at high salinities. It is therefore possible that the difference in salinity levels of the two lagoons is responsible for the difference in the structure and composition of their macrozoobenthos communities, with the community of Amansuri mostly being insect larvae while that of Domini largely worms (annelids) and marine crustaceans. This explains the very low similarity value (C_s= 0.3) which indicates that the two communities are nearly dissimilar. Pertinently, some of the insects found in Amansuri, especially the Chironomid larvae, are reportedly intolerant to salinities beyond 6 ‰ [27][28], hence the freshwater nature of the lagoon is favourable for their survival and development. With the exception of salinity and conductivity, the other environmental parameters in the two lagoons were generally similar although slight variations occurred among stations within a lagoon. The dissolved oxygen (DO) levels in the Domini Lagoon and greater parts of the Amansuri Lagoon were above the 5 mg/l stated as the threshold required to support aquatic life [29], except the northern portions (station C) of Amansuri which had slightly lower levels (averagely 4.7 mg/l). A pH range of 6.5 to 8.5 is generally suitable for growth of aquatic organisms [30]. The pH of Domini ranged from 7.4 – 7.9, whereas that of Amansuri (5.5 – 6.0) was lower implying that the lagoon was slightly acidic thus could have some negative implications on the diversity of its fauna. The acidity range for Amansuri was expected because most of the earth's freshwater bodies surface are slightly acidic due to the abundance and absorption of carbon dioxide [31].

Although the Domini Lagoon had a relatively higher number of invertebrate families (7) than Amansuri (6), its community was very poor in diversity (overall H' = 0.02) and individuals were poorly distributed among the families (overall J' = 0.01) with oligochaetes being highly dominant in the entire lagoon (> 90% at all stations) at extremely high densities (13,290 - 17,489 individuals/m^2). Two main reasons could account for this observation. Firstly, the lagoon is directly open to the sea [16]. These ‘open’ lagoons maintain contact with the sea for greater period of the year or permanently and thus experience a high extent of tidal influence which renders their environments highly unstable from bottom substrata to physico-chemical conditions [24][32]. Benthic organisms that inhabit such habitats therefore require some adaptive mechanisms including burrowing, tolerance to variable salinities and tolerance to low oxygen tensions, and roundworms such as oligochaetes and polychaetes are reported to thrive in these conditions [32]. Secondly, oligochaetes also feed on organic material in water and are common in environments where large amounts of organic material are present due to their ability to survive the resultant low oxygen levels and other reducing conditions better than most other macrobenthos species [19]. Notably, the highest oligochaete density (17,489 individuals/m^2) occurred at station B where the water was most turbid (averagely 98.3 ppm) suggesting organic material as the source of turbidity in the water, which would strongly imply availability of food for the oligochaetes. Against this background, it is conceivable that the oligochaetes are better adapted to conditions in the Domini Lagoon than the other organisms, and they are highly supported by the environment together with the available organic food resources, given the absence of competition. Most probably, this could explain the poor diversity of benthic fauna in the lagoon despite its favourable dissolved oxygen and pH levels. However, the dominance of certain species of oligochaetes in aquatic environments has been found to be an indication of organic pollution [33]. Therefore, the high dominance of oligochaetes in the Domini Lagoon at extremely high densities when compared to the Muni Lagoon in Ghana (< 10,000 individuals/m^2 at all stations) [7] could be a reflection of some level of organic pollution in the lagoon.

The Amansuri Lagoon which had relatively lower oxygen and somehow acidic conditions below suitable limits rather had a higher macrofauna diversity (overall H'= 1.15) and a fairly even distribution of individuals among the different families (overall J'= 0.65). Interestingly, richness and diversity of macrozoobenthic fauna tended to increase towards the northern sections of the lagoon (station C) where important environmental determinants such as DO was minimal and pH more acidic. This suggests that the assemblage of benthic macroinvertebrate fauna in the lagoon might depend partly on some factors other than those assessed in this study, one of which might be the availability of food. Like oligochaetes, chironomid larvae have also been used as indicators of organic pollution because they are often abundant in environments with low oxygen where organic material as food resource is abundant [34][35]. Hence, the occurrence of higher density of these larvae at the middle of the lagoon compared to the other portions suggests that organic matter input was more concentrated at the middle portions of the lagoon.

CONCLUSION

In conclusion, the freshwater Amansuri Lagoon supports a richer and more diverse macrobenthic fauna than the brackishwater Domini Lagoon, with over 90% of the benthos inhabiting the latter being oligochaetes. The dominant benthos in the lagoons (oligochaetes in Domini and chironomid larvae in Amansuri) are both used as bioindicators of organic pollution in aquatic ecosystems. Hence, occurrence of these organisms at higher densities in the entire or certain areas of the lagoons primarily suggests some levels of organic matter input in the lagoons which could potentially be a source of pollution. This study could therefore be a useful reference point for biomonitoring of the ecological health of these lagoons, especially using the zoobenthic community structure, composition and population densities alongside with the physico-chemical factors. A future decline in oligochaete composition or density in the Domini Lagoon, and increase in benthos richness and diversity would imply improved ecological conditions in the lagoon's environment favourable for a wider range of organisms. Similarly, a higher invertebrate diversity across all portions of Amansuri would suggest prevalence of improved conditions across the lagoon. On the other hand, future reduction in invertebrate composition, richness and diversity would imply a change or deterioration in environmental characteristics of the lagoons.

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