Assessment of the Ecological Health Status of River Pra Estuary (Ghana) and Adjoining Wetland using Physico-chemical Conditions and Macroinvertebrate Bioindicators

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Abstract

The Pra River Estuary, which is the second largest estuary in Ghana, has been under severe threat of siltation from illegal alluvial gold mining activities over a decade. To advocate the need for its conservation, the study assessed the ecological health status of the estuary and its connecting wetland using inhabitant benthic macroinvertebrates and prevailing physicochemical conditions as indicators. Physicochemical factors and macrozoobenthic fauna were sampled February 2012 to December 2013, and the macrozoobenthos were analysed for composition, richness, diversity and density. Results indicated low densities (<300 individuals/m^2) of pollution tolerant benthic macroinvertebrates such as *Capitella* spp., *Nereis* spp., *Tubifex* spp. and *Chironomus* spp. in the estuary and wetland, suggesting a possibly low organic pollution. However, high water turbidities close to 1000 NTU remains an environmental stressor of serious concern in the estuary with possible multiplicity of repercussions on the system and its biota. A broader rehabilitation program that incorporates efforts to combat upstream illegal mining activities is therefore crucially needed to decrease turbidity levels and facilitate restoration of the estuarine ecosystem.

Introduction

Anthropogenic disturbances of aquatic ecosystems along Ghana's coastline, especially pollution of lagoons and estuaries, is on the rise (Biney, 1982; Karikari *et al.*, 2006). Over the last decade, the Pra River Estuary which is the second largest estuary in the country after the Volta Estuary, has come under severe threat of siltation from illegal alluvial gold mining activities upstream. The increased siltation which has turned the estuarine waters murky, if not managed, could have potentially detrimental ecological consequences on the ecosystem and its biota, with possible extended implications for productivity in the nearshore marine waters that receive inputs from the estuary. Given the importance of estuaries in offering provisioning, regulatory, maintenance and other habitat services (Thrush *et al.*, 2013), it is imperative to evaluate the ecological health status of threatened estuaries and advocate for their inclusions in management planning.

Several authors present convergent views on the parameters that define "ecosystem health". According to Costanza (1992), an ecological system is healthy and free from 'distress syndrome' if it is stable and sustainable – that is, if it is active and maintains its organization and autonomy over time and is resilient to stress. Similarly, in the view of Costanza and Mageau (1999), a healthy ecosystem has the ability to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience). Boesch and Paul (2001) also defined a healthy ecosystem as one that actively produces and maintains its biological organization over time, and is resilient to stress. In a further extension, Rapport *et al.* (2001) incorporated ecosystem ecology, human health, socio-economic activities and livelihoods as part of the determinants of ecosystem health as they are all linked to the goods and services provided by ecosystems. From these definitions, it is clear that ecosystem structure, function and resilience are the key determinants of ecosystem health. Reports (Boesch & Paul, 2001; Gaydos *et al*., 2008) show that coastal ecosystem health largely relates to their ability to provide clean waters, assure a diverse biota and support fisheries production.

An "indicator" of ecosystem health is a parameter or value that reflects the condition of an environmental (or organismal health) component of the ecosystem, usually with a significance that extends beyond the measurement or value itself (Environment Canada & USEPA, 1999). Boesch and Paul (2001) explained that there are no commonly accepted parameters or benchmarks for assessing the health of all ecosystems. In other words, the same change in an ecosystem can be good for some, and bad for others. In coastal ecosystems, the commonest way to monitor the ecosystem's health is to measure selected indicators in defined areas of the ecosystem to represent the whole (USEPA, 1998). Although measurement of processes or rate of activities, e.g. primary production, flux of nutrients, or yield as reflected by harvests are occasionally used as ecosystem health indicators, the most widely and commonly used indicators are broadly grouped into two categories: (i) assessment of biological structure (e.g. biomass, community composition and diversity, incidence of diseases) and (ii) measurement of physical and chemical states (e.g. temperature, transparency, turbidity, salinity, concentrations of nutrients, dissolved oxygen, pH, chlorophyll, heavy metals).

In assessing biological structures, phytoplankton community composition has proven very useful for evaluating conditions of coastal ecosystems because they are the major primary producers, have fast growth rates, and are sensitive to environmental disturbances (USEPA, 2005). However, benthic macroinvertebrates are preferred because apart from serving as reliable indicators of pollution, hydrologic stress and ecological health in general (Nazarova *et al.*, 2004), they are also inexpensive to sample and easy to identify with already established diversity and monitoring indices. Since different species of macroinvertebrates react differently to environmental stressors such as pollution, sediment loading and habitat changes, quantifying the diversity and density of different benthic macrofauna at a given area can provide evidence of prevailing environmental conditions (Acharyya & Mitsch, 2001; Arslan *et al.*, 2007). In addition, the sedentary nature of macrozoobenthos, together with their ubiquitous distribution and life cycles of measurable duration allow for both long-and short-term analyses (Rosenberg & Resh, 1993). While biological characterisations of ecosystem health are extremely important in part, they are most useful when combined with physical and chemical habitat assessments. This is because the composition and diversity of biological communities, biological productivity and other related biological interactions in ecosystems are largely dictated by the prevailing chemical and physical conditions of the habitats (Craft, 2000).

This study therefore assessed the benthic macroinvertebrate community and physico-chemical conditions (water temperature, turbidity, salinity, dissolved oxygen and pH) of the Pra River Estuary and its adjoining wetland to evaluate their ecological health status. The state of these indicators can provide benchmarks for comparison with other waters and could also be used to define rehabilitation goals and monitor trends.

Materials and Methods

Study area

Having about 1,000 ha of connecting marshlands, mangrove swamp and floodplains, the River Pra Estuary (Fig. 1) in the Shama District of the Western Region of Ghana (- 5° 01’ 06” N, 1°37’ 33” W), provides important fishery resources for fringing communities (CRC/FoN (2010). Six stations spanning from the mouth of the estuary to the riverine reaches and the adjoining wetlands were selected for the sampling of physico-chemical parameters and benthic macroinvertebrates. Stations A-D were located in the estuary (about 1 km apart) while Station E and F were located in the mangrove swamp and the marshland respectively (Fig. 1). In this regard, the use of wetland within the context of this study refers to the mangrove swamp and marshland.

Measurement of physico-chemical factors

Sampling was undertaken monthly from February 2012 to December 2013. Water temperature, salinity, conductivity, turbidity, dissolved oxygen concentration (DO) and pH were measured using a portable water quality checker (Horiba, U-10). The measurements were taken between 6 hrs GMT and 18 hrs GMT in five continuous days in each month at low and high tides to ascertain water physico-chemical dynamics relative to tidal variations. Triplicate measurements were recorded at each station for each tide in a day, amounting to fifteen replicates per tide at each station for a month, and 345 replicates per tide per station for the 23 month study period from which the means were computed.

Benthic macroinvertebrate survey and data analysis

Three replicate sediment samples were collected monthly from each station using Ekman grab (15 cm × 15 cm). Samples were sieved in the field using a set of sieves of mesh sizes 4000 µm, 2000 µm and 500 µm, and the animals retained in the sieves were preserved in 10% formalin for detailed examination in the laboratory. Prior to sorting, a pinch of Bengal rose dye was added to the samples

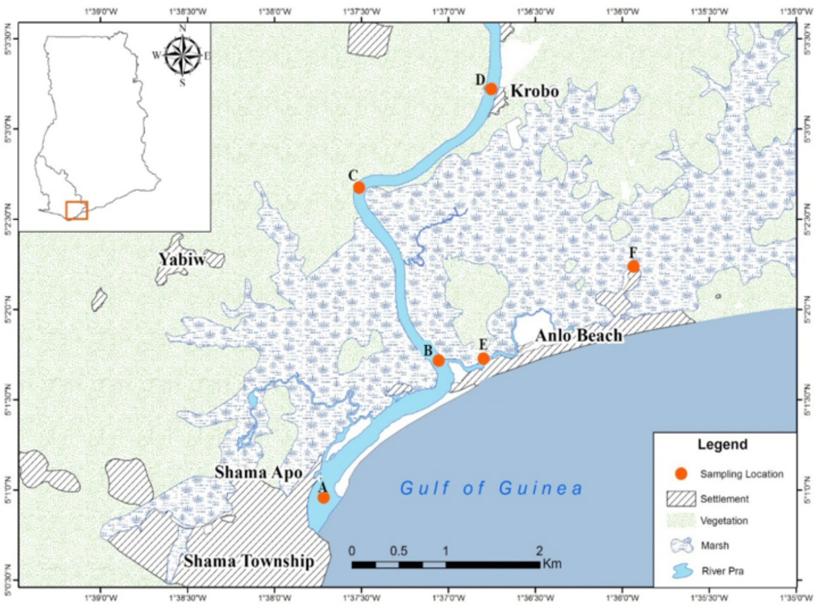

Fig. 1: Map showing the Anlo Beach area and the sampling stations of the Pra River Estuary

to enhance visibility of the organisms. The macrofauna were examined under a dissecting microscope and identified with the aid of laboratory manuals (Day, 1967; Brinkhurst, 1971; Yankson & Kendall, 2001; Hauer & Lamberti, 2006). Counts of the different taxonomic groups in the samples were recorded for further analysis.

The benthos were analyzed for species composition, species richness and diversity. Richness and diversity were ascertained using Margalef's index and the Shannon-Wiener index (Krebs, 1999) respectively. Margalef index (*d*) is given as:

$$\frac{(s-1)}{\ln N}$$

where *s* is number of species in the community, and *N* is the number of individuals in the community. The Shannon-Wiener index (H') is 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. The evenness or equitability component of diversity was calculated from Pielou's index (Pielou, 1966) as:

$$J' = H'/H_{max} \text{ where } H_{max} = \ln s$$

The percentage numerical composition of the different families of macrobenthic animals in the community was calculated. The mean density of each invertebrate class and family (arithmetic mean) was first calculated as the number of individuals of each class or family per dredge area (225 cm^2 = 0.0225 m^2), and the resultant value converted to mean number of individuals per 1 m^2 by multiplying this number by a factor of 44.4 (See Elliott, 1977)

To compute the 95% confidence limits, the variance of transformed counts was first calculated as.

$$\frac{\sum(\log_{10} x - \bar{y})^2}{n-1}$$

where $\bar{y}$ is the arithmetic mean of transformed counts and n is the sample size. The 95% confidence limits were computed as the antilog of

$$\bar{y} \pm t\sqrt{\frac{variance\ of\ transformed\ counts}{n}}$$

where *t* is a tabular statistical value at the 5 % level of probability.

Results

Physicochemical conditions

Figure 2 shows the mean physicochemical conditions at the sampled stations. The lowest temperature of 26.5±0.1 ^{o}C was recorded at the riverine end of the estuary (Station D) while the highest of 29.8±1.7 ^{o}C was recorded in the wetland (Station F) at low tide. On the contrary, the highest turbidity (949±0 NTU) was recorded at the riverine end of the estuary and the lowest (365±30 NTU) in the wetland (Station E) at low tide. In general, turbidity at both low and high tides were statistically similar. Both salinity and conductivity showed a declining trend from the mouth towards the riverine reaches of the estuary, with high tide waters being about three times saline than low tide. Salinity and conductivity at stations within the wetland were higher than the riverine portions of the estuary, but lower than the mouth. Dissolved oxygen concentration (DO) and pH did not vary significantly across the stations. DO was between 4 mg/l and 6 mg/l while pH was between 7 and 8, with the highest values recorded during high tide and the lowest at low tide.

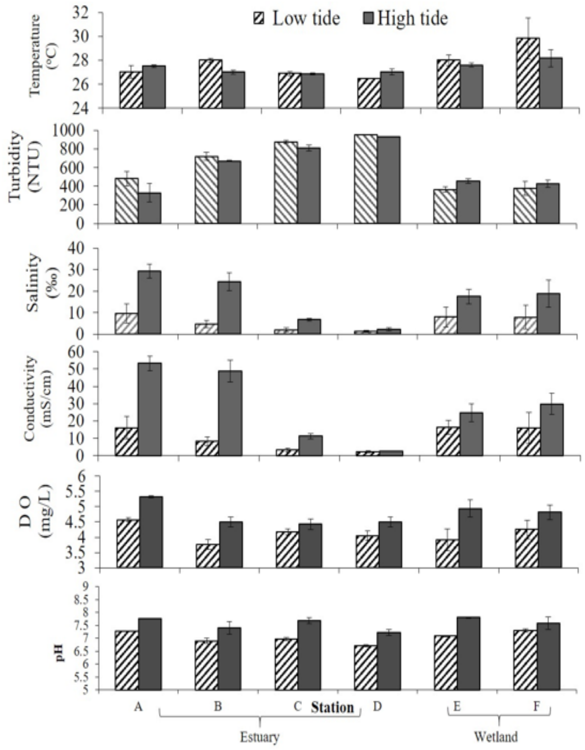

Fig. 2: Mean physicochemical conditions at the stations sampled (vertical bars represent standard errors)

Occurrence of macrozoobenthic organisms

A total of 12174 benthic animals belonging to 49 species were sampled. These comprised 36 species of polychaetes, 4 species of oligochaetes, 7 species of crustaceans and 2 species of insects (Table 1). The polychaetes belonged to fourteen families with Nereidae (rag worms) represented by 11 species, Capitellidae by 6 species and each of the remaining twelve families by 3 or 1 species. Oligochaetes were represented by only two families of which the Tubificidae had 3 species and Naidadae had 1 species. Amphipods of the families Corophidae, Haustoridae, Gammaridae and the isopod family Cirolanidae were the commonest crustaceans. The insects were entirely chironomid larvae from the Family Chironomidae. Unlike polychaetes and oligochaetes which were found at virtually all stations in both habitats, crustaceans were limited to the wetland at Stations E and F while chironomid larvae occurred considerably in the wetland, but sparingly in the estuary. Overall, 9 species were sampled from Station A, 21 from Station B, 6 from Station C and 4 from Station D in the estuary while 17 species were sampled from Station E and 21 from Station F in the wetland.

TABLE 1

Occurrence of benthic macroinvertebrate fauna at the six stations in the Estuary and the Wetland (numbers are total number of specimens; - indicates absent)

			Estuary				Wetland	
Order	Family	Species	A	B	C	D	E	F
Phylum Annelida - Class Polychaeta								
	Scalibregmidae	*Hyboscolex longiseta*	299	253	-	-	72	-
		Polyphysia crassa	-	322	-	-	-	-
		Asclerocheilus capensis	-	-	-	-	68	-
	Capitellidae	*Pulliella armata*	184	368	186	-	-	-
		Capitella capitata	-	138	-	69	-	186
		Notomastus aberans	-	-	-	-	201	-
		Paraheteromastus tenuis	-	-	-	-	-	19
		Heteromastus filiformis	-	161	-	-	-	-
		Dasybranchus bipartitus	-	184	-	-	-	-
	Maldanidae	*Maldanella capensis*	253	-	-	-	-	-
		Maldane sarsi	-	365	-	-	69	117
		Euclymene quadrilobata	-	-	-	-	-	140
	Pisionidae	*Pisione africana*	437	-	-	-	-	-
	Amphimonidae	*Euphrosine capensis*	23	-	-	-	-	-
	Arenicolidae	*Branchiomaldane vincenti*	-	161	-	-	-	-
		Arenicola loveni	-	46	-	-	-	-

TABLE 1
Occurrence of benthic macroinvertebrate fauna at the six stations in the Estuary and the Wetland (numbers are total number of specimens; - indicates absent) - continue

			Estuary				Wetland	
Order	Family	Species	A	B	C	D	E	F
	Chaetopteridae	*Phyllochaetopterus sp.*	-	48	-	-	-	137
	Nereidae	*Nemanereis quadraticeps*	-	437	-	-	-	-
		Namalycastis indica	-	-	-	-	90	
		Dendronereides zulilandica	-	-	-	-	57	803
		Nereis granulata	-	-	46	-	-	-
		Neonereis ankyloseta	-	-	-	-	-	139
		Nereis caudata	-	-	-	-	-	115
		Nereis operta	-	-	-	-	-	24
		Ceratonereis pachychaeta	-	47	-	-	-	91
		Micronereides capensis	-	92	-	-	-	-
		Perinereis falsovariegata	-	163	-	-	-	-
		Leonnates perisca	46	-	-	-	-	-
	Eunicidae	*Eunice siciliensis*	-	135	-	-	-	-
	Alicopidae	*Krohnia lepidota*	-	160	-	-	-	-
		Naiades centrainii	-	-	276	-	-	321
	Nephtyidae	*Nephtys debranchis*	-	-	207	23	-	-
	Sepionidae	*Prionospio cirrifera*	-	-	-	-	48	-
	Orbiniidae	*Scoloplos armiger*	-	18	-	-	-	-
	Phyllodocidae	*Eulalia viridis*	-	-	-	-	-	210
		Eulalia microcerus	-	-	-	-	-	26
Phyllum Annelida - Class Oligochaeta								
	Tubificidae	*Limnodrilus hoffmeisteri*	-	55	53	59	432	567
		Tubifex tubifex	276	230	133	-	463	312
		Limnodrilus angustepenis	-	31	-	-	216	23
	Naididae	*Pristina sp.*	74	144	-	-	163	20
Phyllum Arthropoda - Class Insecta								
Diptera	Chironomidae	*Chironomus sp.*	21	-	-	-	94	-
		Tanytarsus sp.	-	-	-	49	-	73
Phyllum Arthropoda – Crustacea								
Cumacea	Ceratocumatidae	Unidentified species	-	-	-	-	22	65
Amphipoda	Corophidae	*Corophium sp.*	-	-	-	-	71	-
	Haustoridae	Unidentified species	-	-	-	-	89	-
	Gammaridae	*Gammarus locusta*	-	-	-	-	92	138
Tanaidacea	Tanaidae	Unidentified species	-	-	-	-	38	-
Isopoda	Cirolanidae	Unidentified species	-	-	-	-	66	-
Mysidacea	Mysidae	*Mysis relicta*	-	-	-	-	-	25

Diversity of macrozoobenthic communities

Table 2 shows the species richness, diversity and evenness of the macrozoobenthic community at the different stations. The highest diversity of invertebrates ($H'= 2.3$) was found at Station B which was about a kilometer from the mouth of the estuary while the lowest ($H'= 1.0$) occurred at the riverine reaches of the estuary at Station D. With respect to species richness, stations in the wetland had the richest benthic fauna ($d > 2.3$). At all stations, individuals were fairly distributed among the species ($J' \geq 0.6$).

TABLE 2
Diversity of benthic macroinvertebrates at the stations in the estuary and the wetland

	Estuary				Wetland	
Station	A	B	C	D	E	F
Number of Families	9	11	5	4	14	12
Number of Species	9	21	6	4	17	21
Richness (*d*)	1.2	2.3	0.8	0.5	2.7	2.4
Diversity (*H'*)	1.6	2.3	1.4	1.0	2.1	1.4
Eveness (*J'*)	0.9	0.9	1.0	0.9	0.9	0.6

Macroinvetebrate composition and density

Polychaete worms dominated the benthic community, constituting 87.5% in the estuary and 51.3% in the wetland (Fig. 3). This was followed by oligochaete worms with a composition of 11.2 % in the estuary and 38.6% in the wetland. Insect larvae were the least consisting 1.3% and 2.4% in the estuary and wetland respectively, while crustaceans which occurred only in the wetland were 7.8% of the benthos.

Density of the various macroinvertebrate families at the stations is illustrated in Figure 4. At the mouth of the estuary (Station A), polychaetes of the Family Pisionidae (mainly *Pisione africana*) and Scalibregmidae (*Hyboscolex longiseta*) dominated the benthos with mean densities of 94 individuals/m^2 and 63 individuals/m^2 respectively, followed by the oligochaetes of the Family Tubificidae (*Tubifex tubifex*) with 59 individuals/m^2. The densities of organisms were much higher at Station B than A, with the most densely populated organisms being polychaetes of the Families Nereidae (mostly *Nemanereis quadraticeps*; 212 individuals/m^2), Capitellidae (*Pulliella armata*; 153 individuals/m^2), Scalibregmidae (*Polyphysia crassa*; 123 individuals/m^2) and oligochaetes of the Family Tubificidae (*T. tubifex*; 133 individuals/m^2). Contrary to the stations closer to the mouth, the stations

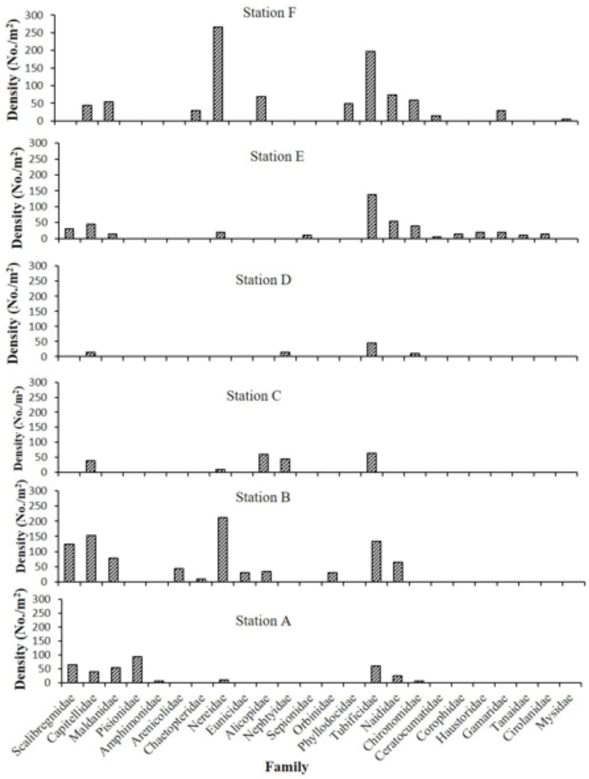

Fig. 4: Mean density of benthic macrofauna families at the six stations in the Pra Estuary and connecting wetland

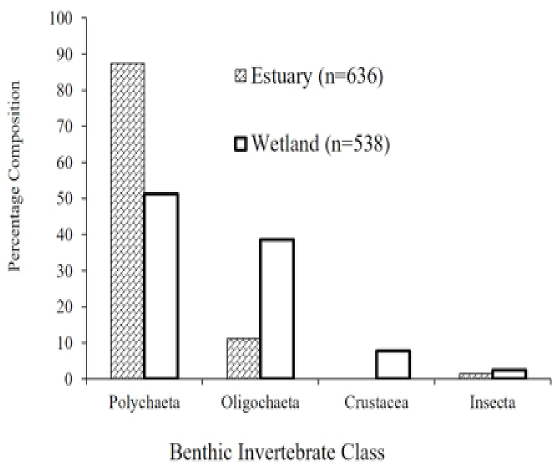

Fig. 3: Percentage composition of benthic macrofauna Classes in the estuary and wetland

nearer to the riverine reaches (Stations C and D) had very few benthic organisms and at relatively low densities (< 50 individuals/ m^2) which declined towards the most riverine protions at Station D where only four species were encountered of which the oligochaete *Limnodrilus hoffmeisteri* (Tubificidae) was the commonest.

In the wetland, tubificid oligochaetes were the most densely populated fauna at Station E (138 individuals/m^2) while both tubificid (197 individuals/m^2) and nereid (266 individuals/ m^2) worms were dominant at Station F. Chironomid larve (Chironomidae) and other freshwater invertebrates also occurred in the wetland but at low densities.

Discussion

The diversity and density of benthic macrofauna at a given location are strongly tied to prevailing environmental conditions and stressors (Acharyya & Mitsch, 2001; Arslan *et al.*, 2007). In the Pra estuary, the lowest richness and diversity of benthic macroinvertebrates were observed at the most turbid sampling location (Station D), where only four species of zoobenthic organisms were found with low densities (less than 50 individuals/m^2). Turbidities caused by large amounts of suspended matter are known to cause clogging of the gills of filter-feeding invertebrates (Kyte & Chew, 1975; Barnes *et al.*, 1991). According to Schubel (1977), acute effects of turbidities on estuarine organisms occur at levels beyond 500 NTU, a concentration far below the values close to 1000 NTU recorded at the Station. This extremely high turbidity at the riverine reaches of the estuary could therefore account for the correspondingly poor macrozoobenthic community. This is similar to the observations of Ishaq and Khan (2013) in the Yamuna river in India where the average macrozoobenthic density showed an inverse relationship with turbidity but was positively correlated with transparency.

Annelid worms, predominantly polychaetes (87.5%) and oligochaetes (11.2%) made up the benthic community in the Pra estuary, with insects occurring sparingly (1.3%). This community had fewer taxa of benthic organisms when compared to other estuaries in Ghana such as the Nyan and Kakum estuaries where Dzapkasu (2012) recorded Annelida, Phoronida, Nemertea, Crustacea, Insecta and Mullusca. It is possible that the two estuaries had more macrozoobenthic taxa due to their low turbidities; the highest turbidity of 120 NTU was recorded for Nyan and 60 NTU for Kakum (Dzapkasu, 2012). This could explain why Pra was dominated by polychaetes of the Families Capitellidae and Nereidae which are known to be typical inhabitants of muddy waters (Yankson & Kendall, 2001), while Nyan was dominated by Orbiniidae (*Scoloplos* sp.) which are reported to prefer clean coarse and fine sands (Fish & Fish, 1996). The occurrence of *Tanytarsus* (Chironimidae) at only Station D in the Pra estuary confirms the reports of Cuomo and Zinn (1997) that freshwater macroinvertebrates such as chironomid larvae usually inhabit the more riverine areas of estuaries.

The benthic community in the wetland connecting the Pra estuary comprised a fair representation of oligochaetes, polychaetes, crustaceans and insects (mainly chironomid larvae). This was richer and slightly diverse compared to the wetland adjoining the Kakum estuary where Okyere *et al.* (2011) reported of only chironomid larvae and oligochaetes as the inhabitant benthos. The richer macrozoobenthic fauna could be attributed to the fact that the pools inhabited by the benthic community in the Pra marshland are persistent and receive continuous tidal inflows which have enhanced the development of a stable and diverse community over time. The pools in the Kakum marshland, on the contrary, are ephemeral habitats that are formed during the rains and dry up during the dry season thereby inhibiting the development of a richer and stable community. Another reason may be the relatively higher dissolved oxygen range in the current wetland (3.5 – 6.5 mg/l) which probably favoured more fauna than the Kakum estuary wetland (2.5 to 4.5 mg/l) that had only organisms that tolerate low DO.

Kenney *et al.* (2009) reported the importance of benthic macroinvertebrates as indicators of water quality. In the present study, the polychaete Families Capitellidae and Nereidae, and the oligochaete Family Tubificidae that dominated the benthos of the habitats are known to be tolerant of low oxygen tensions and organic pollution (Yankson & Kendall, 2001). Specifically, among the benthic macroinvertebrate species occurring in the estuary and wetland, *Capitella* spp., *Nereis* spp., Tubifex spp. and *Chironomus* spp. have been used as indicators of organic pollution (Rae, 1989; Dean, 2008; Martins *et al.*, 2008). In organically polluted systems, density of *Tubifex* have been reported to exceed 5000 individuals/m^2 (Martins *et al.*, 2008) while density of the polychaetes could reach 10,000 individuals/m^2 (Giangrande *et al.*, 2005). However, none of the benthic animals encountered in this study reached such high densities, the highest mean density being 266 individuals/m^2 for *Nereis* spp. at Station F in the wetland. This suggests low organic pollution in the Pra River Estuary and its connecting wetlands.

Although estuarine macrozoobenthic communities are well known to be dominated by polychaetes and some species of oligochaetes due to their euryhaline capacities (Cuomo & Zinn, 1997; Chainho *et al.*, 2006), studies have shown that their high dominance relative to other organisms could also be a result of anthropogenic disturbances which deteriorate the water quality thereby engendering a shift in macrofauna composition in favour of the more tolerant taxa. This is exemplified by the Swan-Canning Estuary in South-western Australia where according to Wildsmith *et al.* (2011), densities and number of species of stressor susceptible crustaceans declined while those of the tolerant polycheates increased consistently with deteriorating environmental conditions in close to two decades. Considering the continual siltation of the Pra estuary from illegal mining activities resulting in the high turbidity which has the propensity to alter the species composition of the system, it is important that this study serves as a baseline for which future monitoring assessments as well as studies on other such anthropogenically disturbed estuaries in the tropics could be compared.

Conclusion and recommendation

The benthic macroinvertebrate fauna of the Pra estuary and its connecting wetland consisted of predominantly polychaetes (87.5% in the estuary and 51.3% in the wetland), and considerably oligochaetes (11.2 % in the estuary and 38.6% in the wetland), with insects and crustaceans constituting low proportions (< 10%). Low densities (<300 individuals/m^2) of pollution tolerant organisms such as *Capitella* spp., *Nereis* spp., *Tubifex* spp. and *Chironomus* spp. were recorded, suggesting a possibly low organic pollution of the estuarine waters. However, high turbidities close to 1000 NTU remains an environmental stressor of concern as it could have a multiplicity of repercussions on the ecosystem and its inhabitant biota. Therefore, efforts tailored to combating upstream illegal alluvial gold mining activities to improve the deteriorated turbidity levels are critically needed to safeguard the ecosystem. This should complementarily incorporate a rehabilitation program and monitoring scheme to facilitate restoration of the Pra estuarine system.

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