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Characterization of macro-benthic fauna for ecological health status of the Fosu and Benya lagoons in coastal Ghana

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Abstract

This study conducted a comparative analysis of benthic macroinvertebrate communities in the Fosu and Benya lagoons in Ghana, based on the anthropogenic effect on the two lagoons. Salinity, oxygen, temperature, conductivity, turbidity and pH were measured, invertebrate richness and species densities were determined. The AZTI Marine Biotic Index (AMBI) and multivariate statistics were used to determine the different responses of fauna to pollution. The fauna were categorized into five ecological groups based on the degree of tolerance of the different species to pollution: disturbance-sensitive species; disturbance-indifferent species, disturbance-tolerant species, second-order opportunistic species; and first-order opportunistic species. The Fosu Lagoon supported more pollution tolerant species, whereas the Benya Lagoon had more species that were sensitive to organic enrichment under relatively unpolluted conditions. *Chironomus* sp., which is adapted to virtually anoxic conditions, was the most abundant in the Fosu Lagoon whereas Nemertea sp. was the most abundant in the Benya Lagoon. The numerical and relative abundance (%) of all 7 taxa in the Fosu Lagoon was 1,359 and 92.35%, respectively. The numerical and relative abundance (%) of all 34 taxa in the Benya Lagoon was 2,459 and 87.52%, respectively. Expectedly, the level of dissolved oxygen in the less saline Fosu Lagoon was higher than that in the more saline Benya Lagoon. The reduced photoperiod and photosynthetic activities of aquatic plants might account for this trend. There is a need to implement comprehensive monitoring and management initiatives for sustaining the ecological health of coastal lagoons in Ghana in order to support the many people that depend upon these ecosystems for their livelihood.

Key words: AMBI index, Benya, Fosu, Ghana, macrobenthic fauna, multivariate statistics

INTRODUCTION

Ecological health is a multidimensional concept that cannot be easily measured or monitored. Nevertheless, the composition and structure of soft-bottom macro-faunal communities are successfully used to characterize environmental conditions and to estimate the extent of environmental impact, as indicators for ecological health (Nyenje et al. 2010). Lagoons have four major categories of sustainability: the production of food and water; the control of climate and disease; the cycling of nutrients and pollination of crops; and cultural benefits, such as providing spiritual and recreational grounds for mankind (Tlig-Zouari et al. 2009). Ghana is involved in the Guinea Current Large Marine Ecosystems initiative. The fisheries of almost all the lagoons and estuaries in Ghana are ar-

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tisanal (large subsistence) but play an important role in the socio-economy of coastal inhabitants in terms of employment and the provision of fish protein. In addition to providing habitats for fish, lagoons are important staging, feeding and roosting areas for migratory birds. Currently, lagoons and estuaries of this region are under stress from anthropogenic interferences such as changing land use, destruction of fringing mangroves, discharges of domestic and industrial wastes and overfishing (French et al. 1995, Armah et al. 2010). The most severe direct results of such pressures on estuaries and lagoons in Ghana are the reductions in freshwater inflow and the deterioration of water quality. Additionally, climate change poses a potentially serious future threat to estuaries and lagoons. Even with moderate rises in sea levels these low-lying ecosystems are at risk of inundation and further erosion (French et al. 1995).

Deterioration of the ecological health of lagoons leads to dissolved oxygen (DO) deficits, aquatic toxicity, variation in organism composition, disappearance of benthic organisms, turbidity and eutrophication-induced odours, reductions in fish size, and fish mortality (Specchiulli et al. 2009, Armah et al. 2010).

Several methods and indices have been used to assess the impact of increasing pollution on the ecological health of lagoons. The Reish Method uses the distribution pattern of pollution-tolerant polychaetes, particularly *Capitella capitata*, while the SAB model (Pearson and Rosenberg 1978) uses macrofauna parameters: specific richness (S), abundance (A) and biomass (B) to estimate the eco-health of lagoons. Lately, other ecological health indices such as the AZTI Marine Biotic Index (AMBI) (Borja et al. 2000) and the BENTIX index (Simboura and Zenetos 2002) have been developed. The AMBI index uses the presence of certain species to indicate pollution. Species such as *Ulva, alpheus, nemerteans, orbinidae, polynoids, pectin* and red algae: *Gracilaria, Porphyra* and *Corallina,* and high structural complexity species, such as Phaeophyta (belonging to *Fucus* and *Laminaria* orders), are generally thought to be the most sensitive to general forms of pollution, whereas species of the order Fucales are considered to cope with moderate pollution (Borja et al. 2000). In contrast, marine Spermatophytae are considered as indicator species of good water quality (Borja et al. 2000). AMBI has been tested under different stress sources (Borja et al. 2003) and has been applied not only in Europe but also in Asia (Lizhe et al. 2003), Northern Africa (Bazairi et al. 2005) and South America (Muniz and Pires-Vanin 2005). This is the first time that it is being applied on coastal ecosystems in Ghana within the West African segment of the Gulf of Guinea.

This study focuses on two pollution sensitive coastal lagoons: a closed lagoon (Fosu) and an open lagoon (Benya), both of which have experienced anthropogenic pressures, although the magnitude and frequency of pollution is not uniform throughout the two. The Fosu Lagoon is considered to be highly polluted (Armah et al. 2010) due to the disposal of waste, water withdrawal for irrigation, reduction in size of the popular black chin tilapia in recent years, and increasing severity of algal blooms (Gilbert et al. 2006, Darkwa and Smardon 2010). Discharge into the lagoon from a cluster of mechanical workshops a source of Iron (Fe), Magnesium (Mn), Cadmium (Cd), Zinc (Zn), and Nickel (Ni) in the Fosu Lagoon (Gilbert et al. 2006). Though there is no industrialization around the Benya Lagoon, its proximity to a fish market, which serves about 500 individuals weekly, creates the likelihood of waste and effluent disposal through the associated anthropogenic activity. A naturally eutrophic-mesotrophic environment is gradually shifting towards eutrophic-dystrophic conditions (Yankson and Kendall 2001). This situation threatens the sustainability of fisheries, and therefore suggests the need for an assessment of the ecological health status of the two lagoons. Consequently, the aim of this study is to determine the physicochemical parameters, and to characterize and quantify the macro-benthic fauna in sediments, in order to estimate pollution levels in these sensitive ecosystems.

MATERIALS AND METHODS

Study area

The Fosu Lagoon (5°6′17.87″ N, 1°15′18.68″ W) is a closed coastal lagoon in Cape Coast, Ghana. It is a shallow brackish body of water separated from the Gulf of Guinea by a sand bar, which is frequently removed by heavy rainfall, or by the local people as part of a series of annual rituals. The temperature of the Fosu Lagoon ranges between 26-33°C. Apart from its significance to the traditional heritage of the people, it provides a livelihood for fishermen (Armah et al. 2010). The Benya Lagoon (5°05′ N and 1°22′ W) is an open Lagoon that is in contact with the sea throughout the year, and therefore, is under tidal influence. The temperature of the Benya Lagoon ranges between 24-32°C and the salinity between 10-40 psu. The depth of the Fosu Lagoon ranges between 0.3 m and 0.8 m; and the depth of the Benya Lagoon ranges between 0.5 m and 2 m. Both lagoons are shown in Fig. 1.

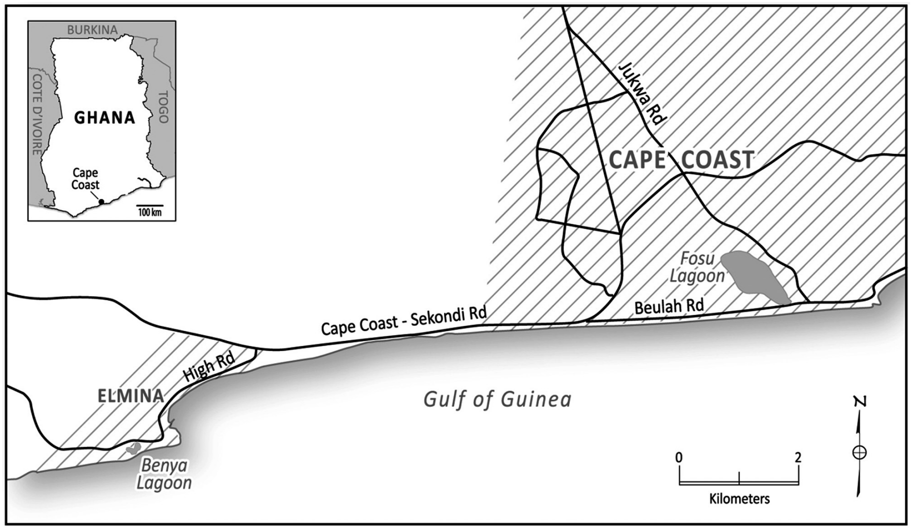

Fig. 1. Map of Ghana coastline showing the Benya and Fosu lagoons.

Data collection

Benthic sampling

This study provides a short-term picture of water quality (i.e., synoptic surveillance study) and is intended to describe the water quality at specific locations, as well as an opportunity to develop a sampling network and long term monitoring program. It is necessary to provide indications of whether more (or possibly fewer) samples are needed in order to gain knowledge of the water quality at various points throughout a water body, in the long term. Four main sites were each selected at the Fosu and Benya lagoons. These sites reflect different pollution sources, including settlement, industrial, and household sewage. The average distance between the observing sites and the pollution source was 25 m. Regarding the Fosu Lagoon, site 1 was located near the drainage; site 2 near the metropolitan hospital; site 3 in the middle of the lagoon; and site 4 near the mechanic workshops. For the Benya Lagoon, Site 1 was located under a bridge-outlet to the sea; Site 2 near human settlements; Site 3 in the middle of the lagoon and Site 4 (near the *Rhizophora* mangrove). Additionally, four sites for the Benya Lagoon and two sites for the Fosu Lagoon were randomly selected for sampling. A total of 120 sample sediments were collected from the Fosu and Benya lagoons November 2010 to March 2011 using the Eckman grab. Samples for the study of macro benthic communities were hand sorted into major taxonomic groups, identified to the lowest practical taxonomic level (usually species level) and counted. From each sampling site, the species list and abundance were obtained by the sum of their respective replicates. The samples were collected bi-weekly for a period of 10 weeks. Before further analyses, the data were checked for compliance with AMBI guidelines (Borja and Muxika 2005). For the development of the AMBI, the soft bottom macro fauna was divided into five groups according to their sensitivity to increasing stress. Group I was obtained by noting organisms that do not thrive well under excessive algal growth and oxygen depletion; group II was obtained by noting organisms that thrive well in excessive algal growth and oxygen depletion; group III was obtained by noting organisms that thrive very well in conditions of organic matter enrichment, but may also do well in unpolluted conditions. Species in group IV were usually short-lived, dispersed rapidly, and were able to colonize harsh or disturbed environments; group V was composed of first-order opportunists, essentially deposit-feeders including oysters, clams, and mussels.

$$AMBI = \{(0 \times \%GI) + (1.5 \times \%GII) + (3 \times \%GIII) + (4.5 \times \%GIV) + (6 \times \%GV)/100\}$$

where % in the AMBI calculation represents total abundance. AMBI and multivariate-AMBI (M-AMBI) were calculated using AMBI ver. 5.0 software (Borja and Muxika 2005). GI-GV refer to groups I to V. M-AMBI involved the ordination of samples based on the values of AMBI, number of species and diversity, followed by a factor analysis to determine the distance of samples from "High" and "Bad" endpoints. For polluted conditions the M-AMBI value is 0, and for unpolluted conditions the M-

AMBI value is 1. The classification boundaries used were the standard boundaries determined by inter-calibration of benthic ecological status assessment between states along the Gulf of Guinea. Table 1 shows the AMBI values and their respective equivalences.

Water chemistry

The water quality measurements for the Fosu Lagoon were made at the same time as benthic sample collection. *In situ* measurement of temperature, pH, DO, salinity, conductivity, and turbidity were carried out at all sites for the Fosu and Benya lagoons. Temperature, conductivity, DO, pH, and turbidity were measured by using a multi parameter probe, Model YSI 6920 with 650 MDS Display/ Logger (YSI Hydrodata Inc., Hertfordshire, UK).

Determination of particle distribution and textural class

Sediment samples were collected, weighed, washed in brine, and first air-dried at 25°C and subsequently, oven dried at 30°C (Dyer 1986). For physical analysis, the dried sample was sieved through a series of Wentworth sieves of variable mesh sizes and retaining the fraction each time, the sieve sizes were 0.5 mm (500 μ), 0.25 mm, 0.125 mm, and 0.0625 mm. Each fraction was carefully weighed.

Data analysis

Descriptive statistics for the water quality data were performed with SPSS ver. 16.0 for windows (SPSS Inc., Chicago, IL, USA). The distributions were approximated to normal distribution based on Kolmogorov-Smirnov (K-S) tests. Relationships among water properties were tested using correlation analysis. Principal component analysis was employed to separate the physicochemical groupings inherent in the structure of the correlation matrix.

RESULTS

Environmental factors

The pH values of the two lagoons (as presented on Table 2) were alkaline although the closed Fosu Lagoon had a higher pH than the open Benya Lagoon. There was a statistically significant difference between the mean pH for the two lagoons ($P < 0.001$). Expectedly, the salinity of the Benya Lagoon was 15 times higher than that of the Fosu Lagoon, which has limited and intermittent contact with

Table 1. Summary of the AMBI values and their equivalences (Borja et al. 2000)

Biotic coefficient	Dominating ecological group	Benthic community health	Site disturbance classification	Ecological status
0.0 < AMBI ≤ 0.2	I	Normal	Undisturbed	High
0.2 < AMBI ≤ 1.2	II	Impoverished		
1.2 < AMBI ≤ 3.3	III	Unbalanced	Slightly disturbed	Good
3.3 < AMBI ≤ 4.3	IV-V	Transitional to pollution	Moderately disturbed	Moderate
4.3 < AMBI ≤ 5.0		Polluted		Poor
5.0 < AMBI ≤ 5.5	V	Transitional to heavy pollution	Heavily disturbed	
5.5 < AMBI ≤ 6.0		Heavily polluted		Bad

AMBI, AZTI Marine Biotic Index.

Table 2. Summary statistics of physicochemical parameters for the Benya and Fosu lagoons ($N = 40$)

	pH	Salinity (psu)	Conductivity (μS/cm)	Turbidity (NTU)	Oxygen (mg/L)	Temperature (°C)
Benya Lagoon						
Mean	7.46	33.70	33,701.50	5.50	1.24	29.49
Standard deviation	0.54	1.87	1,873.31	1.54	0.22	0.46
Fosu Lagoon						
Mean	8.22	2.13	4,446.80	46.30	8.74	31.37
Standard deviation	0.55	0.12	426.47	3.64	1.11	0.73

the Atlantic Ocean. The turbidity of the Fosu Lagoon far exceeded that of the Benya Lagoon. This was indicative of the magnitude of anthropogenic activities around the former. The salinity of the Fosu Lagoon was lower than that of the Benya Lagoon; it was therefore expected that the DO in the Fosu Lagoon would be higher than that of the Benya Lagoon. T-test (2-tailed) showed that there was a statistically significant difference in the DO of the two lagoons ($P < 0.001$). The temperature of the Fosu Lagoon was relatively higher than that of the Benya Lagoon. There was a statistical significant difference between the mean temperature of the Fosu and Benya lagoons ($P < 0.001$). Oxygen was strongly correlated with salinity ($r = 0.499$) at the 0.05 level and conductivity ($r = 0.676$) at the 0.01 level. Turbidity was inversely correlated with pH ($r = -0.509$) and was positively correlated with temperature ($r = 0.483$). These correlations were not consistent for both the Benya and Fosu lagoons, and in several cases, dramatic differences were observed. For instance, in the Fosu Lagoon, there were strong correlations between temperature and pH, conductivity and oxygen, and turbidity and oxygen, whereas a different set of associations were observed for the Benya Lagoon.

Community structure

For the Benya Lagoon, it was observed that during low tides more diversified species were obtained than during high tides. About 2,459 individuals were distributed among 34 taxa in the Benya Lagoon. Only polychaeta and bivalves were widely distributed; however, gastropods, oligochaetes, phoronids and isopods were also important groups in terms of occurrence (Table 3). The diversity of species in the Benya Lagoon was recorded to be 7.11E-01

Table 3. Abundance of macro benthic fauna in sediments from the Benya Lagoon

Benthos	Week						H	Relative
	1	3	5	7	9	Total	H(-∑*Pi*ln*Pi*)	abundance (%)
Alpheus pontederiae	2			1		3	-8.18E-03	0.12
Amphinome rostrata		2				2	-5.79E-03	0.08
Ampithoe sp.	9				5	14	-0.0294	0.57
Senilia senilis		1	1	2	5	9	-0.0205	0.37
Aoridaea sp.			3	1	2	6	-0.0147	0.24
Bryozoa sp.	18			4	4	26	-0.0481	1.06
Capitellidae	5			20		25	-0.0467	1.02
Chaetopterus sp.	3					3	-8.18E-03	0.12
Cirratulidae	4				1	5	-0.0126	0.20
Corophium sp.	2	1				3	-8.18E-03	0.12
Crinophtheiros sp.	1				2	3	-8.18E-03	0.12
Gecarcinidae		2				2	-5.79E-03	0.08
Glycera convulata	1				3	4	-1.04E-02	0.16
Haussorius sp.		5				5	-1.26E-02	0.20
Hermichordata		1				1	-3.18E-03	0.04
Pagurus sp.		1				1	-3.18E-03	0.04
Holothuroidea	5		2	7	8	22	-4.22E-02	0.89
Lumbrineridae	1			3		4	-1.04E-02	0.16
Nemertea	554	349	466	532	251	2,152	-1.17E-01	87.52
Nephtys sp.	3	1	7	5	1	17	-3.44E-02	0.69
Nereidae	26	8	6	13	4	57	-8.73E-02	2.32
Ocypoda stimpsoni	2					2	-5.79E-03	0.08
Onuphidae	2			4		6	-1.47E-02	0.24
Ophelia pulchela	2			4		6	-1.47E-02	0.24
Orbinia ornata	1					1	-3.18E-03	0.04
Pectinaria gouldii	1			1		2	-5.79E-03	0.08
Phoxocephalus sp.	1			2		3	-8.18E-03	0.12
Pitar morrhuana				5		5	-1.26E-02	0.20
Polynoe sp.	1			3		4	-1.04E-02	0.16
Potunidae		1				1	-3.18E-03	0.04
Syllidae		2		17	6	25	-4.67E-02	1.02
Terebellidae		17	2	10	5	34	-5.92E-02	1.38
Total	644	391	493	634	297	2,459	7.11E-01	100.00
Mean	30.66667	30.07692	61.625	35.22222	22.84615			

and the species with the most percentage abundance and numerical abundance was Nemertea (87.52% and 2,152, respectively). *Chironomus* spp., (which is adapted to anoxic conditions) was the most abundant and the total number of individuals in the various species was found to be 1,359 (Table 4). This was distributed among 7 taxa. The relative abundance of *Chironomus* spp., was 92.35%. This implies that *Chironomus* spp. is the dominant species in the Fosu Lagoon, and that the lagoon is characterized by low diversity and poor water quality. Other species, such as *Syllides* sp., *Nermetina* sp., *Ophelia* sp., *Draconema* sp., *Glycera* sp., and *Echinolittorina pulchella,* were less abundant. The M-AMBI values for the respective stations in the Benya Lagoon were 0.804, 0.548, 0.304, 0.491, 0.564, 0.851, 0.879, and 0.849 (Table 5). The M-AMBI values for the respective stations in the Fosu Lagoon were 0.733, 0.695, 0.832, 0.552, 0.554, and 0.911 (Table 6). The diversity and richness of species of the Benya Lagoon was higher than that of the Fosu Lagoon (Tables 6 and 7). The substratum was categorized as gravel, sand, silt or clay depending on the particle size diameters, ≥2.00 mm, 1.00-0.125, 0.05, <0.05, respectively. Fine sediments, primarily clay and silt, characterized the Benya Lagoon. However, though site 4 had a large proportion of gravel that exceeded 30%. In contrast, the Fosu Lagoon was composed of coarse sand and very coarse gravel.

Principal component analysis

Two components each in the Benya and Fosu lagoons had Eigen values greater than 1. Cumulatively, these explain 72% and 70% of total variance in the Benya and Fosu lagoons data, respectively (Table 7). For the Benya Lagoon, salinity and conductivity showed strong positive loadings on factor 1 (natural hydrochemical properties).

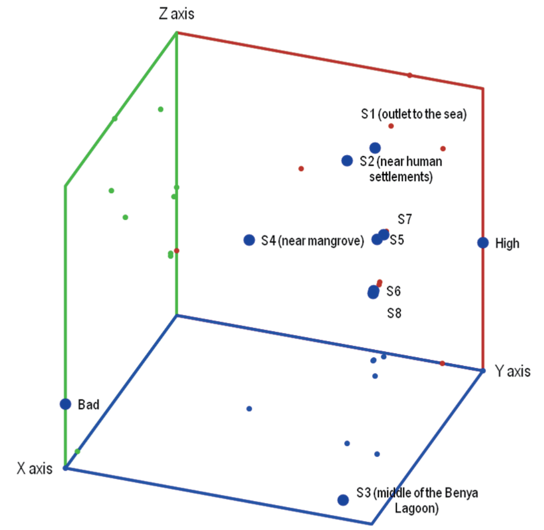

Fig. 2. Scatter plot of sampling locations of the Benya Lagoon based on factor scores of principal components.

This could be attributed to the periodic flushing between the lagoon and the Atlantic Ocean. Also, oxygen showed strong positive loadings on factor 1 whereas temperature showed strong negative loadings on factor 1. This is understandable as flushing is also a process that is coupled with oxygen cycling. Turbidity exhibited strong positive loadings on factor 2 (land use) whereas pH showed strong negative factor loadings on factor 2. Turbidity of the Benya Lagoon is connected with the market activities close to the lagoon. For the Fosu Lagoon, conductivity, oxygen and temperature exhibited strong positive factor loadings on factor 1.

Benthic species near human settlements and sea outlets were similar, and indicated similar pollution levels (Fig. 2). The benthic species near the *Rhizophora* mangrove differed from the middle of the lagoon. S6 and S7

Table 4. Abundance of macrobenthic fauna in sediments from the Fosu Lagoon

Benthos	Week						H	Relative
	1	3	5	7	9	Total	H(-∑P*i*lnP*i*)	abundance (%)
Chironomus sp.	285	246	228	240	256	1,255	-0.074	92.35
Draconema sp.		2	2		3	7	-0.027	0.52
Glycera sp.		3				3	-0.014	0.22
Echinolittorina pulchella			7			7	-0.027	0.52
Nemertina sp.	47			27	3	77	-0.163	5.67
Ophelia sp.	3					3	-0.014	0.22
Syllides sp.	4			3		7	-0.027	0.52
Total	339	251	237	270	262	1,359	0.346	100.00
Mean	84.75	83.66	79	90	87.33			

Table 5. Results of AMBI and M-AMBI for the Benya Lagoon

Stations	Benya AMBI								Benya M-AMBI (multivariate plots)							
	I (%)	II (%)	III (%)	IV (%)	V (%)	AMBI	BI	Disturbance classification	AMBI	Diversity	Richness	X	Y	Z	M-AMBI	Status
Bad									6	0	0	3.274	-2.477	-0.029	8.5E-17	Bad
High									0	2.84	10	-1.991	1.269	-0.003	1	High
1	55.2	6.9	6.9	13.8	17.2	1.966	2	Slightly disturbed	1.965	2.659	8	-1.237	0.148	0.038	0.804	Good
2	50	25	25	0	0	1.125	1	Undisturbed	1.125	1.5	3	0.9547	0.369	0.060	0.548	Moderate
3	100	0	0	0	0	0	0	Undisturbed	0	0	1	2.7	0.775	-0.055	0.364	Good
4	29.4	11.8	0	0	58.8	3.706	3	Moderately disturbed	3.706	1.673	5	0.457	-0.957	0.014	0.491	Moderate
5	92.9	0	0	7.1	0	0.321	1	Undisturbed	0.321	1.264	3	1.118	0.777	0.033	0.564	Good
6	51.8	8.4	3.6	6	30.1	2.313	2	Slightly disturbed	2.313	2.663	10	-1.707	0.006	-0.027	0.851	High
7	51.7	10.1	4.6	7.1	26.4	2.197	2	Slightly disturbed	2.197	2.839	10	-1.869	0.087	-0.005	0.879	High
8	51.8	8.3	3.6	6	30.4	2.321	2	Slightly disturbed	2.3214	2.655	10	-1.699	0.0005	-0.027	0.849	Good

AMBI, AZTI Marine Biotic Index; M-AMBI, multivariate-AMBI.

Table 6. Results of AMBI and M-AMBI for the Fosu Lagoon

Stations	Fosu AMBI								Fosu M-AMBI (multivariate plots)							
	I (%)	II (%)	III (%)	IV (%)	V (%)	AMBI	BI	Disturbance classification	AMBI	Diversity	Richness	X	Y	Z	M-AMBI	Status
Bad									6	0	0	2.795	-3.361	2.751	0	Bad
High									2.95	0.26	6	-1.849	1.19	-1.585	1	High
1	1	1.4	97.6	0	0	2.949	2	Slightly disturbed	2.949	0.187	3	-0.197	0.449	-0.369	0.733	Good
2	0	1.2	98.8	0	0	2.982	2	Slightly disturbed	2.982	0.16	3	-0.06	0.31	-0.118	0.695	Good
3	0	3	97	0	0	2.955	2	Slightly disturbed	2.956	0.262	3	-0.557	0.757	-1.052	0.832	Good
4	0	1.2	98.8	0	0	2.981	2	Slightly disturbed	2.982	0.096	2	0.683	-0.103	0.651	0.552	Good
5	0	0	100	0	0	3	2	Slightly disturbed	3	0.091	2	0.711	-0.139	0.7	0.544	Moderate
6	0.2	1.3	98.4	0	0	2.973	2	Slightly disturbed	2.973	0.194	6	-1.525	0.896	-0.978	0.911	High

AMBI, AZTI Marine Biotic Index; M-AMBI, multivariate-AMBI.

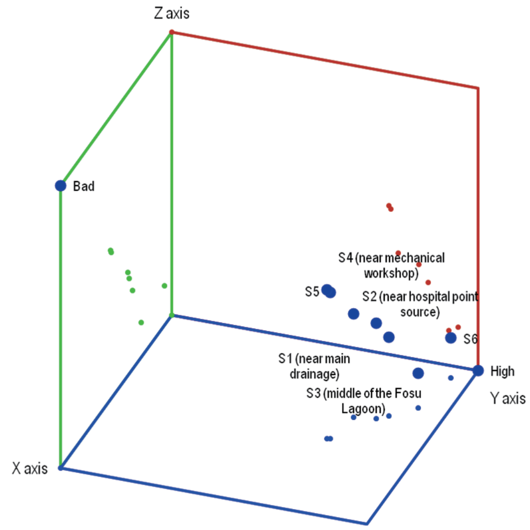

Fig. 3. Scatter plot of sampling locations of the Fosu Lagoon based on factor scores of principal components.

are high, S1, S5 and S8 are good in terms of benthic species diversity whereas S3 is poor (Table 5 and Fig. 2).

From Fig. 3, S1 to S4 are good whereas S5 and S6 are moderate and high in terms of pollution, respectively. Based on the clustering of the sites, the benthic species in S1 to S4 indicate similar pollution levels.

DISCUSSION

The Fosu Lagoon was characterized by slightly disturbed conditions and macrobenthic assemblages that showed some indications of deterioration. These could be due to the channeling of drainage systems into the lagoon (Armah et al. 2012). The level of DO in the closed Fosu Lagoon (less saline) was higher than that in the open Benya Lagoon (more saline). Our finding contradicts the results of Kwei (1977), which showed higher levels of DO in open lagoons, but was consistent with the findings of Davies et al. (2008). In all probability, reduced photoperiod and photosynthetic activities of aquatic plants account for the higher DO in the Fosu Lagoon. Salinity is also an important factor in determining the amount of oxygen that a body of water can hold. As the amount of dissolved salt in water increases, the amount of oxygen the water can hold decreases (Kennish 2002). The low salinity in the Fosu Lagoon compares well to that determined by Yankson and Kendall (2001) for the same lagoon, and is due to the fact that it does not have direct contact with the sea for several months in a year. The oxygen concentration ranged between 6.5 and 10.2 mg/L during the study. Decreased oxygen leads to excessive growth of aquatic weeds particularly *Eichhornia crassipes*.

Effluents from agricultural and other human activities change the ambient conditions in the Fosu Lagoon since there is no seawater coming in within those times to dilute the system. The mechanic workshops near the Fosu Lagoon are sources of heavy metals and polycyclic aromatic hydrocarbons (Armah et al. 2012). The pH of the Fosu Lagoon is alkaline. pH affects metabolism and physiological processes of fish and also exerts considerable influence on the toxicity of ammonia and hydrogen sulphide, as well as the solubility of nutrients, and thereby water fertility (Lamptey and Armah 2008). The mean turbidity of both the Fosu and Benya lagoons were considerably lower than the results of Lamptey and Armah (2008)

Table 7. Total variance of Benya and Fosu lagoons data explained by principal component analysis (PCA)

Component	Initial Eigen values			Extraction sums of squared loadings		
	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
Benya Lagoon						
1	2.677	44.621	44.621	2.677	44.621	44.621
2	1.660	27.674	72.295	1.660	27.674	72.295
3	0.773	12.891	85.186	0.773	12.891	85.186
4	0.617	10.287	95.473	0.617	10.287	95.473
5	0.272	4.527	100.000	0.272	4.527	100.000
Fosu Lagoon						
1	2.625	43.752	43.752	2.625	43.752	43.752
2	1.598	26.633	70.385	1.598	26.633	70.385
3	0.712	11.862	82.247	0.712	11.862	82.247
4	0.488	8.139	90.387	0.488	8.139	90.387
5	0.327	5.442	95.829	0.327	5.442	95.829
6	0.250	4.171	100.000	0.250	4.171	100.000

Extraction method: PCA.

obtained for the Keta Lagoon. However, this was not true of conductivity, which was much higher in this study compared to the results of Lamptey and Armah (2008). Although the Keta Lagoon is considered to be an open lagoon, it is effectively closed for most of the year and is therefore similar to the Fosu Lagoon. Based on these anthropogenic pressures, the Fosu and the Keta lagoons are comparable.

The temperature range determined for the Fosu Lagoon was similar to results obtained by Lamptey and Armah (2008) for the Keta Lagoon. Aquatic plant species are dependent on growth conditions, particularly temperature, organic loading, oxygen status and nutrient availability. In the tropics, however, Edokpayi and Nkwoji (2007) argue that temperature is not an important ecological factor. The particle size composition plays an important role in the distribution of benthic macro fauna populations (Ruellet and Dauvin 2007). The Benya Lagoon substratum was composed of medium sand to coarse gravel, whereas the Fosu Lagoon was composed of coarse sand to very coarse gravel. Certain species (e.g., clams) occur in muddy sediments; others prefer coarse sediments such as amphipods and isopods. Fine sediments accumulate more pollutants and organic matter (Carvalho et al. 2006) and, therefore, are more susceptible to anoxic conditions, which limit the development of sensitive species (Dauer et al. 2000). In these conditions, macro fauna variability was likely not due to the granulometric factor, but to other factors, such as the point sources of pollutants, the degree of exposition, the water circulation, habitat type, and depth (Blanchet et al. 2008). Overall, the group with the highest percentage abundance was ecological group III. Total abundance was positively related to density of the dominant species. The survey of particular sampling stations proved that most of the stations had organisms or species that fell within ecological group III. Species from groups IV and V were not found at the Fosu Lagoon. These were second order opportunists, mainly small-sized polychaetes and first order opportunistic species, essentially deposit-feeders respectively. In the shallow coastal areas, the re-suspension and destabilization of sediments represent a more important disturbance to the benthic fauna (Burger and Gochfeld 2001).

Policy implications

The results of this study have several policy implications for the use and management of the two lagoons. Lagoon pollution is a multi-faceted environmental problem of considerable complexity. The success of lagoon conservation hinges on the prior existence of an adequate institutional/governance environment for development of an integrated management scheme; and the cooperation of local governance structures. In any political strategy for lagoon management it is of paramount importance to make information available to: (i) support the assessments and assign priorities to environmental and socio-economic concerns and issues; (ii) support research activities and development of the technical/scientific knowledge of the area studied (this is research-oriented); (iii) educational and awareness campaigns (e.g., classify and disclose lists of industries ranked by their environmental profiles); (iv) facilitate monitoring activities and enforcement (this is related to regulatory mechanisms); and (v) support decision making processes. These issues are relevant to the sustainable management of both lagoons. There is incentive to protect the lagoons because of the ecosystem services they provide (including the production of food and water; the control of climate and disease; nutrient cycles and crop pollination; and spiritual and recreational benefits). The direct beneficiaries will be the entire population, who will recover the right to have unpolluted water, a pleasant environment, and reduced health risks due to pollution.

CONCLUSION

The AMBI and multivariate statistics were used to determine the ecological health status of the Benya and Fosu lagoons in Ghana. The Benya Lagoon supported higher species richness and densities compared to the Fosu Lagoon. The Fosu Lagoon supported more pollution-tolerant organisms, such as the *Chironomus* sp., which are adapted to virtually anoxic conditions; the lagoon cannot sustain many of the organisms and plant life which thrive in unpolluted systems, due to increases in anthropogenic pollution via a variety of activities. The unstable conditions, depth, and the increasing anthropogenic pressure in the Fosu Lagoon is thought to have resulted in the relatively low species diversities and densities, as well as the dominance of a few species that often form mono-specific benthic aquatic macrofauna. Anthropogenic pressure on the Fosu Lagoon (e.g., agriculture, industrial, domestic waste) has led to the decline or disappearance of pollution-intolerant species and to the proliferation of *Chironomus* sp. that are more favored by high amounts of nutrients and pollutants. Most importantly, the systems under study (Fosu and Benya) differ significantly in mouth status and salinity, which can also explain the differences in macrofaunal sensitivities observed in this study. It is imperative to comprehensively monitor and manage these fragile ecosystems in order to improve the overall ecological health of coastal lagoons in Ghana.

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