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Diversity and spatial variation of benthic macroinvertebrates in the River Gambia estuary, West Africa

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Abstract
This paper aims to reveal the organization of and environmental variables affecting the spatial distribution of benthic macroinvertebrates in the River Gambia estuary. Macroinvertebrates were recorded at 3 stations across the River Gambia estuary corresponding to upstream, midstream and downstream stations i.e. Tendaba, Abuko and Wencho respectively. Macroinvertebrates were sampled during the dry season using a Van Veen grab. A total of 17 taxa distributed among 15 families and 9 orders belonging to annelids (Oligochaeta and Polychaeta), mollusks, crustaceans and insects were collected. Crustaceans represented 81% of the taxonomic richness qualitatively. Taxonomic group abundances show that Oligochaeta and Polycheata (Annelids) dominate the faunal abundance and constitute 60% and 20% of the total macroinvertebrates respectively. Benthic macroinvertebrate community composition was different between upstream, midstream and downstream stations. Salinity gradient is the most influential environmental variable in structuring benthic macroinvertebrate communities in the River Gambia estuary.

Keywords: benthic, macroinvertebrates, river gambia, estuary, salinity

1. Introduction
Estuaries are critical for the continued survival of many species of aquatic life. They provide diverse habitats for aquatic organisms since they are located at the interface between a river and the sea, and there is variability in physical and chemical conditions due to changes in continental and marine influences [1]. Numerous studies have reported that spatial distributions of aquatic organisms are affected by various environmental variables at rivers, estuaries and lagoons [2, 3, 4]. Such is the case for benthic macroinvertebrates, because they are an important component of estuarine ecosystems and they play an important role in the system dynamics [5]. Benthic invertebrates provide essential ecosystem services by accelerating detrital decomposition [6, 7]. They supply food for both aquatic and terrestrial vertebrate consumers (e.g., fishes, turtles and birds). They are also ideal for use in bio-assessment due to their ubiquity in aquatic systems [8]. Distribution of aquatic macroinvertebrates species and communities is controlled by a variety of environmental factors such as habit characteristics [9], salinity and water quality [10, 11], contaminants [12] and by biological factors such as competition and predation [13].
Diversity of wildlife is generally considered to be greater in tropical than in temperate river systems, and the research effort on West African rivers is insufficient, many species being unknown, despite a real improvement in knowledge [14, 15]. Several studies have focused on aquatic biodiversity in the River Gambia estuary [16, 17]; in contrast, few studies have investigated the community structure and distributions of macroinvertebrates. Indeed the Gambia River is a complex biological system and is important for the survival of the human population. The lower stretches of the river are dominated by estuarine and marine species that migrate up the river [16] and whose distribution varies according to environmental parameters. The purpose of the present study is to determine the diversity and spatial distribution of benthic macroinvertebrates in relation to environmental variables in the River Gambia estuary. The results obtained could be used for water quality and ecological monitoring.

2. Materials and Methods

2.1 Study area

Macroinvertebrates were sampled in River Gambia estuary (Figure 1). Three stations located in Tendaba, Abuko and Wencho were sampled corresponding to upstream, midstream and downstream areas respectively. Wencho and Abuko are within 20 kilometers of each other and they are both part of the Tanbi Wetland National Park. Wencho is located at the periphery of Banjul city (the capital of The Gambia) which is known to be only 0.5m above sea level. It is also characterized by the presence of a local settlement zone within village (Ndangane) within the wetland. Abuko is characterized by the presence of local oyster and cockles processing zones. Tendaba is located about 73 kilometers inland beside the Kiang West National Park. It is characterized by the presence of multiple land uses, including tourism, settlement and fisheries.

Sampling sites were defined at each station and located between 10 and 50 meters from the bank corresponding to the intertidal zone, while subtidal zones were corresponding to stations located between 75 and 100 meters. Macroinvertebrates were sampled in three stations, Tendaba, Abuko and Wencho located in upstream, midstream and downstream, respectively. Wencho and Abuko are both part of the Tanbi Wetland National Park. Tendaba is about 73 kilometers away from them and it is on the side of the Kiang West National Park. Two sampling sites were selected in each station corresponding to the intertidal (I1, I2, I3) and subtidal (S1, S2, S3) zones.

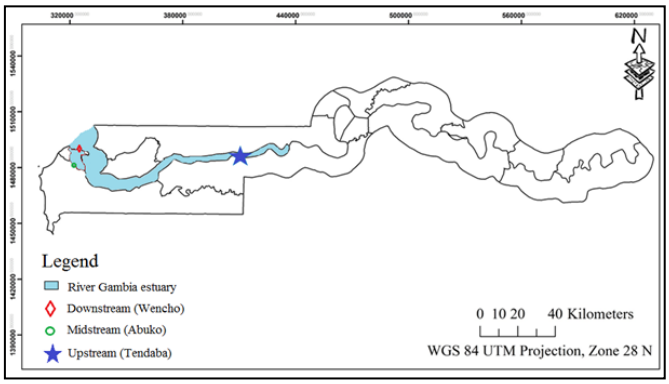

Fig 1: Map of the Gambia River showing the benthic macroinvertebrates sampling stations.

2.2 Sampling

Macroinvertebrates were sampled from June to July 2014 corresponding to the peak dry season. Soft bottoms were collected using a Van Veen grab. At each station, ten samples were collected for benthic macroinvertebrate analyses. Each sample was sieved *in situ* through a 1 mm mesh. The organisms retained by the sieve were sorted and preserved in a 10% formaldehyde solution. At the laboratory, macroinvertebrates were identified using binocular microscope to the lowest possible taxonomic level and counted, although the identification of Oligochaeta was limited to family level. The identification keys used in the study are Elouard (1981), Moor and Day (2002), Konan (2009) and Tachet *et al.* (2010) [18, 19, 20, 21].

At each sampling station, physico-chemical parameters i.e. dissolved oxygen (DO), water temperature (T˚C), salinity (ppt) and pH were measured using a YSI Pro-plus water meter.

2.3 Data analysis

Macroinvertebrate structure was described through the species richness (S), the Shannon-Wiener diversity index (H'), Equitability (E) and abundance (A). These parameters were compared according to upstream, midstream and downstream stations. Significant differences in species richness, diversity indices and abundances were detected using the Kruskall-Wallis test, followed by Rank multiple comparison tests. The analyses were carried out using STATISTICA 7.1 software computer. A level of $p< 0.05$ was considered significant.

Redundancy analysis (RDA) were used to identify environmental gradients and their relationships to the benthic community using CANOCO software [22]. It was performed taking into account the abundance of all taxa as biotic variable and the physico-chemical parameters.

3. Results

3.1 Physico-chemical parameters

Figure 2 shows the physico-chemical parameters measured during the dry season in The River Gambia. Water salinity increased from upstream (29.57 ppt) to downstream station (35.04 ppt). The Kruskall-Wallis test indicates significant differences between the salinity values of Tendaba and Abuko stations and then between Abuko and Wencho ($p<0.05$). In contrast, dissolved oxygen decreases significantly ($p<0.05$) from Tendaba (7.30 mg/l) to Abuko (4.7 mg/l) with similar values between Abuko and Wencho ($p>0.05$). No significant difference ($p>0.05$) in temperature and pH was observed between the different stations. Mean values of water temperature varied slightly from 31.69 to 29.81°C, decreasing slightly as one moved from Tendaba to Wencho. Regarding pH, the water was neutral with low variation (7.30 - 7.61) in three sampling stations.

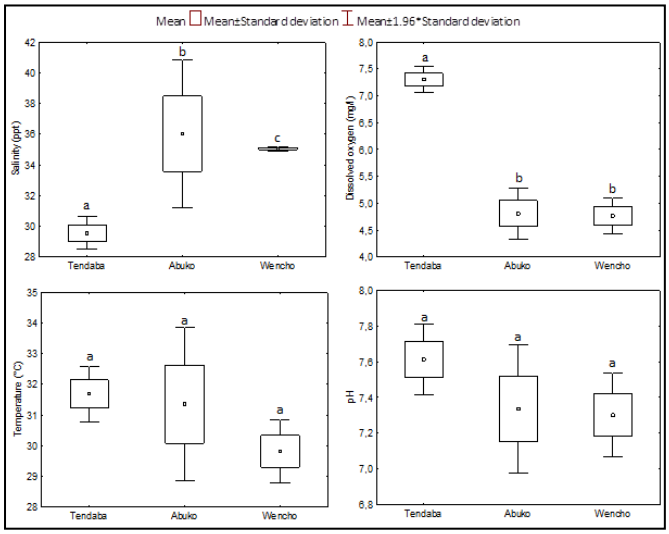

Fig 2: Box plots of physico-chemical parameters at the three sampling stations Tendaba (upstream), Abuko (midstream) and Wencho (downstream) in the River Gambia estuary.

The letters a, b, c on box-plots indicate a significant difference ($p<0.05$) between clusters; there is no significant difference between the box having an alphabetical letter in common ($p>0.05$).

3.2 Community composition and diversity

Dry season surveys at three stations in the River Gambia estuary resulted in the identification of a total of 17 macroinvertebrates taxa (Table 1). These taxa were

distributed among 15 families and 9 orders belonging annelids (Oligochaeta and Polychaeta), molluscs, crustaceans and insects. Samples were qualitatively dominated by crustaceans with eight taxa present in all stations. They represented 81% of the taxonomic richness. Decapoda were represented by two taxa of shrimp (*Macrobrachium* sp. and *Corallianassa coutieri*) and two taxa of crabs (*Liberonautes latidactylus* and *Potamonautes ecorssei*). Amphipoda were represented by two taxa while Arguloida and Isopoda were represented only one taxa (*Argulus foliaceus* and *Asellus aquaticus*, respectively). Four taxa of Gasteropoda were found in sampling stations: *Pachymelania fusca*, *Pisidium* sp., *Sphaerium* sp. and *Cardita* sp. Annelids (Polychaeta and Oligochaetae) were represented by four taxa, including *Leptonereis* sp., *Nephtys* sp. *Stylodrilus* sp. and *E. tetraedra*. These annelids were sampled in all stations of the estuary.

One taxa of freshwater shrimp *Macrobrachium sp.* was collected only at the upstream station (Tendaba). The chironomids represented only insect family obtained during this study. They were collected at midstream and downstream stations.

With regard to diversity index, H' was higher in Abuko (1.88) and relatively low (1.53) in Tendaba and Wencho (1.51) stations. Conversely E reached maximum value in upstream stations (0.85) and decreased in midstream and downstream stations (0.71 and 0.60 respectively).

Table 1: Taxonomic list of benthic macroinvertebrates found at intertidal (I1, I2, I3) and subtidal (S1, S2, S3) zones of the three sampling stations in the River Gambia estuary. Symbol + means the presence of the taxon at the station.

Class	order	Family	Taxons		Tendaba		Abuko		Wencho	
					I1	S1	I2	S2	I3	S3
Oligochaeta	Lumbriculida	Lumbriculidae	*Stylodrilus* sp.	*Sty*	+	+	+	+	+	+
		Lumbricidae	*Eiseniella tetraedra*	*Eis*				+	+	+
Polychaeta	Phyllodocida	Nereidae	*Leptonereis* sp.	*Lep*	+	+	+	+	+	+
		Nephtyidae	*Nephtys* sp.	*Nep*			+	+		+
Mollusca	Mesogastropoda	Melaniidae	*Pachymelania fusca*	*Pac*		+	+	+	+	
	Eulamellibranchia	Sphaeridae	*Pisidium* sp.	*Pis*	+	+	+	+	+	+
			Sphaerium sp.	*Sph*			+	+		
		Carditidae	*Cardita* sp.	*Car*			+			+
Crustacea	Decapoda	Palaemonidae	*Macrobrachium* sp.	*Mac*	+					
		Callianassidae	*Corallianassa coutieri*	*Cor*				+		
		Potamidae	*Liberonautes latidactylus*	*Lib*				+	+	
			Potamonautes ecorssei	*Pot*					+	
	Amphipoda	Gammaridae	*Gammarus* sp.	*Gam*		+		+	+	
		Corophiidae	*Corophium curvispinum*	*Cor*				+		+
	Arguloida	Argulidae	*Argulus foliaceus*	*Arg*				+		
	Isopoda	Asellidae	*Asellus aquaticus*	*Ase*					+	
Insecta	Diptera	Chironomidae	*Chironomus* sp.	*Chi*			+	+		+
Total (S)					4	5	8	13	9	8

3.3 Macroinvertebrate abundance, spatial distribution and relationship with the abiotic variables

Taxonomic richness in the River Gambia estuary differs according to intertidal and subtidal zones (Table 1) but the difference observed was not significant (Newman-Keuls, $p>0.05$). Number of taxa was 6 in Tendaba, 14 in Abuko and 14 in Wencho. The variation was high between stations Tendaba and Abuko but no variation was observed between Abuko and Wencho. Indeed, the taxonomic richness was significantly different between upstream and others sampling stations (midstream and downstream) (Kruskall-Wallis, $p<0.05$).

Abundance of taxonomic groups showed that Oligochaeta and Polycheata (Annelids) dominate the faunal abundance and constitute 60% and 20% respectively of the total macroinvertebrates (Figure 3). However, insects (8%) and Crustacean (4%) show the lowest abundance. With regard to taxa, *Stylodrilus* sp. and *E. tetraedra* account for 39.84% and 19.80% of total abundance. It was followed by *Leptonereis* sp. (12.60%), *Chironomus* sp. (8%) *Nephtys* sp. (7.20%), and *Pisidium* sp. (4.11); other taxa had an abundance of less than 3%.

Spatial distribution of taxonomic group abundance across sampling stations is shown in Figure 4. Oligochaeta increased from 1.54% in Tendaba (upstream) to 35.73% in Wencho (downstream). Similarly, polychaetes increased from 2% to 9.25% in upstream and downstream stations, respectively. On the contrary, abundance of molluscs and insects was higher in Abuko (midstream). Indeed, Kruskall-Wallis test revealed significant difference ($p<0.05$) in macroinvertebrates abundance between both upstream, midstream and downstream stations.

The redundancy analysis revealed that relationships among 17 taxa and physico-chemical parameters in sampling stations follow mainly the first two axes (Figure 5). *Macrobrachium* sp. (*Mac*) was distributed only in Tendaba where pH and dissolved oxygen were higher, but they did not seem to be affected by salinity. Apart from this taxon, all macroinvertebrates were found in Abuko (midstream) and Wencho (downstream) with higher salinity. However, water temperature, oxygen and pH did not have significant affect on their spatial distribution.

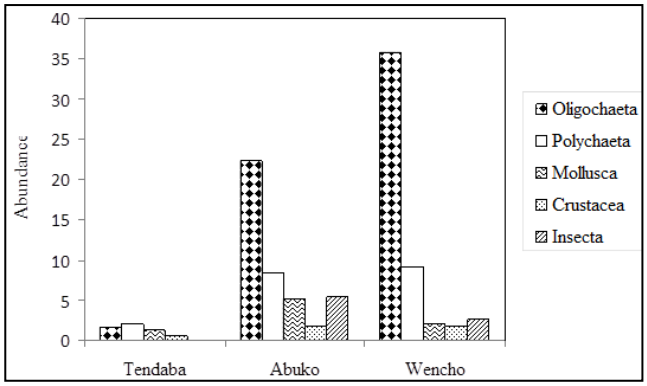

Fig 4: Abundance of macroinvertebrates taxa classes in sampling stations in River Gambia estuary.

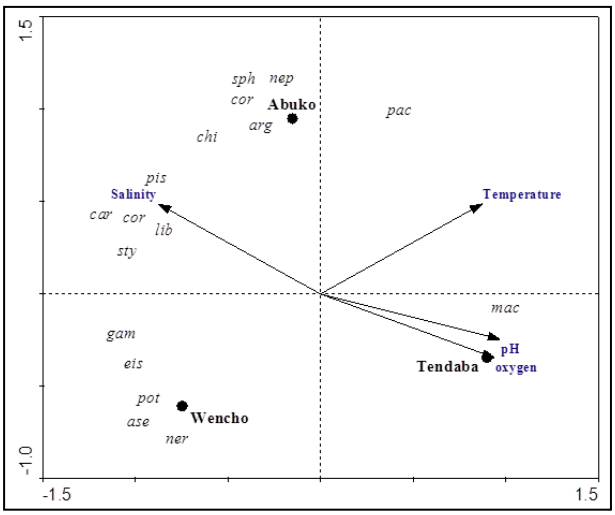

Fig 5: Canonical Correspondence Analysis (CCA) showing relationship among physico-chemical parameters and macroinvertebrates taxa in River Gambia estuary

4. Discussion

The taxonomic composition of benthic macroinvertebrates of River Gambia estuary is characterized by Crustacea, Mollusca, Polychaeta, Oligochaeta and Insecta. This taxonomic list is common to numerous aquatic ecosystems of western Africa such as estuaries and lagoons, but the number of taxa obtained in this study (17 taxa) is very low. For example, 40 and 66 taxa were sampled in Kakum estuary and Ebrié lagoon, respectively [23, 24]. Several reasons may explain the low taxonomic richness of macroinvertebrates in River Gambia estuary. First, a high salinity aquatic environment doesn't allow the development of certain benthic macroinvertebrates such as insects [25]. According to several authors [25, 26, 27], insect larvae are generally sensitive to the impact of salinity except for some orders such as Diptera. This may explain the presence of Chironomidae only in the samples. Furthermore, molluscs, crustaceans and Oligochaeta include both highly sensitive and tolerant species [28].

Furthermore, according to Albaret *et al.* (2004) [17], species of marine origin constitute the majority of species reported in River Gambia estuary because of high values of salinity. Secondly, the sampling period could be a factor related to the low taxonomic richness. In the present study, samples were collected during the dry season. In fact, Tachet *et al.* (2010) [21] indicated that rainy seasons are favorable periods for reproduction of many aquatic species. During this period, salinity is lower favoring the development of sensitive species. Finally, other factors such as sediment composition, nutrients and sampling methods can affect macroinvertebrates diversity [3, 4].

The spatial distribution of these macroinvertebrates showed many differences in taxa composition, diversity and abundance according to sampling station in the River Gambia estuary. Taxonomic richness increased from upstream (6 taxa) to downstream stations (14 taxa) in the present study. This may be related to reduced flows and increased habitats in Abuko and Wencho stations. Sankaré *et al.* (1999) [29] indicated that the number of taxa is higher in downstream station because of its large surface area and the heterogeneity of habitats. According to Palmer *et al.* (2000) [30], a high degree of habitat heterogeneity favours biotic diversity, especially for invertebrates. Indeed, the abundance of food resources and the low presence of predators may be the reason for this spatial distribution [7, 30].

Midstream and downstream station were characterized by abundance of oligochaetes (*Stylodrilus* sp. and *E. tetraedra*) and Polychaetes (*Leptonereis* sp. and *Nephtys* sp.). The probable reasons for the presence of these annelids was the nature of sediment and the organic matter content at these stations. According to Rashid and Pandit (2014) [31], abundance of organic matter is favorable to the development of several communities of organisms such as Annelids. Indeed, many populations use the River Gambia for daily activities such as drinking, irrigation, agriculture, uncontrolled discharge of domestic, urban and industrial wastes and sewages [32]. These activities contributed to the sediment content of Abuko and Wencho stations in the form of organic matter. For example, the nature of the sediment influenced the population dynamics of the oligochaetes of Dal Lake and species such as *Tubifex tubifex*, *Branchura sowerbyii*, *Aelosoma* sp. thrive in sediments rich in organic nutrients [33].

Abundance of some macroinvertebrates may be an indicator of aquatic environment quality [34]. According to Siraj *et al.* (2010) [35], high abundance of annelids such as *Limnodrilus* sp, *Tubifex tubifex* and *Branchiura sowerbyii* reflects the eutrophic status of a wetland. For example, the emergence of species like *Tubifex* sp. and *Chironomus* sp. in Nilnag Lake indicated the eutrophic status of the lake [36]. In the present study, an abundance of annelids (Polychaeta and Ologochaeta) and *Chironomus* sp. was observed in Abuko and Wencho stations. This also revealed a possible eutrophic status of midstream and downstream stations as the organisms recorded mostly occur in eutrophic waters [8].

Redundancy analysis showed that *Macrobrachium* sp. are the only taxa to be negatively influenced by salinity. Shrimps of Palaemonidae family generally live in freshwater ecosystems [37, 38] but can migrate to lagoons and estuaries for breeding and feeding needs [39]. This may justify the presence and low abundance of *Macrobrachium* sp. only in upstream stations, the less salty area.

It is widely acknowledged that many physico-chemical factors influence the occurrence, distribution, abundance and diversity of tropical water invertebrates [2, 3, 11]. Among them, only salinity, temperature, dissolved oxygen and pH were obtained in the present study. The mean salinity is high (>34 ppt) in the midstream and downstream stations indicating a euryhaline zone while the salinity of the upstream is ploy haline (<30 ppt) [1]. The proximity of the River Gambia estuary to the sea and its exchange is certainly the cause for increased salinity in both stations. This was similarly reported in a previous study of the Tanbi Wetland National Park [40]. For dissolved oxygen, its high value upstream can be justified by the flow velocity which maximize the dissolution of oxygen in the water [41]. Temperature and pH have optimal values for the survival of species. Physico-chemical parameters measured in this study are similar to those of Albaret *et al.* (2004) [17] in the River Gambia estuary.

Others physico-chemical factors, turbidity, depth, flow velocity, and their regular or irregular fluctuations at different time scales, have been identified as determinants in estuarine invertebrates ecology [2, 3]. However, salinity was the most important parameter responsible for spatial distribution of benthic macroinvertebrates in the River Gambia estuary.

5. Conclusion

This study provided information on the diversity of macroinvertebrate communities in the River Gambia estuary.

During this study, 17 taxa distributed among 15 families and 9 orders belonging insects, annelids, mollusks, crustaceans were recorded. Crustaceans showed high taxonomic richness qualitatively while annelids dominated the fauna quantitatively. Among physicochemical variables measured, salinity was the most important responsible for spatial distribution of macroinvertebrates in upstream, midstream and downstream stations of the River Gambia estuary. Results of this study may be useful in water quality biomonitoring of this wetland.

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