Structure of benthic macroinvertebrate assemblages in Azagny Channel (Côte d'Ivoire)

ABSTRACT

The Azagny Channel is an estuarine ecosystem connecting Ebrié Lagoon to Bandama River estuary and it is adjacent to Azagny National Park. The aim of this study was to provide the first data on diversity and structure of macroinvertebrates in this estuarine area. Physicochemical parameters were measured monthly in three sampling stations S1, S2 and S3, and the benthic Macroinvertebrates was collected using a Van Veen grab. A total of 28 taxa distributed among 20 families and 11 orders belonging to Annelida, mollusca, Crustacean and Insecta were collected. The taxonomic richness and diversity were higher in S1 compared to S2 and S3, probably due to its proximity to Bandama estuary. The relative abundance revealed that mollusks represented mainly by *Pachymelania aurita* (16.04), *P. fusca* (15.83), *Anodonta anatina* (13.02) dominated the species assemblage; followed by crustaceans with *Macrobrachium vollenhovenii* (31.87) and *Potamon* sp. (5.01). Canonical correspondence analysis revealed that the main factors that influenced macroinvertebrates distribution in Azagny Channel were conductivity, salinity and Total Dissolved Solids (TDS). There is a strong correlation between these three abiotic factors and their influence on species assemblage would be linked to proximity of study area to Atlantic Ocean. These findings provide valuable information that can be used to establish biotic indices to monitor the water quality of Azagny Channel.

Key words: Azagny Channel, macroinvertebrate, diversity, salinity, Bandama estuary, Ebrié Lagoon.

1. INTRODUCTION

Estuaries are important biologically diverse ecosystems and provide critical habitat and vital ecosystem services for plants, animals and ecosystems. They act as breeding places and nurseries for many estuary and marine species and provide essential ecosystem services such as food provision, carbon storage and storm protection [1]. However, excessive amounts of sediment, nutrients and pollutants in runoff from the land puts estuaries and their biodiversity at risk [2].

Numerous studies have reported that spatial distributions of aquatic organisms are affected by various environmental variables at rivers, estuaries and lagoons [3,4]. Such is the case for benthic macroinvertebrates which are often found attached to rocks, vegetation, logs and sticks or burrowed into the bottom sand and sediments. Aquatic macroinvertebrates are an important part of freshwater biodiversity and their importance is widely known [5]. They also have an important role in food webs and are a major food source for many species of freshwater fish [6]. They are influenced by habitat changes and are good indicators of environmental conditions [7,8].

The Azagny Channel is an estuarine ecosystem connecting Ebrié lagoon to Bandama River estuary. It is an environment adjacent to Azagny National Park, which includes several mangrove and swampy forests. Human activities are limited in Azagny Channel but it is influenced by anthropogenic impacts of Ebrié lagoon and Bandama estuary. Several studies have shown a pollution status of water and sediment of these water bodies [9,10,11], which may have an impact on benthic macroinvertebrates diversity of Azagny Channel, because it has been reported that altering the sedimentary environment reduces macroinvertebrates species richness and diversity [4,12]. In addition, the PNA water bodies receive a significant amount of runoff from the watershed, and these waters carries a large quantity of organic matter and its accumulation in water bottom can change macroinvertebrate habitats [10]. Several studies have focused on aquatic diversity in Bandama estuary and Ebrié lagoon [13,14]. However, research of macroinvertebrates structure and distribution is rare in Azagny Channel. Thus, the aim of this work was to provide the first data on diversity and structure of macroinvertebrates in this estuarine environment.

2. MATERIAL AND METHODS

2.1. STUDY AREA

The Azagny Channel is 18 kilometers long and located at the western side of Ebrié Lagoon (Figure 1). It was dug to reach by navigation, Bandama river, Grand-Lahou lagoon and Atlantic Ocean. It is located in Grand-Lahou and Jacqueville Departments and represents the southern limit of Azagny National Park (ANP), which is a protected area of 18,400 hectares. The vegetation is dominated by mangrove forests and the main species were *Rhizophora racemosa* G. Mey., 1818 (Equisetopsida: Malpighiales: Rhizophoraceae) and *Avicennia germinans* (L.) L., 1764 (Equisetopsida: Lamiales: Acanthaceae) [15]. The ANP is home to important diversity of animal species such as primates, reptiles, birds, invertebrates and fish [16]. Physicochemical parameters such as salinity was strongly dependent on abiotic variables of Bandama estuary and Ebrié lagoon. The climate is sub-equatorial with two rainy seasons and two dry seasons. The three sampling stations S1, S2 and S3 were located near the villages Noumouzou, Djateket and Amessan-N'guessandon, respectively (Figure 1). The stations were chosen according to mangrove forests density and habitats diversity.

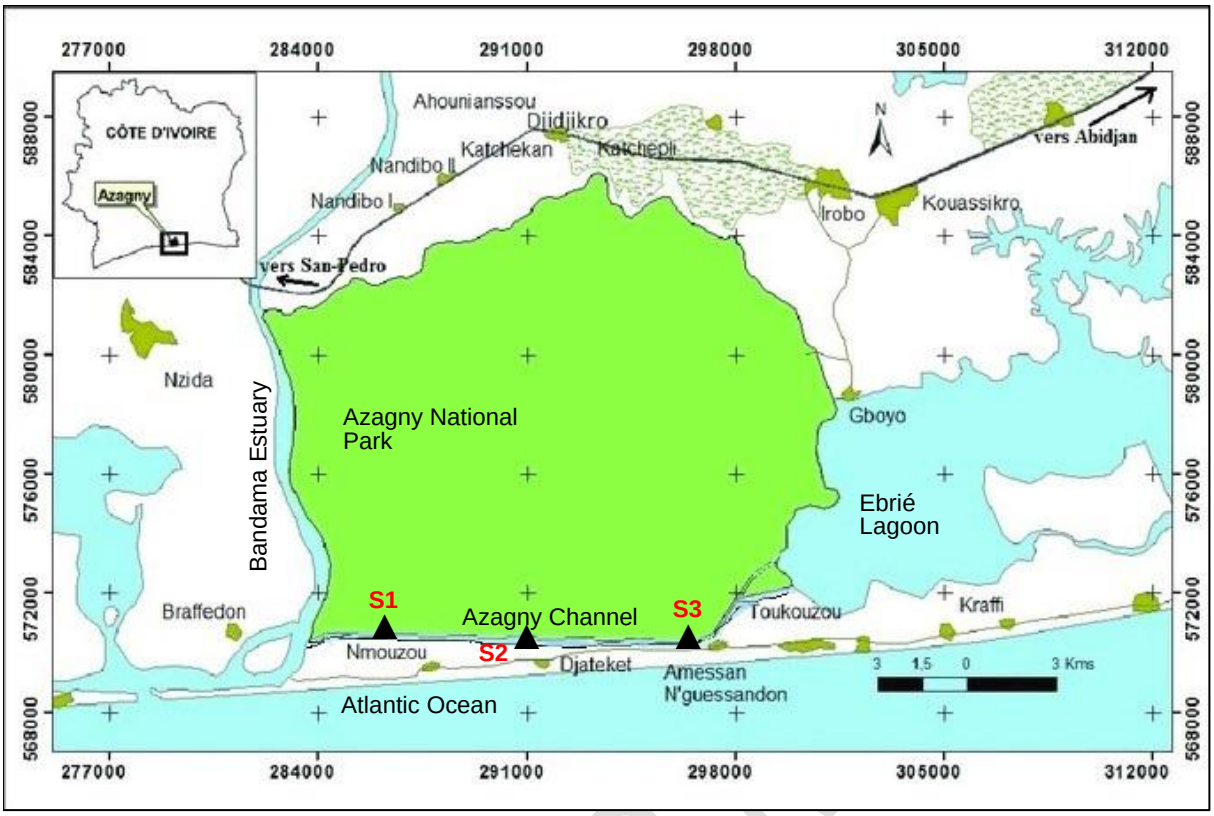

Fig. 1. Map showing Azagny National Park, Azagny Channel and the sampling sites (▲).

2.2 METHODS

2.2.1. SAMPLING

Physicochemical parameters of water were measured at three sampling stations in Azagny Channel between March 2019 and February 2020. Temperature, dissolved oxygen, pH, conductivity and transparency were measured in situ using a multiparameter AQUARED Aquameter. Transparency and water depth were measured by with a Secchi disc and a graduated stick, respectively following [17].

Macroinvertebrates were sampled monthly using a Van Veen grab, 1 m long and 14 cm in diameter as described by [4,18]. In each sampling station, ten random replicate samples were taken at each station from various habitats, for a total area of 0.5 m^2. All large (visible) invertebrates were removed with forceps and put in specimen bottle containing 5% formalin. Samples were sieved in situ through a 500 µm mesh using estuarine water and fixed in the same bottle. Macroinvertebrates were sorted, identified with a binocular microscope using various keys [6, 19, 20] and they were counted. The biomass as dry weight (DW) was obtained by drying the organisms on blotting paper for 1 to 2 minutes and weighing them on a balance accurate to 0.001 g at the laboratory.

2.2.2. DATA ANALYSIS

The relative abundances (RA) of each species were estimated as the percentage of individuals of a particular species out of the total number of individuals of all combined species. The occurrence ratio

(OR) was calculated as the number of times that a particular species was present divided by the total number of sampling events. RA and OR values were expressed as percentages [21]. The species were classified in constant (OR ≥ 50%), common (10 ≤ OR < 50%) and rarely species (OR < 10%) [22].

Biological indices such as the Shannon-Wiener diversity index (H'), Margalef's species-richness index (R), and Pielou's evenness index (J) were also calculated. These indices informed on the distribution of individuals within the taxa to compare the diversity of the communities among the sampling stations [23]. To assess the differences of the physicochemical values and diversity indices between the different sampling sites was applied analyses of variance (One-way Anova, $p<0.05$).

A similarity matrix between samples was constructed using the Bray- Curtis similarity coefficient [24]. In addition, non-metric multidimensional scaling (NMDS) analysis were used as exploratory tools to identify the stations with similar macro-invertebrate communities. Analysis of similarity (ANOSIM) was then used to detect significant differences ($p<0.05$) between these groups [25]. In this analysis, four variables were used: S, A, H' and J. Numerical abundance variables of Macroinvertebrates were log-transformed to diminish the influence of dominant and rare taxa [26] and only taxa with an abundance greater than 1% were included in the analysis. The similarity percentage routine (SIMPER) was calculated to determine the specific importance of each taxon in each group [27]. The Spearman correlation coefficient to determine the relation between physicochemical parameters and biological variables was performed [28]. Only specimens with a total abundance greater than 1% were included in the analysis. Ordination diagrams of canonical correspondence analyses (CCA) were used to evaluate the relationships between sampling sites and environmental conditions. All univariate, multivariate techniques and the diversity indices calculation were undertaken using the *Palaeontological statistics* (Past 3.21) Software [29]. A level of $p< 0.05$ was considered significant.

3. RESULTS

3.1. ENVIRONMENTAL VARIABLES

The spatial variation of physicochemical parameters was presented in Table 1. The mean temperature varied from 28.83 ± 2.05 to 29.62 ± 2.23°C (mean±SD) between sampling stations. The pH varied from 4.04 to 8.97 and the high mean value (6.38 ± 1.03) was obtained in S1. The dissolved oxygen level varied from 2.8 to 10.18 mg/l between stations and S2 showed the highest mean value (6.07 ± 1.57 mg/l). The mean values of TDS (1366.83 ± 2085.06 mg/l) and conductivity (3561.42 ± 3325.15 µS/cm) were higher at S3 compared to other stations. Transparency varied slightly between 0.43 ± 0.13 and 0.49 ± 0.21 m. The minimum and maximum depths were 0.68 and 3.21 m, respectively and the mean depth was higher in S2 (2.02 ± 0.51 m). Salinity showed the highest value in S2 (17.06 ± 17.81 ppm) and the lowest value in S3 (7.99 ± 11.39).

The spatial variation of temperature, pH, dissolved oxygen, depth, conductivity and transparency had shown little change from one site to another and differences were not significant (Anova; $p>0.05$). In contrast, the spatial variation of TDS, conductivity and salinity indicated significant differences (Anova;

p <0.05). For TDS, Tukey's test indicated significant differences for the following pairwise comparison S3-S1 and S3-S2 (p> 0.05) and for salinity, differences were observed between S1-S3 and S2-S3 (p > 0.05).

Table 1. Descriptive statistics on physicochemical parameters of Azagny Channel between March 2019 and February 2020.

Parameters	Stations	Min	Max	Mean±SD	Median
Water Temperature (°C)	S1	26.8	33.9	29.62±2.23	29.55
	S2	25.0	30.62	28.9±1.63	28.85
	S3	25.0	31.40	28.83±2.05	28.70
pH	S1	4.77	8.97	6.38±1.03	6.23
	S2	4.04	8.81	6.26±1.63	6.64
	S3	4.23	8.70	6.48±1.10	6.49
Dissolved oxygen (mg/l)	S1	5.10	6.74	5.98±0.46	5.96
	S2	4.20	10.0	6.07±1.57	5.93
	S3	2.80	10.18	5.26±1.82	5.0
TDS (mg/l)	S1	31.0	6 325	688.58±1788.58	71.25
	S2	67.50	8 197	875.71±2308.99	233.50
	S3	64.0	6 472	1366.83±2085.06	334.50
Conductivity (µS/cm)	S1	37.0	9 704	2 430.08±3573.71	971
	S2	75.0	12 500	2 081.67±3408.01	1 215
	S3	75.0	9 996	3 561.42±3325.15	3065.50
Transparency (m)	S1	0.15	0.76	0.47±0.16	0.50
	S2	0.15	0.94	0.49±0.21	0.50
	S3	0.15	0.63	0.43±0.13	0.47
Depth (m)	**S1**	0.99	3.18	1.79±0.68	1.585
	S2	1.53	3.21	2.02±0.51	1.775
	S3	0.68	2.54	1.83±0.51	1.825
Salinity (ppm)	S1	0.02	55.0	18.30±21.00	8.35
	S2	0.05	45.0	17.06±17.81	10.10
	S3	0.02	29.0	7.99±11.39	0.99

Min = minimum ; Max = maximum ; SD = Standard Deviation

3.2. ASSEMBLAGE COMPOSITION AND DIVERSSITY

A total of 28 taxa of benthic macroinvertebrates belonging four groups (annelids, molluscs, crustaceans and insects), 20 families and 11 orders were collected from Azagny Channel (Table 2). Samples were qualitatively dominated by insects and included 16 taxa in all stations. They represented 57% of the taxonomic richness. Odonata are composed of 9 taxa while only one taxa of Diptera, Chironomus sp. was found in samples. Molluscs and crustaceans were each represented by 5 taxa. Gastropods was represented by the three taxa *Pachymelania aurita*, *P. fusca* and *Theodoxus fluviatilis* while Bivalves were composed of 2 taxa *Sphaerium* sp. and *Anodonta anatina*. Decapoda were represented by two taxa of shrimp (*Macrobrachium macrobrachion* and *M. vollenhovenii*) and two taxa of crabs (*Potamon* sp. and *Eriocheir sinensis*). Annelids were composed of 2 taxa *Nereis* sp. and *Lumbricus* sp. The taxonomic richness was higher in S1 (22 taxa) compared to S2 (16 taxa) and S3 (18 taxa) (Table 3) but the differences were not significant (Kruskall-Wallis, p> 0.05).

In S1, only the two gastropods *Pachymelania fusca* and *P. aurita*, the two decapods *Macrobrachium vollenhovenii* and *Potamon* sp. and the Diptera *Chironomus* sp. presented the highest occurrence ratio, 58.33%, 83.33%, 75.0%, 83, 33%, 50% respectively (Table 2). In S2, only the two decapods had OR greater than 50%. The taxa *P. aurita* (OR = 100%) was sampled every month in S3 while *P. fusca* (OR = 50%) and *Lumbricus* sp. (OR = 50%) were observed in half the samples. In S3, *Nereis* sp, *Anodonta anatina*, *Macrobrachium macrobrachion* and *M. vollenhovenii* had OR greater than 50%. Considering the combined stations (Azagny Channel), only 6 taxa were considered constant: *Nereis* sp., *Lumbricus* sp., *Pachymelania aurita*, *P. fusca*, *Anodonta anatina*, *Macrobrachium vollenhovenii*, *Potamon* sp. and *Chironomus* sp.

The relative abundance (RA) of macroinvertebrates from Azagny channel was 2918 ind./m^2 with proportions of 35.71, 26.79% and 37.49 in S1, S2 and S3, respectively. The abundance Comparison of three sampling stations showed no significant differences (Kruskall-Wallis, p> 0.05). The abundance of macroinvertebrates groups showed that molluscs were the most abundant in S2 and S3, with RA of 41.84% and 52.2, respectively (Figure 2A). However, crustaceans had a higher relative abundance in S2 (48.33). In general, Azagny Channel (combined stations) was dominated by molluscs (45.36%) and crustaceans (40.51%), the proportions of annelids and insects being very low (5.76% and 8.37%, respectively).

The species abundance showed that S1 was dominated by *Macrobrachium vollenhovenii* (30.12), *P. aurita* (22.07) and *P. fusca* (19.19%) (Table 2). In S2, the dominant taxa were *M. vollenhovenii* (36.06) and *P. fusca* (30.43) and for S3, *Anodonta anatina* (33.27), *M. vollenhovenii* (30.53%) and *P. aurita* (16.45%). Ten taxa had their relative abundance greater than 1% in Azagny Channel : *M. vollenhovenii* (31.87), *P. aurita* (16.04), *P. fusca* (15.83), *Anodonta anatina* (13.02), *Potamon* sp. (5.01), Nereis sp. (3.84), *Macrobrachium macrobrachion* (3.15), *Chironomus* sp. (2.74), *Lumbricus* sp. (1.92), *Pseudagrion punctum* (1.03). Overall, the shrimp *M. vollenhovenii* was the most dominant taxa in the study area.

Table 2. Taxonomic list, Relative Abundance (RA, %), Occurrence ratio (OR, %), Biomass (DW, g/m^2) of aquatic macroinvertebrates from three sampling station of Azagny Channel (Côte d'Ivoire).

Phyla / Order / Family	Taxa	Station 1			Station 2			Station 3			Azagny Channel		
		RA	RO	DW	RA	OR	DW	RA	OR	DW	RA	OR	DW
ANNELIDA													
Polychaeta													
Nereididae	*Nereis* sp. Linnaeus, 1758	5.18	41.67	0.358	3.84	50.0	0.668	2.56	58.33	0.028	3.84	83.33	1.054
Oligochaeta													
Lumbricidae	*Lumbricus* sp. Linnaeus, 1758	0.58	16.67	1.022	3.32	41.67	4.486	2.19	50	1.792	1.92	66.67	7.300
MOLLUSCA													
Gastropoda													
Thiaridae	*Pachymelania aurita* (Müller, 1774)	22.07	83.33	591.426	7.42	41.67	121.232	16.45	100.0	424.462	16.04	100.0	1137.12
	Pachymelania fusca (Gmelin, 1791)	19.19	58.33	411.15	30.43	41.67	758.924	2.19	50.0	57.428	15.83	91.67	1227.502
Neritidae	*Theodoxus fluviatilis* (Linnaeus, 1758)	—	—	—	0.26	8.33	1.24	0.37	16.67	2.480	0.20	16.67	3.720
Bivalvia													
Sphaeriidae	*Sphaerium* sp. Scopoli, 1777	0.20	8.33	0.410	0.77	8.33	1.61	—	—	—	0.27	8.33	2.020
Unionidae	*Anodonta anatina* (Linnaeus, 1758)	0.38	16.67	0.304	1.53	25.0	1.728	33.27	75.0	131.58	13.02	83.33	133.612
CRUSTACEA													
Amphipoda													
Gammaridae	*Echinogammarus sp.*Stebbing, 1899	0.38	8.33	0.006	—	—	—	0.37	16.67	0.004	0.27	25.0	0.010
Decapoda													
Palaemonidae	*Macrobrachium macrobrachion* (Herklots, 1851)	4.22	25.0	37.704	4.09	8.33	15.104	1.46	16.67	5.764	3.15	33.33	58.572
	Macrobrachium vollenhovenii (Herklots, 1857)	30.12	75.0	168.906	36.06	83.33	114.258	30.53	75.0	121.916	31.87	100.0	405.08
Potamonidae	*Potamon* sp. Savigny, 1816	4.22	83.33	65.622	8.18	58.33	66.106	3.47	66.67	95.620	5.01	83.33	227.348
Grapsidae	*Eriocheir sinensis* Edwards, 1853	0.20	8.33	4.246	—	—	—	0.37	8.33	4.304	0.21	16.67	8.550

Table 2. Continued.

INSECTA													
Ephemeroptera													
Baetidae	*Acentrella sinaica* Bogoescu, 1931	0.20	8.33	0.128	—	—	—	—	—	—	0.07	8.33	0.128
Ameletidae	*Ameletus inopinatus* Eaton, 1887	1.15	8.33	0.030	0.51	8.33	0.016	—	—	—	0.55	8.33	0.046
Odonata													
Coenagrionidae	*Pseudagrion punctum* (Rambur, 1842)	1.15	16.67	0.012	1.28	16.66	0.010	0.73	8.33	0.016	1.03	33.33	0.038
	Coenagrion sp. Kirby, 1890	0.20	8.33	0.024	—	—	—	—	—	—	0.07	8.33	0.024
	Erythromma sp. Charpentier, 1840	1.34	16.67	0.294	0.26	8.33	0.042	—	—	—	0.55	8.33	0.336
	Enallagma cyathigerum (Charpentier, 1840)	—	—	—	—	—	—	0.19	8.33	0.002	0.07	8.33	0.002
Libellulidae	*Sympetrum* sp. Newman, 1833	0.96	8.33	0.240	—	—	—	1.28	16.66	0.336	0.82	8.33	0.576
	Bradinopyga strachani Kirby, 1893	0.38	8.33	0.296	—	—	—	0.91	8.33	0.070	0.48	8.33	0.366
	Palpopleura lucia (Drury, 1773)	—	—	—	0.26	8.33	0.148	—	—	—	0.07	8.33	0.148
Corduliidae	*Somatochlora* sp. Selys, 1871	2.5	25.0	1.734	—	—	—	—	—	—	0.89	25.0	1.734
Lestidae	*Chalcolestes viridis* (Vander Linden, 1825)	0.20	8.33	0.190	—	—	—	—	—	—	0.07	8.33	0.190
Hemiptera													
Notonectidae	*Notonecta* sp. Linnaeus, 1758	—	—	—	—	—	—	2.01	8.33	0.154	0.75	8.33	0.154
Coleoptera													
Dystiscidae	*Dytiscus* sp. Linnaeus, 1758	0.20	8.33	0.228	—	—	—	—	—	—	0.07	8.33	0.228
	Platambus maculatus (Linnaeus, 1758)	—	—	—	0.26	8.33	0.228	—	—	—	0.07	8.33	0.228
Elmidae	*Elmis* sp. Curtis, 1830	—	—	—	—	—	—	0.19	8.33	0.010	0.07	8.33	0.010
Diptera													
Chironomidae	*Chironomus* sp. Meigen, 1803	4.98	50.0	0.044	1.53	16.67	0.012	1.46	41.67	0.016	2.74	75.0	0.072

Table 3. Metrics and diversity indices of aquatic macroinvertebrates from the sampling sites of Azagny Channel (Côte d'Ivoire).

Metrics	S1	S2	S3	CS
Specific richness	22	16	18	28
Total abundance	1042	782	1094	2918
Relative abundance (%)	35.71	26.8	37.49	100
Mean Biomass (g/m2)	45.87±132.8	38.78±142.2	30.21±84.4	114.86±308
Total Biomass (g/m2)	1284.37	1085.81	845.98	3216.17
Shannon and Wiener (H')	2.05	1.81	1.83	2.12
Margalef (R)	3.36	2.51	2.7	3.71
Equitability (J)	0.66	0.65	0.63	0.63

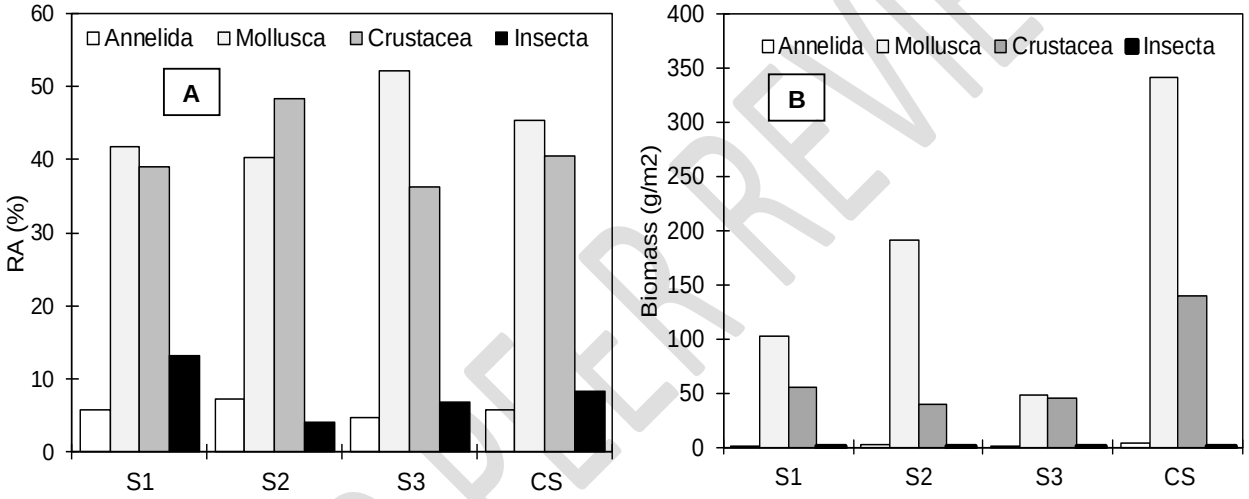

Fig. 2. Relative Abundance (RA) and mean Biomass (g/m^2) of benthic macroinvertebrates from three sampling stations (S1, S2 and S3) of Azagny Channel (Côte d'Ivoire). CS: combined stations.

The mean biomass of macroinvertebrate groups was shown in Figure 2B. Molluscs had the highest biomass in all stations. In Azagny Channel, crustaceans and molluscs had a mean biomass of 139.91 ± 174.2 and 341.71 ± 593.73 g/m^2 (mean±SD), respectively. The biomass of insects (0.27 ± 0.42 g/m^2) and annelids (4.18 ± 4.42 g/m^2), as a result of which they are slightly visible on the graph. The total biomass of samples showed that the two gastropods *Pachymelania fusca* (1227.5 g/m^2) and *Pachymelania aurita* (1137.12 g/m^2) had the highest biomass, followed by the two decapods *Macrobrachium vollenhovenii* (405.08 g/m^2), *Potamon* sp. (227.35 g/m^2), the bivalve *Anodonta anatina* (133.612 g/m^2) and the shrimp *M. macrobrachion* (58.57 g/m^2); the biomass of other taxa was less than 10 g/m^2 (Table 2).

Diversity indices Shannon (H'), Maragalef (R) and Equitability (J) were higher in S1, with respective values of 2.05, 3.36 and 0.66, compared to other stations (Table 3). H 'and J indices don't vary

significantly according to sampling stations (KW, p> 0.05) while R inS1 is significantly different than that of S2 (KW, p <0.05) and S3 (p <0.05).

3.3. RELATIONSHIP BETWEEN ENVIRONMENTAL VARIABLES AND MACROINVERTEBRATES

Spearman correlation between the most abundant macroinvertebrate taxa (RA > 1%) and eight abiotic variables was presented in Table 4. *Macrobrachium vollenhovenii* showed a positive correlation with depth (r = 0.78; p = 0.002) and salinity (r = 0.79; p = 0.002). Similarly, the correlation between *Potamon* sp. and TDS was significant positive (r = 0.58; p = 0.04)

The separation of S1, S2 and S3 stations does not appear to be confirmed by the ordination with NMDS of Macroinvertebrates data (Figure 3). An ANOSIM was performed to test for statistical differences in taxonomic composition between the pairs of stations S1, S2 and S3. A value of R = 0.040 supported the results of the classification and ordination of the data and indicated significant differences in taxonomic composition between S2 and S3 stations (p < 0.05). The other pairs of comparisons (S1-S2 and S1-S3) showed no significant differences. The SIMPER was applied to identify those taxa that contribute most to the observed differences between S2 and S3 samples (Table 5). Only seven taxa were more abundant in S2 samples, while six taxa were more abundant in S3 sample. The taxa *Pachymelania fusca*, *Macrobrachium vollenhovenii* and *Potamon* sp. were the best indicator taxa for samples taken in S2 and accounted for 30.70% of the observed differences. The S2 station was characterized by relatively higher abundances of *Pachymelania aurita*, *Macrobrachium vollenhovenii*, *Potamon* sp.

Ordination diagrams, based on canonical correspondence analysis (CCA), were used to evaluate the relationship between each sampling site and environmental conditions (Figure 4). The first two ordination axes accounted for 71.92% of the total variance. The axis 1 was positively correlated with TDS, conductivity and transparency while the axis 2 was positively correlated with pH, DO and TDS. S1 showed a strongly relationship with depth and transparency and conductivity while the relationship between station S2 and DO was high, and S3 was strongly correlated with TDS. A second CCA was used to explore the relationships between species and environmental factors (Figure 5). Both axis of CCA separated the abundant species into two groups. The first group consisted of six taxa, *Lumbricus* sp., *Anodonta anatina*, *Pachymelania aurita* and *Macrobrachium vollenhovenii*, *Potamon* sp. and *Chironomus* sp. These taxa were positively correlated with conductivity, TDS and transparency. The second group was composed of *Nereis* sp., *P. fusca*, *M. vollenhovenii* and *Pseudagrion punctum* which are positively correlated with salinity, dissolved oxygen and depth. The main parameters that influenced macroinvertebrate assemblage distribution in Azagny Channel were conductivity, TDS and salinity.

Table 4. Spearman's correlation coefficient between physicochemical parameters and macroinvertebrate taxa in Azagny Channel.

Taxa	Temp	pH	DO	TDS	Cond	Transp	Depth	Sal
Lumbricus sp.	-0.23	0.03	0.15	-0.24	-0.49	-0.11	-0.37	-0.33
Nereis sp.	-0.28	0.09	0.05	-0.04	0.07	0.03	0.00	0.35
Anodonta anatina	-0.54	0.27	0.27	-0.45	-0.65	-0.39	-0.32	-0.53
Pachymelania aurita	-0.17	-0.10	0.00	-0.28	-0.10	-0.26	-0.17	-0.20
Pachymelania fusca	0.09	-0.27	0.54	0.51	0.20	0.34	-0.38	-0.35
Macrobrachium macrobrachion	-0.05	0.02	0.06	0.11	0.07	0.03	-0.05	-0.30
Macrobrachium vollenhovenii	0.01	0.08	-0.44	-0.06	0.21	-0.17	0.78*	0.79*
Potamon sp.	0.14	-0.03	0.40	0.58*	0.40	0.36	0.09	-0.27
Pseudagrion punctum	0.25	-0.45	-0.21	0.39	0.46	0.24	0.54	0.50
Chironomus sp.	-0.15	-0.02	0.47	0.27	0.04	0.13	-0.39	-0.21

Temp = temperature; DO = Dissolved Oxygen; TDS = Total Dissolved Solids; Cond = Conductivity; Transp = transparency; Sal = Salinity. Values followed by an asterisk (*) indicated significant differences ($p<0.05$)

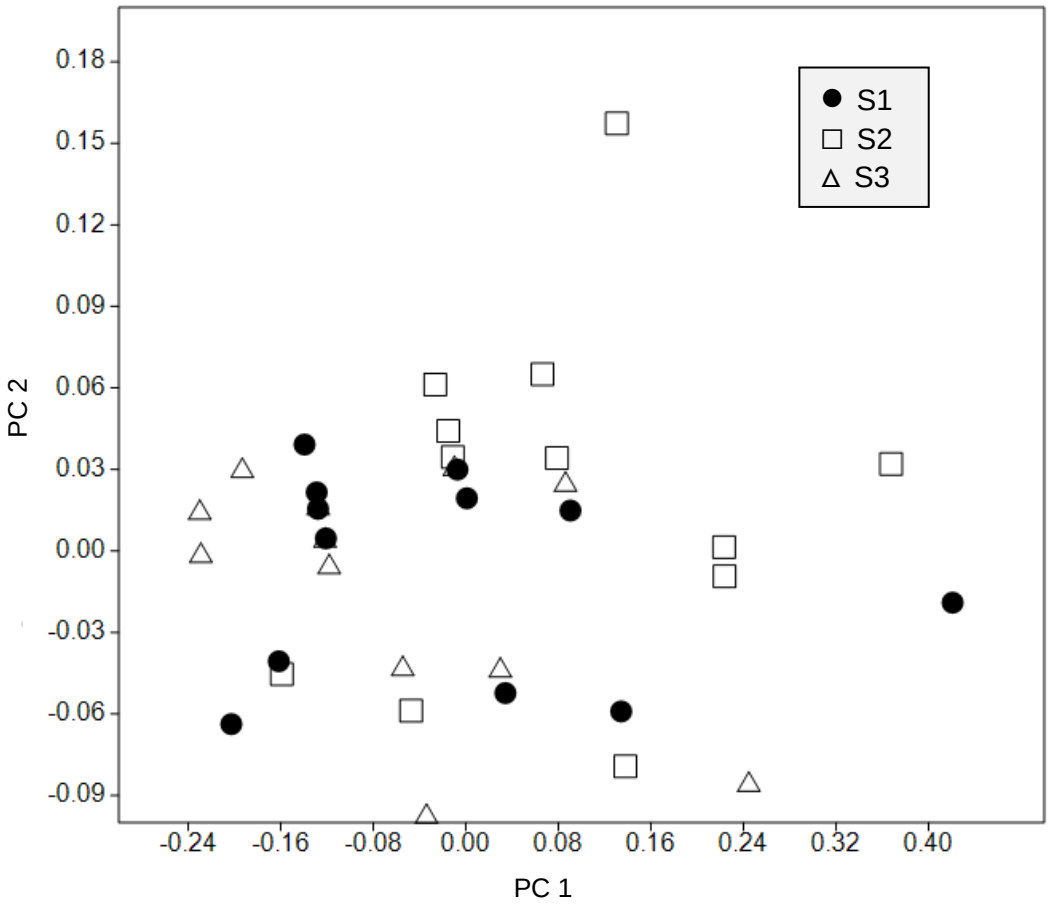

Fig. 3. Non-metric Multidimensional Scaling (NMDS) Ordination derived from the Bray Curtis similarity matrix of benthic Macroinvertebrates taxa from three stations (S1, S2 and S3) of Azagny Channel (Côte d'Ivoire).

Table 5. Results of SIMPER analyses for the dissimilarity of macroinvertebrates taxa abundance between sampling stations S2 and S3 of Azagny Channel. Overall average dissimilarity = 21.83.

Taxa	Mean Abundance		Contribution (%)	Cumulative Contribution (%)
	S2	S3		
Pachymelania fusca	2.08	1.08	41.94	41.94
Pachymelania aurita	1.46	1.95	20.70	62.64
Macrobrachium macrobrachion	1.20	0.90	12.67	75.31
Potamon sp.	1.51	1.28	9.53	84.84
Chironomus sp.	0.78	0.90	5.26	90.10
Pseudagrion punctum	0.70	0.60	4.08	94.18
Macrobrachium vollenhovenii	2.15	2.22	3.09	97.28
Lombricus sp.	1.11	1.08	1.46	98.74
Nereis sp.	1.18	1.15	1.26	100.0

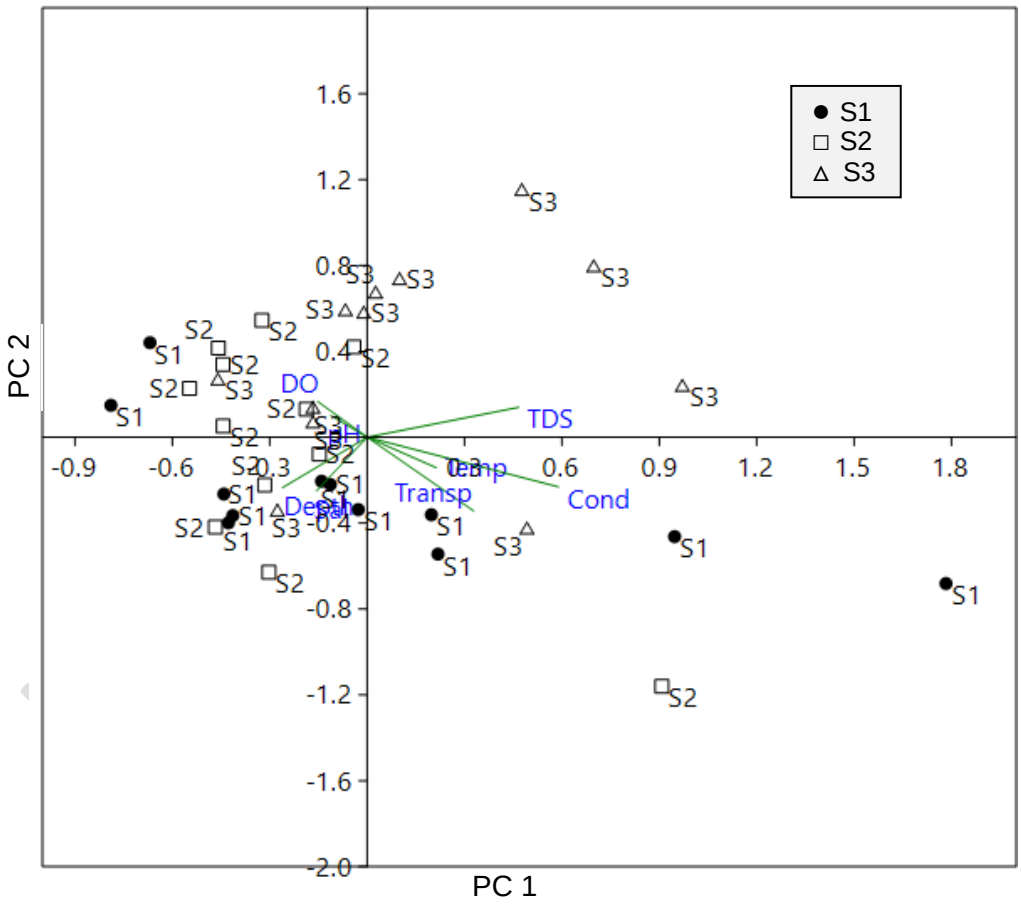

Fig. 4. CCA analysis of samples and the following environmental factors: Temperature (Temp), pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Conductivity (Cond), Depth and Salinity (Sal).

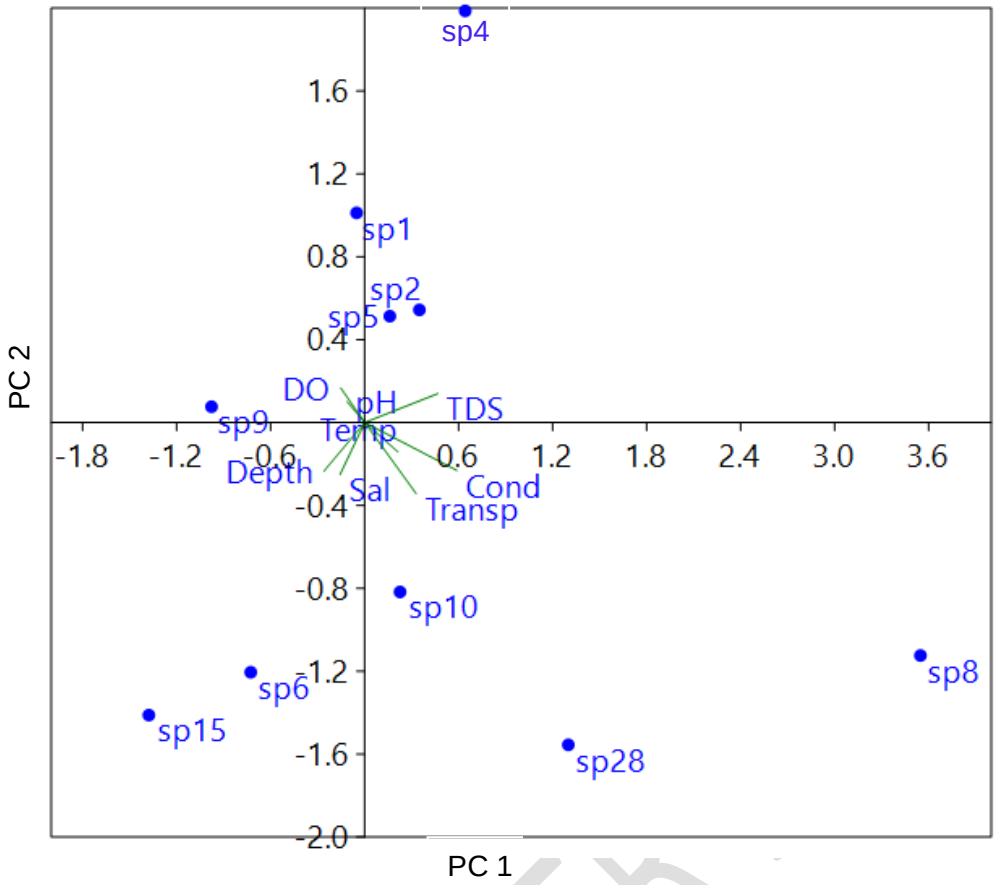

Fig. 5. CCA analysis of the most abundant macroinvertebrates taxa and physicochemical parameters. sp1: *Nereis* sp.; sp2: *Lumbricus* sp.; sp4: *Anodonta anatina*; sp5: *Pachymelania aurita*; sp6: *P. fusca*; sp8: *Macrobrachium macrobrachion*; sp9: *M. vollenhovenii*; sp10: *Potamon* sp.; sp15: *Pseudagrion punctum*; sp28: *Chironomus* sp.

4. DISCUSSION

The physicochemical parameters analysis showed that spatial variation of TDS, conductivity and salinity indicated significant differences. The salinity showed a large variation from 0.02 to 55.0 ppm and the highest mean values were observed in stations S1 and S2. Indeed, the salinity of Azagny Channel was influenced by the salinity of Bandama Estuary, which is connected to Atlantic Ocean, which justifies high values of this parameter of both stations. This large variation of salinity may be related to influence of inland waters during flooded periods and low water periods [30]. The proximity of S1 and S2 stations to the sea (Atlantic Ocean) and its exchange is certainly the cause for increased salinity. Likewise, TDS and conductivity showed large variations during the sampling period. Several authors have reported that these parameters are correlated and are influenced by the salinity and organic matter decomposition releasing nutrient salts into the water body [31]. The mean DO level varied between 5.98 and 6.07 mg/l and reflects good oxygenation conditions for the survival of aquatic species [32] and seems to be related to the continual exchanges of water in Ebrié Lagoon and

Bandama estuary. The low spatial variation of other parameters such as pH, temperature and DO indicates a certain homogeneity of sampling stations.

The present work has indicated the benthic macroinvertebrates structure in Azagny Channel. The assemblage indicated 28 taxa consisting of 2 taxa of annelids, 5 taxa of gastropods, 5 taxa of crustaceans and 16 taxa of insects. This specific composition has been compared to several estuarine ecosystems. For example, only 17 taxa have macroinvertebrates were collected from 3 stations in Gambia River Estuary [33]. On the other hand, the specific composition of Aby-Tendo-Ehy Lagoon and Ebrié Lagoon showed 86 and 98 taxa, respectively [34, 35]. Several reasons may explain the low taxonomic richness of macroinvertebrates in Azagny Channel. First, the environment receives a significant amount of sediment linked to stormwater runoff, which can have an impact on decreased depth and species habitats [12]. Secondly, the high level of salinity during periods of low water does not allow the development of certain benthic freshwater macroinvertebrates such as insects [36]. According to several authors, insect larvae are generally sensitive to the impact of salinity except for some orders such as Diptera [36, 37].

Among the sampled species, four taxa *M. vollenhovenii* (31.87), *P. aurita* (16.04), *P. fusca* (15.83), *Anodonta anatina* (13.02) were the most abundant. The occurrence analysis also showed that they were constant species in Azagny Channel [22]. Several reasons can justify the abundance of gastropods: they have a longer life cycle; they also have the ability to hide in the substrate and escape predators [38]. Indeed, the family Melaniidae is represented in the lagoons, estuaries and mangrove swamps by the genus *Pachymelania*, which is endemic to West Africa [39]. *Pachymelania* adapts perfectly to freshwater but prefers brackish water of higher salinity and is often extremely abundant in the mangrove swamps and on the mud-flats within reach of the tide, in lagoons and river estuaries [40]. *Pachymelania aurita* lives in sandy-mud sediment at water depths of down to 5 m in the open lagoons and avoids areas with a strong current. It is a euryhaline species inhabiting areas of salinity variation between 0 and 27‰ and prefers the upper region of the infra-littoral [41]. Moreover, most shrimp species of the genus *Macrobrachium* need a larval phase of brackish water and the roots of mangroves trees constitute for these species preferential habitats to escape predators and fishing pressures [42]. This tends to justify the postive correlation of *M. vollenhovenii* with depth and salinity.

Taxonomic richness was highest in S1 (22 taxa) and diversity indices showed higher values in S1. Indeed, this station is the furthest from Ebrié Lagoon which presents a state of organic pollution in various places [13, 14, 43], which tends to show that S1 presents optimal conditions for the macroinvertebrates development unlike other stations. It should also be mentioned the diversity of habitats of mangrove forest in S1, which may be responsible for a great diversity of species in these environments [44].

It is widely acknowledged that many physicochemical factors influence the occurrence, distribution, abundance and diversity of tropical water invertebrates [3, 45]. Among them, conductivity, salinity and TDS were the main factors reported in the present study. In fact, there is a strong correlation between these three parameters [31, 46]. Similar results were obtained in most estuaries (Gambia River, Tasmanian Estuaries) where salinity influenced species distribution [33, 47, 48]. Others

physicochemical factors, turbidity, depth, flow velocity, and their regular or irregular fluctuations at different time scales, have been identified as determinants in estuarine invertebrates ecology [3, 49]. However, conductivity and salinity were the most important parameter responsible for spatial distribution of benthic macroinvertebrates in Azagny Channel.

5. CONCLUSION

This study provided information on the diversity of macroinvertebrate assemblage in Azagny Channel. During this study, 28 taxa belonging insects, annelids, mollusks, crustaceans were recorded. Mollusca represented mainly by *Pachymelania aurita*, *P. fusca* and *Anodonta anatina* were the most dominant with the highest biomass. The macroinvertebrates diversity was highest S1 station near the Bandama Estuary. Among physicochemical variables measured, conductivity, TDS and salinity were the main abiotic factors responsible for spatial distribution of macroinvertebrates in Azagny Channel. The findings of this study may be useful in water quality biomonitoring of this estuarine area.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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