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Aquatic macroinvertebrates associated with free-floating macrophytes in a marginal lentic ecosystem (Ono Lagoon, Côte d' Ivoire)

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Abstract
This study aims to investigate macroinvertebrate communities associated with floating macrophytes of Ono lagoon (Côte d'Ivoire). Samples were monthly collected from September 2015 to August 2016. Similarly, abiotic variables (temperature, transparency, depth, conductivity, TDS, pH, dissolved oxygen, NH_4^+, NO_3^-, NO_2^- and PO_4^{3-}) were measured. A total of 150 macroinvertebrates belonging to 46 families and 15 orders were identified. Specifically, 125 taxa were found on *Eichhornia crassipes,* 77 on *Salvinia molesta* and 62 on *Pistia stratiotes* of which 52 taxa were exclusively associated with *E. crassipes,* 15 with *S. molesta* and 7 with *P. stratiotes*. Libellulidae (14.39-22.42%) and Corduliidae (10.56-16.47%) exhibited the highest densities. Higher values of taxonomic richness, Shannon index and evenness were recorded for macrophytes stands with a significant difference between invasive plants (*E. crassipes* and *S. molesta*) and native plant (*P. stratiotes*). In flood season, *E. crassipes* was greatly colonised by Odonata and Arachnida and was highly correlated with dissolved oxygen, temperature, PO_4^{3-} and depth. The rainy season was characterised by Coleoptera, Diptera, and Gasteropoda as well as highest levels of pH and NO_3^-. This season was correlated with *S. molesta* and *P. stratiotes*. In dry season, Heteroptera, Decapoda, Lepidoptera and Epheroptera were abundant and correlated with transparency.

Keywords: Aquatic macroinvertebrates, aquatic plants, biodiversity, Ono lagoon, Côte d'Ivoire

Introduction

Marginal lagoons, usually possess at their littoral regions extensive macrophyte stands [1], which play an important role in providing a stable habitat structure to the aquatic ecosystems [2, 3]. These submerged and floating macrophyte communities play a crucial role for animals and lower plants in aquatic ecosystems by providing habitat complexity and breeding areas, as well as being substrata for periphyton and sites of abundant food production for many aquatic animals [4, 5]. However, non-native species such as *Eichhornia crassipes* and *Salvinia molesta* may seriously alter the functions that macrophytes provide [6]. According to Etien and Arfi [7], these free-floating species have colonized about 70% of the Ivorian water surface. Their prolific growth causes considerable economic problems and affects fisheries, traffic, irrigation, water supply and the whole ecology of the infested aquatic ecosystems.

Aquatic macroinvertebrates play an important role in the coastal zone of water bodies, controlling the biomass of periphyton, acting in the decomposition and cycling of detritus [8]. In addition, their community assemblages can act as good indicators of the prevailing hydrological regime and water quality in aquatic systems. There are works concerning macroinvertebrate communities and invertebrate assemblages associated with *E. crassipes* and *P. stratiotes* roots of freshwater ecosystems [9-11]. However, no study investigating relationships between free-floating macrophytes, macroinvertebrate community and water properties was done in marginal lagoons. This study aims to describe the composition and structure of macroinvertebrates associated with free-floating macrophytes for better understanding the relationship between their assemblages and plant architectures as well as abiotic factors in Ono lagoon.

2. Materials and methods

2.1. Study area

Ono lagoon (5°22'22"N and 3°33'53"W) is a marginal freshwater ecosystem of 481 ha located in the Southeast of Ivory Coast (Figure 1).

Its surface includes a wide variety of habitat types such as emerged plants, free-floating macrophytes, floating leaf plants, submerged plants and white habitats. Because this lagoon is invaded by several macrophytes, the exploitable surface is 162 ha. It is irrigated by a small river (Wamon river) and connected in downstream to Comoé River. This lagoon, permanently connected to these rivers has an equatorial climate, including two rainy seasons (April-July and October-November) and two dry seasons (December-March and August-September). The permanent linkage with the Comoé river produces typical freshwater characteristics of this lagoon.

2.2. Data collection and laboratory procedure

Sampling of free-floating macrophytes and associated macroinvertebrates was carried out monthly from September 2015 to August 2016. Samples of water and macrophytes were collected in the upstream, the middle and the downstream of the lagoon. To assess the macroinvertebrate assemblages associated with each free-floating macrophytes, a net of 0.053 m² surface area with a 500-µm mesh size was used. Organisms on free-floating macrophytes were collected by submerging the edges of the sampling “kick-net” quadrat underneath the individuals to extract them from the water. The net was carefully lifted out of the water to prevent the escape of agile animals, then pooled per free-floating macrophytes and transferred into a plastic bag. For the isolation of macroinvertebrate from the collected plants, all plant materials were washed in a plastic bowl and filtered through a sieve of 0.2 mm mesh size. Subsequently, samples were preserved in a 10% formaldehyde solution in a plastic container for further analysis.

At laboratory, sub-samples of macrophytes were identified by specialists. Preserved samples were washed to remove formaldehyde solution and then screened through a 500 µm mesh size to collect all macroinvertebrates on white plates. They were then fixed in a 70% alcohol solution for identification. Large macroinvertebrates were sorted by the naked eye while smaller fauna was sorted under a binocular loupe. All animals were then sorted out into different taxonomic groups, counted and identified up to lowest possible taxon under binocular loupe according to the keys of [12-15].

For biomass determination, the wet weight of several individuals of each species were taken after broadly dividing into various size groups and mean individual weight of each species was worked out. Separated and washed plants were drained of excess water, weighed to estimate plant wet biomass and dried up to 105 °C for 2 days to express the dry weight.

The physical parameters, namely, transparency, depth, pH, total dissolved solids, conductivity and dissolved oxygen were recorded in *situ*. Water samples were taken, stored in polyethylene bottles (500 mL) and kept at a temperature below 4 °C for further determination of ammonium-nitrogen (NH_4^+; mg/L), nitrate (NO_3^-; mg/L), nitrite (NO_2^-; mg/L) and phosphate (PO_4^{3-}; mg/L). The samples were filtered through Whatman GF/C fibreglass filters and concentrations were determined using a spectrophotometer Model HACH DR 6000.

2.3. Data analysis

The number of species, density of individual species and total macroinvertebrate density were used to compute the species richness, the Shannon-Wiener index the evenness and the abundance. To determine the abundance of macroinvertebrates, densities were calculated based on the total number of individuals (N) per 100 g dry weight (dw) of macrophytes. All indices as well as individual species densities were tested by one-way analyses of variance, followed by Tukey multiple comparison tests for significant differences among the considered habitat types and seasons. One-way analysis of variance was also used to test the differences in physicochemical characteristics between seasons.

Redundancy Analysis (RDA), a constrained linear ordination method based on significant ($p<0.05$) forward selected environmental variables was carried out in order to search for and define the best explanatory water properties characterising the macrophyte and influencing the distribution of the associated macroinvertebrates. The statistical significance of the first four ordination axes was tested by using a Monte Carlo permutation test with 499 permutations under a reduced model. Data analysis was performed using the software CANOCO version 5.0.

3. Results

3.1. Environmental variables

The pH, transparency and depth exhibited significant variability amongst seasons (Table 1). The highest values of depth and pH were recorded in flood and rainy seasons, while the lowest values were observed in the dry season. The values of transparency were high in dry season and low in flood and rainy seasons. No significant variation of the other parameters was observed (ANOVA, $p>0.05$) (Table 1). Higher levels of temperature, dissolved oxygen, conductivity, TDS, NH_4^+ and PO_4^{3-} were registered in flood season while the values of NO_3^- were high in rainy season.

3.2. Macroinvertebrate diversity

A total of 150 macroinvertebrates belonged to 46 families and 15 orders were identified on macrophytes (Table 2). The major orders were Ephemeroptera, Odonata, Heteroptera, Lepidoptera, Coleoptera, Diptera, Trichoptera, Araneae, Trombidiformes, Decapoda, Pharyngobdelliformes, Haplotaxida, Architaenioglossa, Basommatophora and Littorinimorpha. *E. crassipes* recorded the highest number of taxa followed by *S. molesta* and *P. stratiotes*. One hundred and twenty-five taxa were found on *E. crassipes*, 77 on *S. molesta* and 62 on *P. stratiotes* of which 52 taxa were exclusively associated with *E. crassipes*, 15 with *S. molesta* and 7 with *P. stratiotes*. Thirty-seven common taxa were found in all macrophytes (Table 2). Of all the total assemblage of macroinvertebrates recorded, the groups with the highest family richness were Dytiscidae (28), Hydrophilidae (12), Libellulidae (10) and Chironomidae (10). The floating macrophyte stands were generally dominated by low frequent group (*E. crassipes* 70; *S. molesta* 42 and *P. stratiotes* 30) (Table 2).

Density of macroinvertebrates ranged from 2721 to 3060 ind. per 100 g d.w, and was much higher in *S. molesta* (3060 ind. per 100 g d.w.) followed by *E.crassipes* (2926 ind. per 100 g d.w.) and *P. stratiotes* (2721 ind. per 100 g d.w.) (Table 2). On specific level, macroinvertebrate communities were dominated by insects, with 88% in *E. crassipes*, 90% in *P. stratiotes* and 98% in *S. molesta*. This order was typically dominated by Odonata: between 34% in *E. crassipes* stands (997 ind. per 100 g d.w.) to 56% in association with *S. molesta* (1718 ind. per 100 g d.w.), and Coleoptera between 14% (378 ind. per 100 g d.w.) in association with *P. stratiotes* and 30% (873 ind. per 100 g d.w.) with *E. crassipes*. Libellulidae (14.39% in *E. crassipes* and 22.42% in *S. molesta*) and Corduliidae (10.56% in *E. crassipess* and 16.47% in *S. molesta*) exhibited the highest densities in all habitat.

The taxonomic richness ($F_{2, 36}$=12.49; p= 0.0001), Shannon-Wiener index ($F_{2, 36}$= 8.77; p = 0. 0001) and evenness ($F_{2, 36}$= 13.45; p= 0.0001) varied significantly (ANOVA, $p<0.05$) according habitat types (Figure 2). Higher values of taxonomic richness and Shannon-Wiener index were registered with *E. crassipes* followed by *S. molesta* and *P. stratiotes*. Concerning the eveness, the values were higher with *P. stratiotes* and lower with *E. crassipes* (Figure 2).

The results of the RDA showed that the first two RDA axes explained 100% of the relation taxon-environment. The environmental variables, namely temperature, conductivity and TDS were positively correlated with axis 1. Another parameter associated with axis 1, but negatively was nitrate. The axis 2 was negatively correlated with pH, depth, dissolved oxygen, and phosphate but positively correlated with transparency (Figure 3). In flood season, *E. crassipes* was greatly colonised by Odonata and Arachnida and was highly correlated with dissolved oxygen, temperature, PO_4^{3-} and depth. The rainy season was characterised by Coleoptera, Diptera, and Gasteropoda as well as highest levels of pH and NO_3^- and correlated with *S. molesta* and *P. stratiotes*. In dry season, Heteroptera, Decapoda, Lepidoptera and Ephemeroptera were abundant and correlated with transparency (Figure 3).

Table 1: Mean (± standard deviation) of abiotic parameters in Ono lagoon

Parameter	Rainy Season	Dry Season	Flood Season
Depth (m)	2.53 ± 0.08^b	2.31 ± 0.18^a	2.75 ± 0.22^b
Transparency (m)	1.33 ± 0.41^b	2.00 ± 0.35^c	0.89 ± 0.06^a
Temperature (°C)	26.99 ± 1.65	27.17 ± 1.58	27.60 ± 1.50
pH	7.02 ± 0.47^b	5.93 ± 0.76^a	6.11 ± 0.45^a
Dissolved oxygen (mg/L)	2.44 ± 1.40	1.87 ± 1.39	3.26 ± 3.22
Conductivity (µs/cm)	15.19 ± 4.59	18.84 ± 6.81	21.61 ± 2.26
Total dissolved solids (mg/L)	7.50 ± 2.35	9.51 ± 3,64	10.83 ± 1.07
Nitrate (mg/L)	3.71 ± 1.45	2.95 ± 1.10	2.30 ± 0.90
Nitrite (mg/L)	0.17 ± 0.30	0.30 ± 0.56	0.01 ± 0.00
Ammonium-nitrogen (mg/L)	0.08 ± 0.04	0.07 ± 0.09	0.10 ± 0.06
Phosphate (mg/L)	0.49 ± 0.20	0.44 ± 0.32	0.53 ± 0.83

Table 2: Macroinvertebrates recorded with occurrence and density (ind per 100 g dry weight) for each macrophyte. EICCR = E. crassipes, SALM0 = *S. molesta*, PISST = *P. stratiotes*, + = sporadic, ++ = low frequency, +++= frequent, ++++ = very frequent, – = absent

	Taxa	% Occurrency			Density (ind per 100 g d.w)		
Order	**Family/ Species**	**EICCR**	**SALMO**	**PISST**	**EICCR**	**SALMO**	**PISST**
Ephemeroptera	Baetidae	+++	++++	+++	36 ± 5	64 ± 4	96 ± 5
	Cloeon aerolatum	+++	+++	-	17 ± 2	29 ± 2	0 ± 0
	Cloeon bellum	++	++++	+++	9 ± 2	35 ± 2	42 ± 4
	Cloeon gambiae	-	-	+++	0 ± 0	0 ± 0	34 ± 3
	Pseudocloeon sp.	++	-	++	10 ± 2	0 ± 0	20 ± 3
	Leptophlebiidae	++	-	-	7 ± 1	0 ± 0	0 ± 0
	Thraulus bellus	++	-	-	4 ± 1	0 ± 0	0 ± 0
	Thraulus sp.	++	-	-	3 ± 1	0 ± 0	0 ± 0
Odonata	Aeshnidae	++	++	-	11 ± 1	8 ± 1	0 ± 0
	Aeshna sp.	++	++	-	11 ± 1	8 ± 1	0 ± 0
	Coenagrionidae	++++	++++	++++	106 ± 8	313 ± 20	296 ± 8
	Ceriagrion sp.	+++	+++	-	34 ± 3	58 ± 4	0 ± 0
	Ceriagrion tenellum	+++	++++	++++	31 ± 2	105 ± 5	133 ± 3
	Nehalennia sp.	-	+++	-	0 ± 0	21 ± 2	0 ± 0
	Pseudagrion sp.	+++	+++	++++	21 ± 2	52 ± 5	103 ± 4
	Pseudagrion wellani	++++	+++	+++	21 ± 1	76 ± 7	60 ± 5
	Corduliidae	++++	++++	++++	309 ± 13	504 ± 15	321 ± 9
	Cordulia aenea	++++	++++	++++	69 ± 4	119 ± 2	86 ± 3
	Epitheca bimaculata	++++	++++	++++	69 ± 4	123 ± 3	114 ± 7
	Hemicordulia olympica	++++	+++	-	59 ± 3	72 ± 7	0 ± 0
	Oxygastra curtisii	++++	++++	++++	69 ± 5	122 ± 6	115 ± 3
	Somatochlora sp.	++++	++++	+	43 ± 1	68 ± 4	5 ± 1
	Libellulidae	++++	++++	++++	421 ± 18	656 ± 34	412 ± 9
	Brachythemis leucosticta	+++	++	+++	27 ± 3	52 ± 6	60 ± 6
	Bradinopyga strachani	++	+++	-	18 ± 3	59 ± 6	0 ± 0
	Crocothemis erythraea	++++	+++	+++	48 ± 3	50 ± 5	32 ± 3
	Diplacodes lefebvrii	++++	+++	++	46 ± 2	30 ± 3	21 ± 3
	Leucorrhinia sp.	+++	-	-	12 ± 1	0 ± 0	0 ± 0
	Libellula sp.	++++	++++	++++	125 ± 7	189 ± 6	163 ± 6
	Orthetrum caffrum	++++	++++	++	43 ± 1	83 ± 5	21 ± 4
	Palpopleura lucia lucia	+++	+++	++	46 ± 4	71 ± 5	81 ± 2
	Sympetrum sp.	++++	+++	+++	49 ± 3	76 ± 5	34 ± 4
	Urothemis sp.	++	+++	-	7 ± 1	47 ± 5	0 ± 0

	Macromiidae	++++	++++	+++	150 ± 4	237 ± 7	128 ± 9
	Macromia picta	+++	++++	+++	69 ± 5	135 ± 5	63 ± 4
	Macromia sp.	++++	+++	+++	68 ± 4	74 ± 5	65 ± 6
	Phyllomacromia picta	++	-	-	13 ± 2	0 ± 0	0 ± 0
	Phyllomacromia sp.	-	++	-	0 ± 0	27 ± 3	0 ± 0
Heteroptera	Belostomatidae	++++	+++	++++	112 ± 4	93 ± 8	256 ± 12
	Diplonychus annulatus	+++	+++	++	32 ± 2	26 ± 3	26 ± 3
	Diplonychus rusticus	+++	++	++++	18 ± 2	10 ± 2	91 ± 4
	Diplonychus sp.	+++	+++	++	22 ± 2	58 ± 6	21 ± 3
	Diplonychus stappersi	++++	-	++++	40 ± 1	0 ± 0	117 ± 5
	Corixidae	-	++	-	0 ± 0	14 ± 2	0 ± 0
	Micronecta scutellaris	-	++	-	0 ± 0	14 ± 2	0 ± 0
	Gerridae	++	++		18 ± 2	45 ± 6	12 ± 2
	Eurymetra sp.	-	++	-	0 ± 0	17 ± 2	0 ± 0
	Limnogonus chopardi	++	++	-	18 ± 2	28 ± 4	0 ± 0
	Rhagodotarsus hutchinsoni	-	-	++	0 ± 0	0 ± 0	12 ± 2
	Naucoridae	+++	++++	+++	45 ± 4	219 ± 9	162 ± 12
	Macrocoris flavicollis	+++	++++	+++	23 ± 3	91 ± 4	92 ± 7
	Naucoris cimicoides	+++	++++	+++	22 ± 2	128 ± 5	70 ± 5
	Nepidae	++	-	-	21 ± 3	0 ± 0	0 ± 0
	Ranatra parvipes	++	-	-	21 ± 3	0 ± 0	0 ± 0
	Notonectidae	++	++	++	12 ± 2	10 ± 2	22 ± 4
	Anisops lundbladiana	-	-	++	0 ± 0	0 ± 0	10 ± 2
	Anisops sardea	++	++	++	12 ± 2	4 ± 1	12 ± 2
	Anisops sp.	-	++	-	0 ± 0	6 ± 1	0 ± 0
	Pleidae	+++	++	-	25 ± 3	26 ± 3	0 ± 0
	Plea pullula	+++	++	-	25 ± 3	26 ± 3	0 ± 0
	Veliidae	-	++	++	0 ± 0	13 ± 2	14 ± 3
	Microvelia pygmaea	-	++	++	0 ± 0	13 ± 2	14 ± 3
	Mesoveliidae	-	++	++	0 ± 0	17 ± 2	11 ± 2
	Mesovelia vittigera	-	++	++	0 ± 0	17 ± 2	11 ± 2
Lepidoptera	Crambidae	++++	++	++	105 ± 4	38 ± 4	138 ± 7
	Cataclysta lemnata	+++	++	++	19 ± 2	14 ± 3	21 ± 3
	Elophila obliteralis	++++	++	++	83 ± 3	8 ± 2	92 ± 6
	Parapoynx stratiotata	++	++	++	4 ± 1	16 ± 2	26 ± 5
Coleoptera	Curculionidae	++++	++	++	247 ± 14	28 ± 4	43 ± 6
	Bagous sp.	+++	++	+	66 ± 8	12 ± 2	13 ± 4
	Cyrtobagous salviniae	+++	++	++	13 ± 1	11 ± 2	4 ± 1
	Neochetina eichhorniae	++++	++	++	109 ± 4	6 ± 1	26 ± 4
	Neohydronomus sp.	++	-	-	11 ± 2	0 ± 0	0 ± 0
	Pseudobagous sp.	++	-	-	6 ± 1	0 ± 0	0 ± 0
	Stenopelmus sp.	++++	-	-	41 ± 2	0 ± 0	0 ± 0
	Dryopidae	++	-	-	11 ± 1	0 ± 0	0 ± 0
	Polyphaga sp.	++	-	-	11 ± 1	0 ± 0	0 ± 0
	Dytiscidae	+++	+++	+++	349 ± 21	223 ± 19	158 ± 15
	Agabus paludosus	+++	-	-	10 ± 1	0 ± 0	0 ± 0
	Agabus sp.	+++	++	-	37 ± 3	25 ± 3	0 ± 0
	Bidessus sp.	++	-	-	13 ± 2	0 ± 0	0 ± 0
	Canthydrus minutus	++	-	-	7 ± 1	0 ± 0	0 ± 0
	Canthydrus xanthinus	++	++	-	9 ± 2	20 ± 3	0 ± 0
	Canthyporus sp.	+++	-	+++	16 ± 1	0 ± 0	26 ± 3
	Cybister tripunctatus	++	++	-	9 ± 1	12 ± 2	0 ± 0
	Cybister fimbriolatus	+++	++	-	29 ± 2	26 ± 3	0 ± 0
	Clypeodytes sp.	-	-	+++	0 ± 0	0 ± 0	48 ± 4
	Dytiscus sp.	-	++	-	0 ± 0	6 ± 1	0 ± 0
	Guignotus sp.	++	-	-	27 ± 3	0 ± 0	0 ± 0
	Heterydrus senegalensis	++	++	-	8 ± 1	16 ± 2	0 ± 0
	Hydaticus paganus	-	+++	-	0 ± 0	40 ± 5	0 ± 0
	Hydrocanthus micans	++	++	-	20 ± 2	24 ± 3	0 ± 0
	Hydrocoptus simplex	+++	++	++	14 ± 1	19 ± 3	40 ± 5
	Hydroglyphus sp.	++	-	-	10 ± 1	0 ± 0	0 ± 0
	Hydroporus erythrocephalus	++	-	-	13 ± 3	0 ± 0	0 ± 0
	Hydroporus sp.	-	++	-	0 ± 0	6 ± 1	0 ± 0
	Hydrovatus sp.	++	-	+++	13 ± 2	0 ± 0	40 ± 4
	Hygrotus sp.	+++	-	+	9 ± 1	0 ± 0	3 ± 1
	Hyphydrus africanus	++	-	-	5 ± 1	0 ± 0	0 ± 0
	Ilybius sp.	-	++	-	0 ± 0	5 ± 1	0 ± 0
	Laccophilus inornatus	++	-	-	8 ± 1	0 ± 0	0 ± 0
	Laccophilus sp.	++	-	-	22 ± 3	23 ± 3	0 ± 0

	Limnoxenus niger	+++	-	-	32 ± 2	0 ± 0	0 ± 0
	Neptosternus tricuspis	++	-	-	4 ± 1	0 ± 0	0 ± 0
	Porhydrus sp.	++	-	-	13 ± 3	0 ± 0	0 ± 0
	Yola tuberculata	++	-	-	22 ± 3	0 ± 0	0 ± 0
	Elmidae	+++	-	+++	80 ± 5	0 ± 0	51 ± 4
	Elmis sp.	-	-	+++	0 ± 0	0 ± 0	38 ± 4
	Leptelmis seydelis	++	-	-	6 ± 1	0 ± 0	0 ± 0
	Limnius sp.	++	-	++	24 ± 3	0 ± 0	14 ± 3
	Nor*mandia* sp.	+++	-	-	20 ± 2	0 ± 0	0 ± 0
	Potamophilus sp.	++	-	-	6 ± 1	0 ± 0	0 ± 0
	Potamophilus acuminatus	++	-	-	3 ± 1	0 ± 0	0 ± 0
	Riolus sp.	++	-	-	21 ± 3	0 ± 0	0 ± 0
	Haliplidae	++	-	-	3 ± 1	0 ± 0	0 ± 0
	Haliplus sp.	++	-	-	3 ± 1	0 ± 0	0 ± 0
	Noteridae	++	-	-	25 ± 3	0 ± 0	0 ± 0
	Noterus sp.	++	-	-	25 ± 3	0 ± 0	0 ± 0
	Hydrophilidae	++++	++++	+++	157 ± 7	315 ± 20	126 ± 10
	Amphiops sp.	++++	+++	+++	43 ± 2	127 ± 8	92 ± 7
	Anacaena globulus	++++	++++	-	49 ± 2	62 ± 3	0 ± 0
	Berosus signaticollis	++	-	-	5 ± 1	0 ± 0	0 ± 0
	Cymbiodyta marginela	++	+++	-	20 ± 3	39 ± 4	0 ± 0
	Enochrus bicolor	++	-	-	10 ± 1	0 ± 0	0 ± 0
	Enochrus melanocephalus	++	-	++	7 ± 1	0 ± 0	7 ± 1
	Enochrus sp.	++	++	+	8 ± 1	11 ± 2	7 ± 2
	Hydrochara caraboides	++	-	-	6 ± 1	0 ± 0	0 ± 0
	Hydrochara sp.	++	++	++	9 ± 2	24 ± 3	20 ± 3
	Hydrophilus sp.	-	++	-	0 ± 0	10 ± 2	0 ± 0
	Laccobius minutus	-	++	-	0 ± 0	5 ± 1	0 ± 0
	Paracymus aeneus	-	+++	-	0 ± 0	37 ± 4	0 ± 0
	Hygrobiidae	-	++	-	0 ± 0	19 ± 4	0 ± 0
	Hygrobia tarda	-	++	-	0 ± 0	19 ± 4	0 ± 0
Diptera	Ceratopogonidae	++++	++	-	49 ± 4	9 ± 1	0 ± 0
	Bezzia sp.	++	++	-	18 ± 2	9 ± 1	0 ± 0
	Culicoides sp.	++++	-	-	31 ± 2	0 ± 0	0 ± 0
	Chaoboridae	++	-	-	4 ± 1	0 ± 0	0 ± 0
	Chaoborus anomalus	++	-	-	4 ± 1	0 ± 0	0 ± 0
	Chironomidae	++++	++++	+++	181 ± 7	134 ± 6	189 ± 18
	Chironomus imicola	++++	++	++	45 ± 2	11 ± 2	60 ± 7
	Chironomus sp.	++	-	-	9 ± 1	0 ± 0	0 ± 0
	Clinotanypus claripennis	-	-	+++	0 ± 0	0 ± 0	39 ± 4
	Cricotopus sp.	+++	-	-	28 ± 3	0 ± 0	0 ± 0
	Nilodorum sp.	++	-	-	8 ± 1	0 ± 0	0 ± 0
	Orthocladius sp.	++	+++	-	6 ± 1	23 ± 3	0 ± 0
	Polypedilum sp.	-	-	+++	0 ± 0	0 ± 0	44 ± 4
	Stictochironomus sp.	++++	-	-	27 ± 2	0 ± 0	0 ± 0
	Tanypus sp.	++++	++++	+++	43 ± 2	85 ± 5	46 ± 4
	Tanytarsus sp.	++	++	-	15 ± 2	15 ± 3	0 ± 0
	Psychodidae	++	-	-	10 ± 1	0 ± 0	0 ± 0
	Pericoma fuliginosa	++	-	-	10 ± 1	0 ± 0	0 ± 0
	Tabanidae	++	-	-	24 ± 2	0 ± 0	0 ± 0
	Tabanus bovinus	++	-	-	13 ± 2	0 ± 0	0 ± 0
	Tabanus sp.	++	-	-	10 ± 2	0 ± 0	0 ± 0
Trichoptera	Leptoceridae	++	-	-	3 ± 1	0 ± 0	0 ± 0
	Parasetodes sp.	++	-	-	3 ± 1	0 ± 0	0 ± 0
	Philopotamidae	+++	-	++	57 ± 6	0 ± 0	15 ± 3
	Chimarra petri	+++	-	-	29 ± 3	0 ± 0	0 ± 0
	Philopotamus sp.	+++	-	++	28 ± 3	0 ± 0	15 ± 3
Araneae	Pisauridae	+++	+++	+++	23 ± 1	37 ± 2	34 ± 3
	Thalassius margaritatus	++	++	-	5 ± 1	16 ± 2	0 ± 0
	Thalassius massajae	+++	++	++	4 ± 0	7 ± 1	11 ± 2
	Thalassius rossi	+++	+++	+++	10 ± 1	14 ± 1	23 ± 2
	Thalassius sp.	++	-	-	3 ± 1	0 ± 0	0 ± 0
	Tetragnathidae	-	++	++	0 ± 0	11 ± 2	15 ± 2
	Tetragnatha maxillosa	-	++	-	0 ± 0	3 ± 1	0 ± 0
	Tetragnatha sp.	-	++	++	0 ± 0	8 ± 2	15 ± 2
Trombidiformes	Hydrachnidae	+++	++	++	85 ± 8	20 ± 4	84 ± 8
	Hydrachna globosa	++	-	++	28 ± 5	0 ± 0	65 ± 8
	Hydrachna sp.	+++	++	++	58 ± 8	20 ± 4	19 ± 4
Decapoda	Crangonidae	++++	-	++	75 ± 7	0 ± 0	41 ± 5

	Crangon crangon	++++	-	++	75 ± 7	0 ± 0	41 ± 5
	Palaemonidae	++	-	-	4 ± 1	0 ± 0	0 ± 0
	Palaemon elegans	++	-	-	4 ± 1	0 ± 0	0 ± 0
	Panaeidae	+++	-	++	72 ± 5	0 ± 0	27 ± 3
	Parapenaeus longirostris	++	-	-	12 ± 2	0 ± 0	0 ± 0
	Penaeus notialis	+++	-	++	60 ± 5	0 ± 0	27 ± 3
	Pasiphaeidae	++	-	-	15 ± 3	0 ± 0	0 ± 0
	Glyphus marsupialis	++	-	-	15 ± 3	0 ± 0	0 ± 0
Pharyngobdelliformes	Erpobdellidae	++	-	-	9 ± 2	6 ± 1	0 ± 0
	Erpobdella sp.	++	-	-	9 ± 2	0 ± 0	0 ± 0
	Glossiphoniidae	-	++	-	0 ± 0	3 ± 1	0 ± 0
	Theromyzon tessulatum	-	++	-	0 ± 0	6 ± 1	0 ± 0
Haplotaxida	Naididae	++	-	-	4 ± 1	0 ± 0	0 ± 0
	Ophidonais sp.	++	-	-	4 ± 1	0 ± 0	0 ± 0
Architaenioglossa	Ampullariidae	+++	-	++	37 ± 4	0 ± 0	23 ± 3
	Lanistes ovum	+++	-	++	15 ± 1	0 ± 0	23 ± 3
	Pila africana	++	-	-	12 ± 2	0 ± 0	0 ± 0
	Pila globosa	++	-	-	10 ± 1	0 ± 0	0 ± 0
Basommatophora	Planorbidae	++	-	++	6 ± 1	0 ± 0	21 ± 3
	Bulinus africanus	++	-	++	6 ± 1	0 ± 0	21 ± 3
	Physidae	++	-	+++	10 ± 1	0 ± 0	26 ± 2
	Physa sp.	++	-	+++	3 ± 1	0 ± 0	26 ± 2
	Aplexa marmorata	++	-	-	7 ± 1	0 ± 0	0 ± 0
Littorinimorpho	Bithyniidae	++	-	-	5 ± 1	0 ± 0	0 ± 0
	Gabiella kisalensis	++	-	-	5 ± 1	0 ± 0	0 ± 0
	Total density				2926	3060	2721
	Specific richness (S)				125	77	62

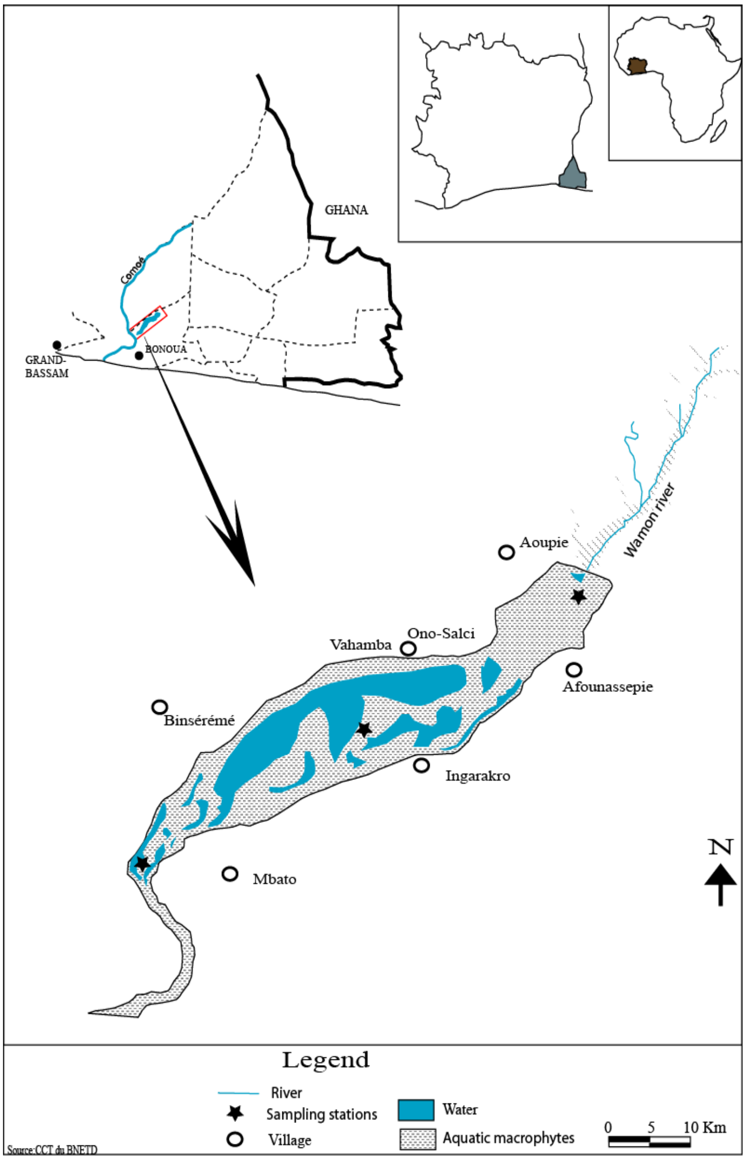

Fig 1: Location of the study area showing the sampling sites of Ono river (Côte d'Ivoire)

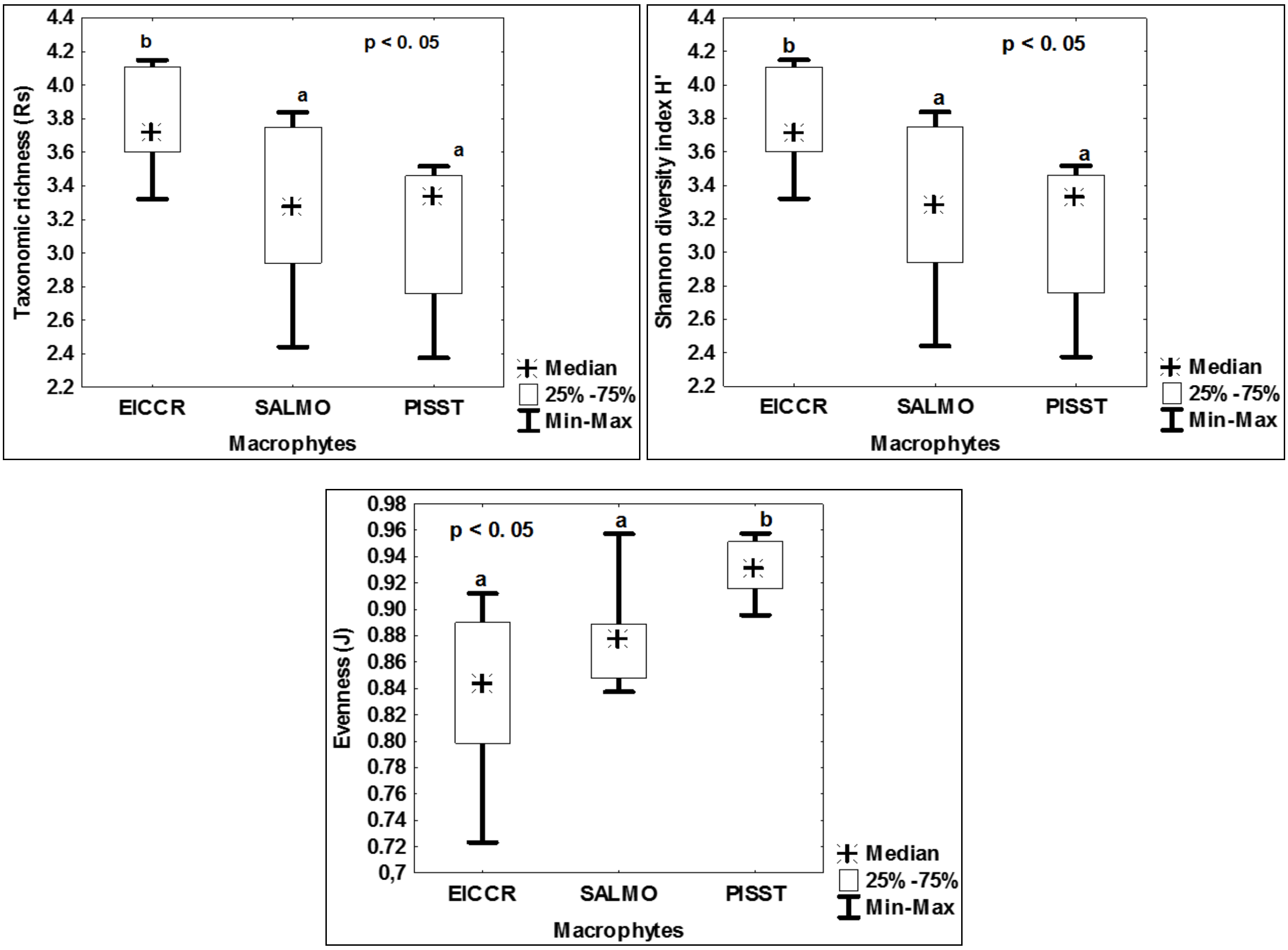

Fig 2: Macroinvetebrate taxon diversity recorded for different free-floating macrophytes (EICCR = *E. crassipes*; SALMO = *S. molesta*; PISST = *P. stratiotes*

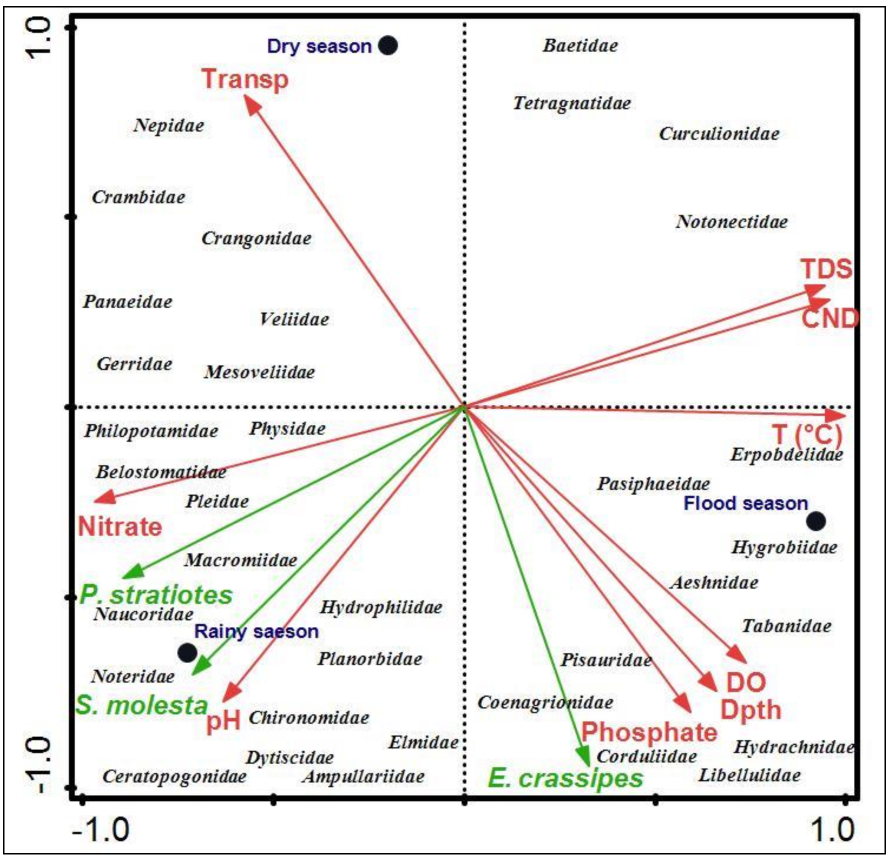

Fig 3: Redundancy Analysis (RDA) showing the relationships between environmental variables, floating macrophytes and macroinvertebrates. (DO= dissolved oxygen, CND= Conductivity, T= temperature, Trans= transparency and Dpth= depth).

4. Discussion

This work is the first study on the macroinvertebrates communities associated with aquatic macrophytes in Ono lagoon, a small lagoon largely invaded by floating, emergent and submerged macrophytes in Ivory Coast. The results showed that the most abundant floating macrophytes recorded in this lagoon were *E. crassipes, S. molesta* and *P. stratiotes*. Although environmental variables did not vary significantly according month, pH, transparency and depth exhibited significant seasonal variations. Ono lagoon has typical freshwater characteristics due to the permanent linkage with the Comoé and Wamon rivers. Dissolved oxygen (DO) values were low during the sampling period and varied in accordance with the work of [16]. The lowest values of oxygen levels may be due to the removal of free oxygen through respiration by, macrophytes bacteria and animals as indicated by [17]. The pH was acidic in dry and flood seasons and neutral in rainy season. This acidity comes mainly from plant organic matter decomposition, with production of CO_2 in the first layers of the soil [18, 19]. The low transparency values recorded during the rainy and flood seasons are the result of turbulence due to the arrival of runoff and the Comoé River. The nutrients represented by ammonium-nitrogen, phosphate, nitrate and nitrite were low and did not vary between seasons.

The floating macrophytes of Ono lagoon supported a rich community of benthic and epiphytic macroinvertebrates compared to Taabo Lake [11] and Malilangwe Reservoir [20], where 43 and 42 families were respectively recorded. We noted 17 similar taxa to both previous ecosystems while 18 and 19 taxa were respectively different to those of Taabo Lake and Malilangwe Reservoir. This could be attributed to the timing, location or many other sampling technique factors and anthropogenic activities. The abundance of macroinvertebrate was higher in floating macrophytes but a large number and variety were recorded on *E. crassipes*. These differences could partly arise from the fact that these plants vary in morphology and thickness and thus offer widely different amount of colonizable surface per unit of plant weight. It has been demonstrated that macrophyte complexity is positively correlated with faunal richness and abundance [21, 22]. According to Trivinho-Strixino *et al*. [23], the extensive fascicled roots of *E. crassipes* can promote a great retention of particulate organic matter and detritus accumulation, favouring the presence of animals. On the other hand, greater variation in space sizes may provide living space to organisms with a wide variety of body sizes, thereby increasing specific richness. So, habitats with high size heterogeneity may be able to support a great number of taxa by providing liveable space to organisms of varying body sizes [24]. Populations of *Pistia stratiotes* remained small and scattered throughout the study period, resulting in lower variation of taxa associated with them and less developed stands. Populations of *E. crassipes* and *S. molesta* reached higher standing biomasses, supporting more epiphytic macroinvertebrates than *P. stratiotes*. According to Cyr and Downing [25] invertebrate numbers or biomass are positively correlated with plant biomass. However, the macroinvertebrate stands were diverse and well-structured because most of taxa had low frequencies, suggesting that the communities got good environmental conditions for their development. Schäfer [26] reported that extreme habitats, such as eutrophic waters, have poor communities characterized by a limited number of highly-adapted species. On the other hand, in habitats which have balanced conditions, a biocoenosis richness in terms of number of species and uniform distribution of individuals can be found.

In view of the evenness values, the microhabitats studied showed a relative heterogeneity. *Salvinia molesta* showed a higher variation in evenness values while *E. crassipes*, with values varying between 0.72 and 0.92 presented the lowest median value of evenness. These values are high when compared with those of Albertoni *et al.*, Kouamé *et al*. and Dalu *et al*. [27, 11, 20] respectively in Taabo Lake and Malilangwe Reservoir. According to Schäfer [26], high levels of evenness indicate an environment with heterogeneous conditions regulated by a community which is rich in the number of species and the multiplicity of their mutual relationships. Values found in our study suggest that conditions were heterogeneous in some sampling sites and homogeneous in others, leading to a less rich community structure. The values of Shannon-Wiener index were significantly high in invasive plants (*E. crassipes* and *S. molesta*), suggesting that the invasive macrophytes were able to sustain a richer associated community. Albertoni *et al*. [27] made the same observation in subtropical lakes of south Brazil.

The density of macroinvertebrates found in *S. molesta* was slightly higher than that found in the other macrophytes. These densities were higher than those recorded for *Nymphoides peltata* and *Polygonum amphibium* (1,882 and 2,718 per 100 g d.w.) and lower than those of *Ceratophyllum demersum* and *Carex sp*. (12,501 and 5,789 ind. per 100 g d.w.) of the Kopački rit Nature Park in Croatia [28]. The groups of macroinvertebrates with higher density were Corduliidae and Libellulidae (Odonata). The same situation was observed in Argentina by Poi De Neiff and Carignan [29]. Odonata are predatory insects which use macrophytes as substrate and ambush points to capture their prey [30]. The Heteroptera, dominated by Naucoridae and Belostomatidae were regularly recorded in all macrophyte microhabitats. These aquatic insects belonging to the genera Naucoris (Naucoridae) and Diplonychus (Belostomatidae) are the transmission vectors of the Buruli ulcer [31]. Therefore, the increase of the abundance of these Heteroptera could cause a potential risk for the lakeside communities, particularly for fishermen and those who are regularly in contact with this lagoon. A high number of Diptera belonging to Chironomidae family was also recorded. Chironimidae species are typical macroinvertebrate communities of eutrophic water bodies. So, their increased densities represent increasing levels of eutrophication. According to Merritt and Cummins [30], the range of conditions under which Chironomidae are found is more extensive than that of any other group of aquatic insects, and their wide ecological amplitude is related to the very extensive array of morphological, physiological and behavioural adaptations.

The structure of the macroinvertebrate community associated to floating macrophytes did not seem to be influenced by the set of abiotic parameters. However, if evaluated in an isolated way, the oxygen, pH and the depth influenced some groups of invertebrates in flood and rainy seasons. Theses parameters are the main environmental variables which play an important role in determining species composition of macroinvertebrate assemblages. The better oxygenation of water and pH near neutrality in flood and rainy seasons were probably the key factors favouring the occurrence of a great number of macroinvertebrates. Silva and Henry [32] made the same observations with macroinvertebrates associated with *E. azurea* in marginal lentic ecosystems. Stiers *et al*. [33] noted that most of macroinvertebrates are sensitive to low concentration of dissolved oxygen. They also find refuge from prevailing hypoxic conditions in overlaying waters by using the oxygen excluded from the roots of the macrophyte.

5. Conclusion

In this study of Ono lagoon, microhabitats created by invasive plants (*E. crassipes* and *S. molesta*) recorded the highest number of taxa and density community than the native macrophyte (*P. stratiotes*). A total of 150 macroinvertebrates belonged to 46 families, 15 orders and six classes were identified on macrophytes. Specifically, 125 taxa were found on *E. crassipes*, 77 on *S. molesta* and 62 on *P. stratiotes* of which 52 taxa were exclusively associated with *E. crassipes*, 15 with *S. molesta* and 7 with *P. stratiotes*. The groups with highest family richness were Dytiscidae (28), Hydrophilidae (12), Libellulidae and Chironomidae (10). Distribution of aquatic macroinvertebrates of Ono Lagoon was best explained by pH, Depth, transparency, temperature, conductivity, dissolved oxygen, phosphate, nitrate and Total dissolved solids.

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