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Macroinvertebrate Communities Associated with *Hydrilla verticillata* (Royle, 1839) and Relationship with Environmental Factors in Ono Lagoon, Southeast of Côte d'Ivoire

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***Abstract*—** *The macroinvertebrates associated with Hydrilla verticillata was studied in Ono lagoon, South-eastern of Côte d'Ivoire. M*onthly samples of macrophytes with their associated macroinvertebrates were collected in *upstream, centre and downstream*using a Van veen grab *of 0.314 m^2 internal area. The environmental variables (temperature, transparency, depth, conductivity, TDS, pH, dissolved oxygen,* NH_4^+, NO_3^-, NO_2^- *and* PO_4^{3-}*) were also recorded. A total of 71 taxa belonging to 28 families, 11 orders, 05 classes and 03 phyla of which 40 taxa were recorded in upstream, 45 taxa in centre and 44 taxa in downstream. Insects numerically dominated the capture, comprising 91.55% of the collectedtaxa with Odonata and Coleoptera being the most diverse and abundant groups. The density was higher in upstream (1407ind. per 100 g d.w.) and lower in downstream (1062 ind. per 100 g d.w.), whist theLibellulidae and Corduliidae exhibited the highest density communities. The rarefied richness did not show spatial variation but vary significantly between seasons. The Evenness did not show spatial and seasonal variations. However, Shannon diversity index varied significantly between sites and seasons. From the results of RDA analysis, conductivity and pH showed a strong environmental gradient and had a structuring effect on macroinvertebrate communities.*

***Keywords*— *Aquatic macroinvertebrates, macrophytes, Ono lagoon, taxonomic richness, Côte d'Ivoire*.**

I. INTRODUCTION

Submerged macrophytes in freshwater lakes, reservoirs, lagoons and ponds play an important role in aquatic systems, providing shelter, breeding habitat and epiphytic forage for numerous fishes and aquatic macroinvertebrates. The macroinvertebrate communities associated with specific macrophytes in freshwater have frequently been examined(Albertoni*et al*., 2007; Kouamé*et al*., 2011; Phiri *et al*., 2011). It has been reported that macroinvertebrates are not equally abundant on all plant species (Downing and Cyr, 1985). According to Carpenter and Lodge (1986), aquatic plants provide a physically and chemically complex habitat in aquatic ecosystems, and architectural features of this habitat can affect invertebrate species diversity, density and distribution. Submerged vegetation significantly modifies the water flow, while emerged species stabilise the sediment and shoreline zone and thus improve water quality (Krischik*et al*., 1999). Submerged and floating-leaved macrophytes differ in structure, offering diverse opportunities for phytophilous organisms (Cattaneo*et al*., 1998). Macroinvertebrates abundance is often higher on macrophytes with dissected leaves than on those with undissected leaves, because the latter have a larger surface with periphyton for grazing macroinvertebrates and because additional complexity provides a better refuge from predators(Cheruveli*et al*., 2002). However, according to Cyr and Downing (1988) and Irvine *et al*. (1990),

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macrophytes with complex broad leaves can be a better refuge from predators than macrophytes with dissected leaves. Macrophytes like *Ceratophyllumdemersum* and *Myriophyllum* spp. generally do not support higher macroinvertebrates abundance in relation to macrophytes with broad leaves. Can *Hydrilla verticillata* which looks about the same as *Ceratophyllumdemersum* and *Myriophyllum* spp. support more macroinvertebrates abundance? This current study is one of the first to be carried out on macroinvertebrate community of Ono lagoon. The aim was to investigate the spatial and seasonal variation of macroinvertebrates associated with *H. verticillata* and their relationship with environmental factors.

II. MATERIAL AND METHODS

2.1. Study area

Ono lagoon (5°22'22 "N; 3°33'53" W) is located in the Southeast of Côte d'Ivoire (Fig. 1). This lagoon had an initial surface area of about 481 ha. In recent decades, the exploitable area has been reduced to 162 ha because of variety of habitat types such as emerged plants, free-floating macrophytes, floating leaf plants, submerged plants and white habitats.This lagoon is irrigated by a small river (Wamonriver) and connected in downstream to Comoériver. The climate of the study region is tropical and humid characterized by two seasons (dry and rainy seasons). The dry season extends from December to March and from August to September while the rainy season extends from April to July and from October to November.

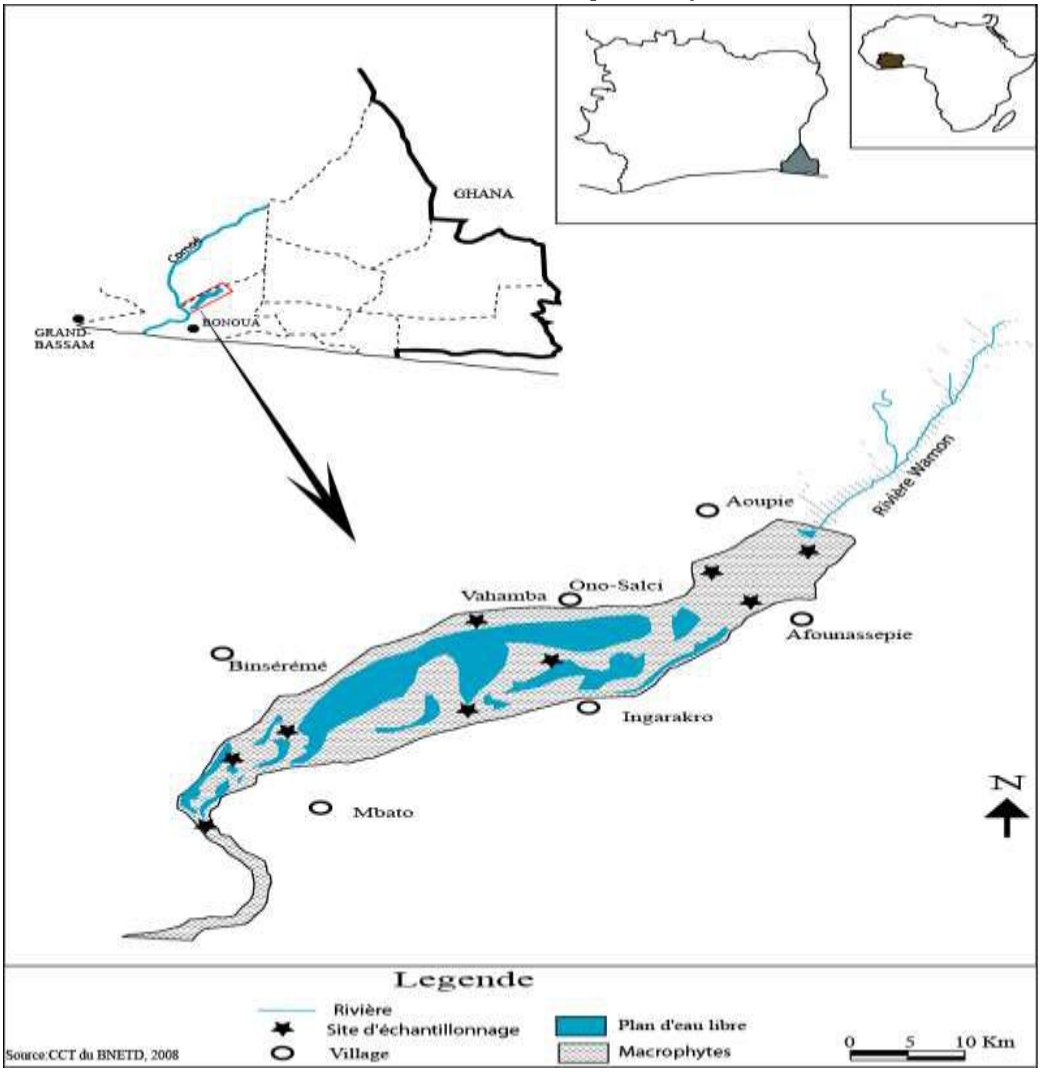

Fig.1: Map showing Ono Lagoon and the different samplings stations.

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2.2. Data collection and laboratory procedure

Sampling in Ono Lagoon spanned a period of one year (September 2015 to August 2016). Samples of water and macrophytes with their associated macroinvertebrates were monthly collected in upstream, centre and downstream (Fig. 1). *Hydrilla verticillata*was sampled using a Van veen grab of 0.314 m^2 internal area. The great transparency of water allowed us to position and close the grab with a relative precision at the level of the portion to be studied. Parts of macrophytes reported in excess and overflowing the jaws of the grab were removed by cutting, to keep only those located inside. All plant material and associated macroinvertebrates of the grab were washed into a bowl, then filtered through a 0.2 mm mesh sieve. Subsequently, the samples were preserved in a 10% formaldehyde solution in a plastic container for further analysis. At laboratory, 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, counting and weighing. Separated and washed plants were drained of excess water, weighed to estimate plant wet biomass and dried up to 105°C for 2 daysto express the dry weight. Large macroinvertebrates were sorted by the naked eye while smaller fauna was sorted under a binocular loupe. The macroinvertebrates were identified up to lowest possible taxon according to Déjoux*et al*. (1981), De Moor *et al*. (2003a; 2003b) and Tachet*et al*. (2003).

2.3.Measurement of environmental variables

Simultaneously to the biological examinations, a number of physical and chemical analyses were conducted. On each sampling site, the temperature, transparency, water depth, pH, Total Dissolved Solids (TDS), conductivity and dissolved oxygen were monthly measured *in situ* between 08.00 am and 10.00 am. Water samples were taken, stored in polyethylene bottles (500 mL) and kept at a temperature below 4°C and conducted to laboratory where analyses of dissolved inorganic nutrients (ammonium NH_4^+, nitrite NO_2^-, nitrate $NO_3^-$and phosphorus PO_4^{3-}) were carried using a spectrophotometer Model HACH DR 6000.

2.4. Data analysis

The macroinvertebrate density was characterised based on the total number of individuals (N) per 100 g dry weight (d.w.) of macrophytes. Invertebrate diversity was assessed as: taxon richness, Shannon-Wiener diversity and evenness indices. The total taxa were rarefied for each site for a given number of individuals drawn randomly from a sample (Magurran, 2004). The rarefaction was used to avoid any bias related to differences inabundances between samples using the lowest abundance (56 individuals for this study) found in all sites asthe target number of individuals following Oksanen *et al*., 2013.

Before performing comparison analyses, data normality was tested using Shapiro test. As the biotic and abiotic data distribution was not normal ($P<0.05$), the non-parametric test of Kruskal-Wallis was performed to compare data between sampling sites. When Kruskal-Wallis test is significant, Mann-Whitney U test was used for pairwise comparison.

Redundancy Analysis (RDA) was used to assess relationships between macroinvertebrate distribution and environmental variables. A Monte Carlo permutation test was performed to assess the statistical significance of the environment variables and the full model to arrive at the significance of the first two axes. All analyses were conducted using the R package.

III. RESULTS

3.1. Environmental variables

The mean values of Ono environmental variables for study period are summarize in TABLE 1. Significant variation in water parameters was not observed among the sampling zones (ANOVA results of Kruskal-Wallis test, $P > 0.05$), except for temperature. This parameter varied significantly among the sampling sites ($H_{2,36} = 3.37$, $p = 0.048$) with thehighest value occurring in downstream (27,91 ± 1,51°C).For the other parameters, namely water depth, transparency, dissolved oxygen, nitrate, nitrite and phosphate, the values were slightly high in downstream. The mean values of conductivity and total dissolved solids were rather high in upstream than in downstream.

*Table.1: Spatial mean values*of the measured environmental variables *(mean ± (SD))* in *Ono Lagoon*. *Means with different letters within stations differ statistically p < 0.05*

Parameters	Upstream	Centre	Downstream
Water depth (m)	2,39 ± 0,27	2,43 ± 0,11	2,55 ± 0,26
Transparency (m)	1,49 ± 0,48	1,50 ± 0,48	1,79 ± 0,67
Temperature (°C)	26,36 ± 1,40[a]	27,27 ± 1,48[ab]	27,91 ± 1,51[b]
pH	6,37 ± 0,96	6,32 ± 0,67	6,28 ± 0,81

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Dissolved oxygen (mg/L)	1,70 ± 2,22	2,36 ± 1,74	2,81 ± 1,36
Conductivity (µS/cm)	19,98 ± 4,17	17,26 ± 5,87	17,01 ± 7,35
Total dissolved solids (mg/L)	10,15 ± 2,57	8,50 ± 3,00	8,53 ± 3,70
Nitrate (mg/L)	3,22 ± 0,91	2,67 ± 1,15	3,40 ± 1,63
Nitrite (mg/L)	0,18 ± 0,41	0,18 ± 0,41	0,28 ± 0,52
Ammonium-nitrogen (mg/L)	0,06 ± 0,04	0,10 ± 0,05	0,08 ± 0,10
Phosphate (mg/L)	0,43 ± 0,22	0,34 ± 0,15	0,65 ± 0,63

3.2. Macroinvertebrate Assemblages

A total of 71 taxa belonging to 28 families, 11 orders, 05 classes and 03 phyla of which 40 taxa were recorded in upstream, 45 taxa in centre and 44 taxa in downstream (TABLE 2). Aquatic Insects numerically dominated the capture, comprising 91.55% of the collected taxa with Odonata (22 taxa) and Coleoptera (18 taxa) being the most diverse and abundant groups. Libellulidae was the most represented family (08 species), followed by Corduliidae and Coenagrionidae(05 species each). Only one species of Crangonidae(*Crangoncrangon*) and Ampullariidae(*Marisa cornuarietis*)families were identified.

The density of macroinvertebrates was highest in upstream (1407 ind. per 100 g d. w.), followed those recorded incentre (1213 ind. per 100 g d. w.) and downstream (1062 ind. per 100 g d. w.) (Table 2). Insects dominated the community, with 94.44% (1325 ind. per 100 g d.w.)in upstream and 97% both in centre (1183 ind. per 100 g d.w.) and downstream (1038 ind. per 100 g d.w.) (Table2). Odonata and Coleoptera had the highest densities and were constantly present in all sites. The most abundant macroinvertebrate order was Odonata. Their density ranged from 48.54% (681 ind. per 100 g d.w.)in upstream to 44.81% (544 ind. per 100 g d.w.)in centre. The second largest group was Coleoptera with a density varying from 8.98% (96 ind. per 100 g d.w.) in downstream to 20.46% (287 ind. per 100 g d.w.) in upstream, followed by Heteroptera (from 10.76% in upstream to 17.30% in centre), Diptera (from 6.49% in upstream to 10.38% in centre) and Lepidoptera (from 3.29% in centre to 11.79% in downstream). The lowest densities were observed in Ephemeroptera, Decapoda, Pharyngobdelliformes, Architaenioglossa and Plecoptera.Libellulidae (from 19% in both centre and downstream to 24% in upstream) and Corduliidae (from 10% upstream to 16.64% in centre) exhibited the highest family densities in sampling stations.

Table.2: Density (number of individuals per 100 g dry weight) of macroinvertebrates recorded on Hydrilla verticillata at different sampling stations

Major groups			**Taxa**	**Density (ind per 100 g d.w)**		
Phyla	**Class**	**Orders**	**Famillies/species**	Upstream	Centre	Downstream
Arthropoda	**Insecta**	**Ephemeroptera**	**Baetidae**	0 ± 0	45 ± 4	75 ± 5
			Cloeonaerolatum	0 ± 0	23 ± 2	36 ± 3
			Cloeonbellum	0 ±	22 ± 2	7 ± 1
			*Pseudocloeon*sp.	0 ± 0	0 ±0	32 ± 2
			Leptophlebiidae	0 ± 0	0 ± 0	8 ± 1
			Thraulusbellus	0 ± 0	0 ± 0	8 ± 1
		Plecoptera	**Perlidae**	0 ± 0	0 ± 0	5 ± 1
			Neoperlaspio	0 ± 0	0 ± 0	5 ± 1
		Odonata	**Aeshnidae**	11 ± 1	18 ± 3	0 ± 0
			*Aeshna*sp.	11 ± 1	18 ± 3	0 ± 0
			Coenagrionidae	105 ± 7	78 ± 4	94 ± 5
			*Ceriagrion*sp.	34 ± 3	0 ± 0	0 ± 0
			Ceriagriontenellum	29 ± 2	0 ± 0	38 ± 2
			*Nehalennia*sp.	0 ± 0	40 ± 3	0 ± 0
			*Pseudagrion*sp.	20 ± 2	5 ± 1	16 ± 2
			Pseudagrionwellani	23 ± 1	32 ± 3	40 ± 3

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			Corduliidae	142 ± 8	200 ± 11	145 ± 8
			Corduliaaenea	77 ± 5	54 ± 4	0 ± 0
			Epithecabimaculata	0 ± 0	91 ± 6	91 ± 4
			Hemicorduliaolympica	64 ± 3	0 ± 0	11 ± 2
			Oxygastracurtisii	0 ± 0	55 ± 3	0 ± 0
			*Somatochlora*sp.	0 ± 0	0 ± 0	44 ± 4
			Libellulidae	340 ± 18	232 ± 9	211 ± 10
			Brachythemisleucosticta	26 ± 3	50 ± 3	28 ± 4
			Bradinopygastrachani	23 ± 4	0 ± 0	20 ± 2
			Diplacodeslefebvrii	0 ± 0	0 ± 0	13 ± 3
			*Leucorrhinia*sp.	22 ± 2	0 ± 0	0 ± 0
			*Libellula*sp.	129 ± 5	114 ± 6	93 ± 3
			Palpopleuralucialucia	77 ± 7	68 ± 2	59 ± 4
			*Sympetrum*sp.	53 ± 4	0 ± 0	0 ± 0
			*Urothemis*sp.	9 ± 2	0 ± 0	0 ± 0
			Macromiidae	86 ± 3	15 ± 2	61 ± 3
			*Macromia*sp.	68 ± 4	7 ± 1	61 ± 3
			Phyllomacromia picta	17 ± 3	0 ± 0	0 ± 0
			*Phyllomacromia*sp.	0 ± 0	8 ± 2	0 ± 0
		Heteroptera	**Belostomatidae**	58 ± 3	26 ± 3	40 ± 2
			Diplonychusannulatus	36 ± 3	8 ± 2	10 ± 2
			*Diplonychus*sp.	22 ± 2	18 ± 3	29 ± 2
			Gerridae	0 ± 0	18 ± 3	8 ± 2
			*Eurymetra*sp.	0 ± 0	18 ± 3	0 ± 0
			Limnogonuschopardi	0 ± 0	0 ± 0	8 ± 2
			Naucoridae	56 ± 6	145 ± 10	62 ± 2
			Macrocorisflavicollis	31 ± 4	52 ± 4	28 ± 3
			Naucoriscimicoides	25 ± 2	93 ± 6	35 ± 4
			Nepidae	8 ± 2	0 ± 0	8 ± 2
			Ranatraparvipes	8 ± 2	0 ± 0	8 ± 2
			Notonectidae	0 ± 0	0 ± 0	9 ± 2
			Notonectaglauca	0 ± 0	0 ± 0	9 ± 2
			Pleidae	28 ± 3	8 ± 1	0 ± 0
			Plea pullula	28 ± 3	8 ± 1	0 ± 0
			Veliidae	0 ± 0	14 ± 2	0 ± 0
			Microveliapygmaea	0 ± 0	14 ± 2	0 ± 0
			Mesoveliidae	0 ± 0	0 ± 0	5 ± 1
			Mesoveliavittigera	0 ± 0	0 ± 0	5 ± 1
		Lepidoptera	**Crambidae**	116 ± 5	41 ± 5	125 ± 13
			Cataclystalemnata	21 ± 2	16 ± 3	8 ± 1
			Elophilaobliteralis	89 ± 3	8 ± 2	54 ± 5
			Parapoynxstratiotata	5 ± 1	17 ± 2	63 ± 10
		Coleoptera	**Curculionidae**	65 ± 8	13 ± 3	15 ± 2
			*Bagous*sp.	65 ± 8	13 ± 3	0 ± 0
			*Stenopelmus*sp.	0 ± 0	0 ± 0	15 ± 2
			Dryopidae	15 ± 2	0 ± 0	0 ± 0
			*Polyphaga*sp.	15 ± 2	0 ± 0	0 ± 0

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			Dytiscidae	64 ± 4	89 ± 9	48 ± 3
			*Agabus*sp.	0 ± 0	26 ± 4	0 ± 0
			Canthydrusxanthinus	11 ± 2	22 ± 3	7 ± 2
			Cybistertripunctatus	0 ± 0	10 ± 2	0 ± 0
			Cybisterfimbriolatus	37 ± 3	8 ± 2	15 ± 2
			*Hydrovatus*sp.	16 ± 2	0 ± 0	26 ± 2
			*Laccophilus*sp.	0 ± 0	22 ± 3	0 ± 0
			Elmidae	26 ± 3	0 ± 0	20 ± 3
			*Normandia*sp.	21 ± 2	0 ± 0	0 ± 0
			*Potamophilus*sp.	5 ± 1	0 ± 0	0 ± 0
			Potamophilusacuminatus	0 ± 0	0 ± 0	20 ± 3
			Hydrophilidae	119 ± 5	113 ± 7	15 ± 1
			*Amphiops*sp.	53 ± 3	67 ± 3	0 ± 0
			Anacaenaglobulus	58 ± 2	0 ± 0	0 ± 0
			*Enochrus*sp.	8 ± 1	22 ± 2	5 ± 1
			Hydrobiusfuscipes	0 ± 0	0 ± 0	10 ± 1
			*Hydrochara*sp.	0 ± 0	14 ± 2	0 ± 0
			*Hydrophilus*sp.	0 ± 0	10 ± 2	0 ± 0
		Diptera	**Chironomidae**	91 ± 7	127 ± 16	78 ± 10
			Chironomusimicola	59 ± 4	29 ± 4	0 ± 0
			Clinotanypusclaripennis	0 ± 0	16 ± 2	16 ± 2
			*Cricotopus*sp.	33 ± 4	20 ± 3	0 ± 0
			*Cryptochironomus*sp.	0 ± 0	16 ± 2	16 ± 2
			Nilodorumfractilobus	0 ± 0	20 ± 3	20 ± 3
			*Procladius*sp.	0 ± 0	25 ± 3	25 ± 3
	Crustacean	**Decapoda**	**Crangonidae**	68 ± 11	6 ± 1	6 ± 1
			Crangon crangon	68 ± 11	6 ± 1	6 ± 1
Annelida	**Achaeta**	**Pharyngobdelliformes**	**Erpobdellidae**	7 ± 1	7 ± 1	7 ± 1
			*Erpobdella*sp.	7 ± 1	7 ± 1	7 ± 1
			Haemopidae	0 ± 0	6 ± 1	6 ± 1
			Haemopissanguisuga	0 ± 0	6 ± 1	6 ± 1
	Oligochaeta	**Haplotaxida**	**Lumbricidae**	4 ± 1	6 ± 1	6 ± 1
			Lumbricusrubellus	0 ± 0	6 ± 1	6 ± 1
			*Ophidonais*sp.	4 ± 1	0 ± 0	0 ± 0
Mollusc	**Gastropoda**	**Architaenioglossa**	**Ampullariidae**	0 ± 0	6 ± 1	6 ± 1
			Marisa cornuarietis	0 ± 0	6 ± 1	6 ± 1
Total density				1407	1213	1062
Total taxa			**71**	**40**	**45**	**44**
Rarefied richness				**39.99**	**44.99**	**44**

3.3. Diversity indices

The rarefied richness was 44.99 in centre, 44.00 in downstream and 39.99 in upstream (Table.2). This richness did not show spatial variation (Fig. 2) but vary significantly between seasons (upstream and centre). In downstream, there were no significant differences amongst seasons (Fig.3 A). The Shannon diversity index showed a significant difference between sites,withhighest values recorded in centre(3.18) and lowest values in downstream (2.21). The Shannon-Weaver index is greater than 2 in all sampling sites (Fig.2). Significant seasonal variations were found and the values were significantly highest in rainy season (centre and downstream) and lowest in dry season (upstream, centre and downstream) (Fig.3 B). The Evenness

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index ranged from 0.7 in upstream to0.98in downstream and did not show spatial and seasonal variations (Fig.2&Fig.3 C).

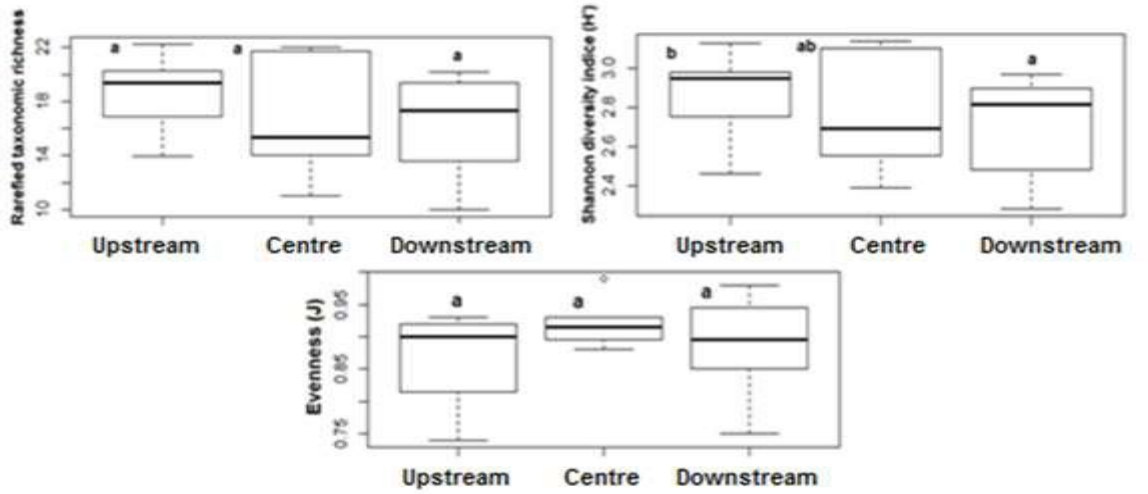

Fig.2: Spatial variation of Rarefied Taxonomic richness (Rs), Shannon diversity indices and Evenness (J) Different letters within sites indicate significant difference based on Mann-Whitney, comparison test at $p < 0.05$.

3.4. Macroinvertebrate communities and environmental factors influence

The results of the Redundancy Analysis (RDA) showed that the correlation between environmental variables and macroinvertebrate taxa was mainly explained by the first two axes with 49.96% of total variance (Fig.4). From the RDA ordination diagram, two factors (conductivity and pH) had a significant impact on the macroinvertebrate communities. The temperaturewas the only parameter positively correlated with the axis 1 and no parameters were negatively correlated with this axis. The second axis, was positively correlated with conductivity and phosphate but negatively with pH, dissolved oxygen, nitrate and nitrite.

In rainy season (RS1, RS2 and RS3), the sites were characterized by high values of pH and nitrate and low values of phosphate and conductivity. This season was associated with the presence of Odonata (Aeshnidae, Corduliidae and Libellulidae), Coleoptera (Dytiscidae and Dryopidae), Heteroptera (Gerridae and Veliidae) and Diptera (Chironomidae). The centre was characterized in Flood season (FS2) by high values of Ammonium-nitrogen (NH_4^+) and Dissolved oxygen and the presence of Heteroptera (Naucoridae and Pleidae) and Ephemeroptera (Leptophlebiidae and Baetidae). The centre and downstream were associated in dry season (DS2 and DS3) with the presence of Plecoptera (Perlidae), Heteroptera (Notonectidae and Mesoveliidae) and Decapoda as well as high values of Temperature. The upstream recorded in Flood and Dry season (FS1 and DS1), high values of Phosphate. This station was associated with the presence of Coleoptera (Curculionidae, Elmidae and Hydrophilidae), Heteroptera (Nepidae and Belostomatidae), Achaeta (Erpobdellidaeand Haemopidae), Oligochaeta (Lumbricidae) and Gasteropoda (Ampullariidae).

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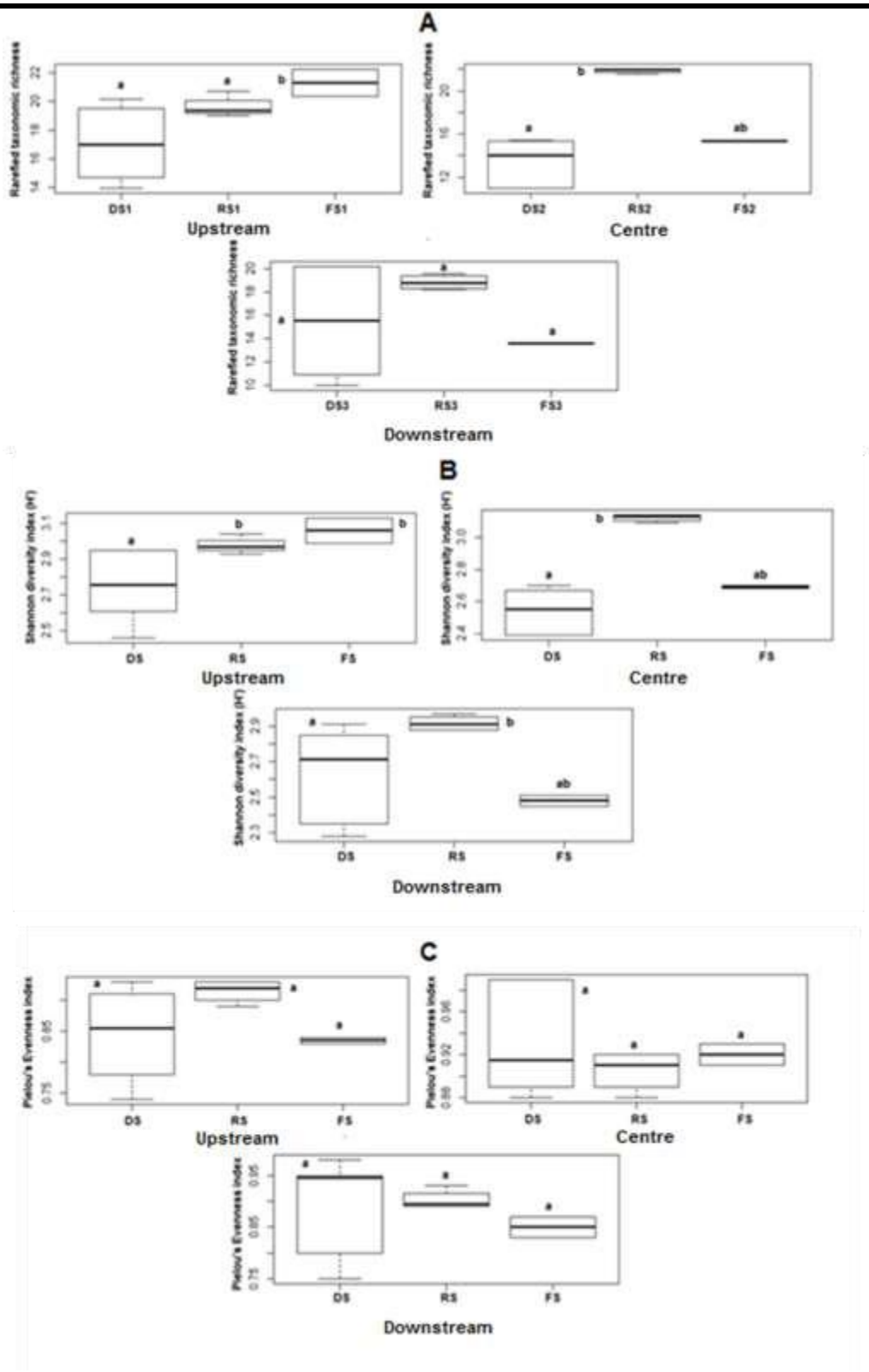

Fig.3: Box-plots showing seasonal variation of the diversity index (A, B & C) of macroinvertebrates recorded on Hydrilla verticillata at sampling stations. Different letters within seasons denote significant differences between them (Mann-Whitney, $p<0.05$).

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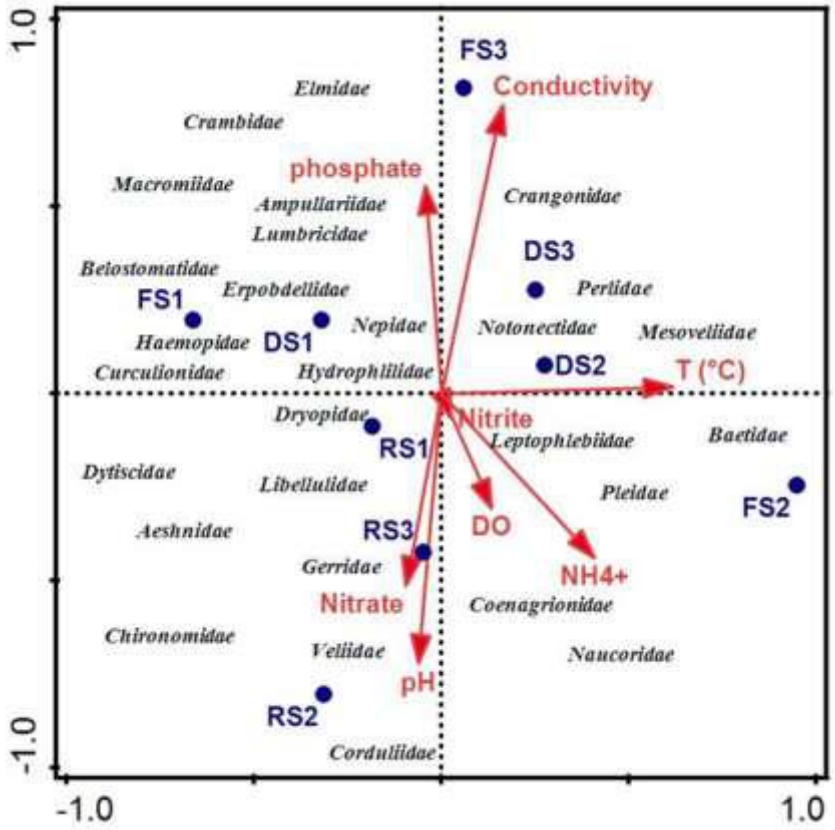

Fig.4: Redundancy Analysis (RDA) showing macroinvertebrates sampling seasons on different sampling sites in relation to environmental variables. (DO= dissolved oxygen, CND= Conductivity, T= temperature, Trans= transparency and Dpth= depth).

IV. DISCUSSION

Analysis of the physical and chemical parameters of Ono lagoon reveals that the parameters (water depth, pH, dissolved oxygen, transparency, TDS, conductivity, nitrate, nitrite and phosphate)show no significant variation between sites, except for the temperature. Temperature plays an important role in the physical and chemical characteristics of lagoon environment, affecting the rate of CO_2 fixation by phytoplankton (primary productivity) and solubility of gases such as O_2, CO_2 and NH_4^+ which on turn affect all aquatic organisms (Gawad and Abdel-Aal, 2018). Dissolved oxygen (DO) mean values were very low (1.70-2.81 mg / L), attesting that plant cover and root density influence strongly oxygen concentration in the lagoon. When *H. verticillata*forms cohesive mats, a considerable biochemical oxygen demand is created by both trapping organic matter and the decay of their own vegetative parts. Colon-Gaud (2003) noted that the dense mats of *H. verticillata* reduced water circulation and light penetration in water bodies and influenced dissolved oxygen concentrations. On the other hand, 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 Tohouri*etal*. (2017). The pH was acidic during the study period. This acidity comes mainly from plant organic matter decomposition, with production of CO_2 in the first layers of the soil (Matini*et al*., 2009; Ebli*net al*., 2014). The nutrients represented by ammonium-nitrogen, phosphate, nitrate and nitrite values did not vary between sites. However, phosphate and nitrate values were relatively higherthan those reported in Taabo lake (Kouamé*et al*., 2011) and lower Comoé river (Kra*et al*., 2018). The contamination of surface waters by total phosphorus can be induced by leaching of cropland containing phosphate fertilizers and some pesticides. Indeed, the Ono lagoon watershed closes several industrial plantations (rubber, palm oil, pineapple) that require the use of fertilizers and pesticides over large areas.

A total of 71 macroinvertebrates taxa belonging to 28 families, 11 orders, 05 classes and 03 phyla were recorded

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demonstrating a relatively similar taxa to those recorded in Manasbal Lake (Sami *et al*., 2012) and Atchafalaya River Basin (Colon-Gaud, 2003). This indicates that macrophytes provide excellent microhabitats that enhance the establishment and colonisation of many invertebrates.Rakhi *et al*. (2014) reported that *H. verticillate* represents a suitable well-illuminated substrate in the water column. The dominant groups of our study were Odonata and Coleoptera whereas Diptera, Gasteropoda, Ephemeroptera, Decapoda, Amphipoda and Hemiptera dominated macroinvertebrate community of Atchafalaya River Basin. However, the number of taxafound in this study was higher than that of Scott and Osborne (1981)in Central Florida Lake (54 taxa), Heather *et al*. (2008) in Earthen experimental ponds (24 taxa) and Sami *et al*. (2012) in Manasbal lake (15 taxa). Insects numerically dominated the capture, comprising 91.55% of the collected taxa with Odonata and Coleoptera being the most diverse and abundant groups. The high insect taxonomic representativeness and abundance of this group was a pattern also observed in other studies (Tomaz*et al*., 2008; Lucca *et al*., 2010). According to Tachet*et al*. (2003), insects represent one of the most important groups of freshwater invertebrates especially due to their diversity. Some macroinvertebrate taxa (Ephemeroptera and Plecoptera) were not recorded in upstream where lowest values of dissolved oxygen were measured. Also, differences in taxon composition and abundance within the same taxonomic group (class or order) were observed. Similarly, Merritt and Cummins (1996)found that macroinvertebrate abundance and species composition was strongly influenced by water quality.

The total density of macroinvertebrates found in the microhabitat created by *H.verticillata*was higher (1407 ind. per 100 g d. w.) in upstream and lower (1062 ind. per 100 g d. w.) in downstream. The groups which had the highest densities were Insects (from94,44% to 97,45%) of all the organisms collected, with Odonata (from 44,81% to 48,54%) being the most abundant groups. Our results are similar to findings of Poi De Neiff and Carignan (1997) who observed the same situation in floodplain of the Paraná River. Odonata larvae are known to use the aquatic plants as their egg laying site (Singh, 1989) and as ambush points to capture their prey (Merritt and Cummins, 1996). Density of coleoptera was found to be the second dominant as reported in SantragachiJheel Lake by Patra *et al*. (2012), attesting that Odonata and Coleoptera are well associated with macrophyte.

The rarefied richness did not vary significantly among sites but showed a significant seasonal variation. The rarefied richness shows that in absence of any bias in samples, flood and rainyseasons were rich in the number of species. The Shannon diversity index showed significant spatial and seasonal variationsfrom a minimum of 2.2 (downstream) to a maximum of 3.18 (centre),suggesting that the centre was able to sustain a richer associated community. In addition, the lowest and highest values were respectively recorded in dry and rainy seasons, indicating that rainy and flood seasons were able to sustain a richer associated macroinvertebrates community than dry season. The maximum of Shannon diversity index takes place when species richness increases as found by (Brown and Lomolino, 1998). Concerning the Evenness values, no significant spatial and seasonal variations was observed. However, Evenness values varied from a minimum of 0, 74 in upstream to a maximum of 0, 96 in downstream. These values are high when compared with those recorded in subtropical lakes of south Brazil(Albertoni*et al*., 2007), in Central Florida Lake (Scott *et al*., 1981) and in Lake Nasser Khors of Egypt(Gawad and Abdel-Aal, 2018), showing the equitability in the distribution of individuals among the species. According to Schäfer (1980), 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.

From the results of RDA analysis, macroinvertebrate communities of Ono lagoon were most influenced by water quality variables such as conductivity, pH, temperature, phosphate, ammonium-nitrogen and nitrate. However, conductivity and pH showed a strong environmental gradient and had a structuring effect on macroinvertebrate communities. These communities were similar in rainy season and different in flood season.

V. CONCLUSION

In this investigation, we collected an important number of species (71) associated with Hydrilla verticillata. Insects with 91.55% of total species was the most diverse class. This class recorded the highest density community (94.44% to 97.45%) and macroinvertebrate assemblages were qualitatively (22 taxa) and quantitatively (44.81% to 48.54% of total density) dominated by Odonata.

The centre recorded the greatest taxonomic richness (45 taxa). However, the higher density was reported in upstream (1407 ind.per 100 g d.w.). Distribution of aquatic macroinvertebrates by *H. verticillata* was best explained by conductivity, pH, temperature, ammonium-nitrogen, phosphate and nitrate. The spatio-temporal values of

diversity indices were high and showed the equitably distribution of community individuals among taxa. However, low dissolved oxygen values reported are a signal of this environment degradation marked by the absence of Ephemeroptera upstream.

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