



Influence of the Granulometric parameters on the Diversity and Distribution of Benthic Macroinvertebrates in the Mabounié Watershed (Central West Gabon)

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Abstract

In order to evaluate the influence of mineral substrates on the distribution of benthic macroinvertebrates, an ecological study was conducted from November 2015 to November 2016 in 10 forest streams in the Mabounié watershed in Central West Gabon. The environmental typology of these streams are characterized by four types of mineral substrates: pebbles, stone blocks, aggregates, coarse and fine sand.

Sampling of the benthic macroinvertebrates was carried out using a Surber net of 30 cm X 30 cm side and 500 µm of mesh opening. The Self Organizing Maps (SOM) has defined 4 groups and the biotopology show a predominance of ETP. The group I whose substrate is composed of pebbles and blocks of stones, have 72.87% relative abundance of EPT and is distinguish by *Tricorythus sp* and *Adenophlebia sp* (Ephemeroptera), group II characterized by aggregate substrate present 64.05% of relative abundance of EPT and, reveal *Macrostemum sp* and *Hydropsyche betteni* (Trichoptera), group III dominated by fine sand, in which the EPT group show 63, 75% of relative abundance, singularised by *Atyaephyra desmarestii* (Decapoda) and group IV by coarse sand, with 66.16% of EPT relative abundance and, *Neoperla sp0* (Plecoptera) and *Dicercomyzon femorale* (Ephemeroptera) like emblematics taxa.

Keywords: Macroinvertebrates, substrates, SOM, taxonomic richness, forest rivers

Introduction

Among biological communities, benthic macroinvertebrates is currently the most used and the most efficient in the ecodiagnosis of the quality of hydrosystems (Bénoit-Chabot, 2014), the assessment of the overall health of rivers (Kalyoncu *et al.*, 2011) and the impact of human activities (Tchakonté *et al.*, 2014).

Their taxonomic richness, their abundance, their diversity, their sedentary life, their varied life cycle, their variable tolerance to pollution and habitat degradation, the flexibility linked to their ecological requirements make it possible to assess the local environmental quality of their habitats rivers (Moisan and Pelletier 2010). In addition, they integrate the

cumulative and synergistic short-term effects of the multiple physical, biological and chemical disturbances of which watercourses may be victims (MDDEFP, 2013 Drouin, Sircis and Archambault, 2006 and 2011).

Although the benthic macrofauna is currently study in several parts of the world (Europe, North America), but it remains little documented in Africa and particularly in Gabon, because of the total absence of any related study. Thus, for forest hydrosystems, it is urgent to multiply faunistic inventories in order to build databases to serve as a reference for managers of natural environments in the context of biomonitoring programs (Foto Menbohan *et al.*, 2010). Today, benthic macroinvertebrate communities, organisms visible to the naked eye, colonize different strata of water (Sanogo *et al.*, 2014), and synthetically expressing of all the ecological parameters of aquatic environments (Zouggaghe *et al.*, 2014). Moreover, by participating in the transformation of organic matter and decomposing litter (Ben Moussa *et al.*, 2014), benthic macroinvertebrates are undeniable bioindicators of the ecological health of hydrosystems (Moisan and Pelletier, 2010, Tchakonté *et al.*, 2014, Zouggaghe *et al.*, 2014 and Lamri *et al.*, 2016), such a potential makes benthic macroinvertebrate communities good integrators of alterations in both water and habitat quality (Usseglio-polatera and Beisel, 2002). The quality of the benthic habitat thus becomes an indispensable link to a better understanding of the ecology of these organisms is based on the ability of different benthic habitats to harbor pollen-sensitive taxa. Ten substrate groups coded as 9 (bryophytes) to 0 (algae) were defined and, it appears that groups 9 (bryophytes) and 6 (stones and pebbles) have the strongest ability to shelter a pollutant-sensitive fauna (Usseglio-polatera and Beisel, 2002).

Although most European forest streams have beds covered with plant substrates, in Central Africa, Cameroon and Gabon, forest stream beds are mainly dominated by mineral substrates including stones and pebbles. This study, conducted for first time in Gabonese territory, aims to determine degree of connection between the nature of mineral substrates and the macrobenthic diversity in forest streams of the Mabounié basin, which also have the particularity of shelter a mining deposit whose entry into operation is imminent. It will then be: (1) inventory fauna of benthic macroinvertebrates; (2) identify and characterize different mineral substrates; (3) identify

the different pairs that may form between nature of substrate and benthic macroinvertebrates community.

Materials and Methods

Study area

Mabounié watershed is located about 40 km southeast of Lambaréné town, in Moyen-Ogooué province located between 10 ° 28'12 " and 10 ° 37'00 " east longitude and 0 ° 41'12 " and 0 ° 48'18 " south latitude. This basin is approximately 100 km², it extends over a plain littered with hills whose altitude varies from about 20 m to 100 m. It is bordeline to the north and north-east by Mandjibé River watershed, to west by Madiminzé watershed, then to east and south by Rié and Mandjimabolè rivers, two tributaries of Ikoy river, whose waters also flow toward Ngounié, a main tributary of Ogooué river on the left bank. The study area is under the influence of the equatorial warm and humid transition climate, characterized by constant temperature (25 ° ± 2 ° C), as well as abundant and regular rainfall ranging from 1,800 to 2,200 mm (Rabekogo, 2007). There are two rainy seasons and two dry seasons of unequal importance: a small dry season that starts from January to February, a big rainy season from March to May, a long dry season from June to September, and a short rains season, from October to December (Mbega, 2004).

The hydrographic network of Mabounié flows over sedimentary formations composed of clay, sandstone, ferrallitic and hydromorphic soils. From its source to its confluence with the Ngounié river, the Mabounié travels 18.5 km. Sixteen stations (Figure 1) were selected and sampled monthly from November 2015 to November 2016. On the main course, three stations coded MAC01 (0 ° 42'32.28 "S; 10 ° 32' 30.78"E), MAC09 (0 ° 45'13.32 "S; 10 ° 32'52.08' 'E) and MAC13 (0 ° 46'27.78"S; 10 ° 31 ' 18,18"E) were selected respectively in the upper course 3.5 km from the source, in the middle 10.3 km from the source and in the lower 16.1 km from the source.

On the left bank, 9 stations were selected: MAC02 (0 ° 42'35,40 "S; 10 ° 33'47,16"E) and MAC04 (0 ° 43'40,86' 'S; 10 ° 33'10,8) " E) located respectively in the upper (2.51 km from the source) and lower (4.91 km from the source) sub-basin Okoumba north of the mine, MAC05 (0 ° 45'10, 62 " S; 10 ° 33'0.18 " E) located in the upper course (317 m from the source) of the Mayombo sub-basin, of the MAC03 (0 ° 44'9.84 " S; 10 °) 34'27.00 " E) and MAC14 (0 ° 44'9.84 " S;

10 ° 34'27.00 " E) located respectively in the middle courses (4.2 km from the source) and superior (615 m from the source) of the Prospere sub-basin, of MAC06 (0 ° 44'56.10 " S; 10 ° 33'41,22 " E), MAC07 (0 ° 44'59,04 ') 34 ° 34,32 " E) and MAC08 (0 ° 44'44,10 " S; 10 ° 34'25,26 " E) located respectively in the lower courses (5,68 km source), average (3.73 km from the source) and greater (264 m from the source) of the Vidrine sub-basin in the mine, then from the MAC11 station (0 ° 46'16.92 " S; 10 ° 32'46.68 " E) which is in the upper course (328 m from the source) of the

Bordamur sub-basin, to the south of the mine. On the right bank, 4 stations were prospected including MAC10 (0 ° 44'55.92 "S; 10 ° 32'37.02"E) in the middle course (2 km from the source) of the sub-basin Boubala, MAC12 (0 ° 46'22.32 "S, 10 ° 31'13.08"E) in the lower reaches (1.74 km from the source) of the Mabwede sub-basin, MAC15 (0 ° 43 '19, 14 "S; 10 ° 32'28.80"E) in the lower course (2.23 km from the source) of the Mayila sub-basin and MAC16 (0 ° 44'27.48"S 10 ° 32'42.54"E) in the upper course (1 km from the source) of the Rabenkogho sub-basin.

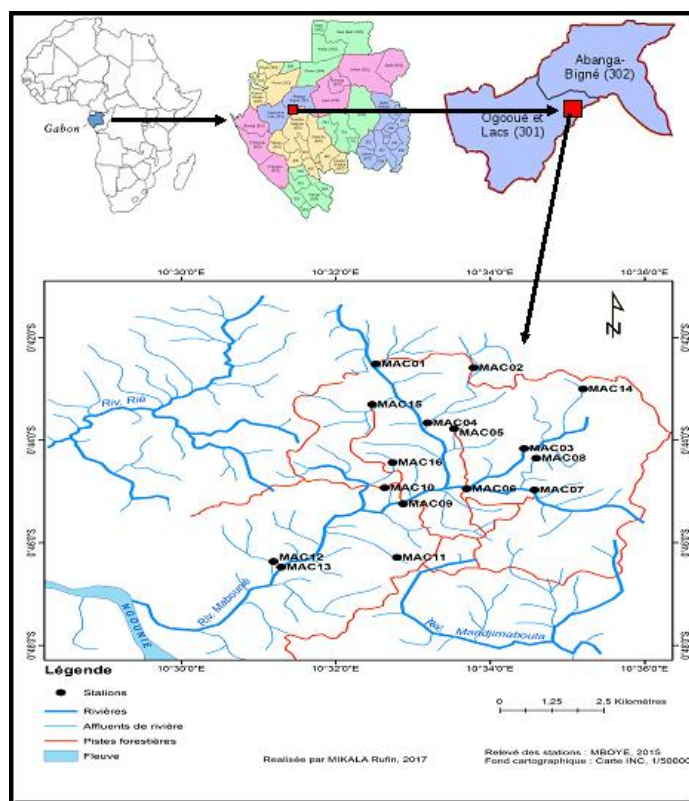


Figure 1: Map of the Mabounié Basin showing the sampling stations.

Sampling of granulometric variables

The granulometric variables (blocks of stones, pebbles, aggregates, and sand) were collected quarterly at each station (1 kg in the threshold and 1 kg in the wet). In the field, the contents of each sample were separated using three mesh sieves respectively 1 cm, 500 µm and 250 µm. In the field, large particles (> 128 mm) were photographed using a Canon digital camera. In the laboratory, digital photos were

processed using the tpsDig2 software, which measured the diameters of large particles. On the other hand, the small particles (aggregates, coarse and fine sands), contained in the last two sieves, were analyzed at the Pedological laboratory of the Agronomic and Forestry Research Institute (IRAF) of Libreville with the help of 4 sieves (500 µm, 250 µm, 125 µm, and 63 µm). All substrates were classified according to the Wentworf method (Jolicoeur *et al.*, 2007).

Sampling and identification of benthic macroinvertebrates

Collection of benthic macroinvertebrates (MIB) was done according to the multihabitat approach of Beauger (2008) and Mary & Archaimbault (2011), taking from each station 5 microhabitats (2 in the threshold and 3 in the wet) using a Surber net 30 cm X 30 cm side and 500 µm mesh vacuum. The contents of each sample were poured into a series of three mesh sieves respectively apertures of 1cm, 500µm and 250 µm to separate the coarse fragments from the fine fractions, the contents of each sieve being subsequently fractionated for the harvest organisms. The organisms harvested were kept in a referenced zip bag (station code, substrate code, date and sample number) containing 70% alcohol. In the laboratory, the organisms were rinsed under running water, sorted, grouped according to their morphological resemblance and observed using a binocular stereomicroscope or a Nikon microscope, then identified using appropriate literature of Tachet *et al.* (2000), Durand and Lévêque (1981), Heidemann and Seidenbusch (2002), Reynaldson *et al.* (2000), Merritt *et al.* (2008).

Data analysis

The Shapiro test tested the normality of the distributions, while those of Kruskal-Wallis and Mann-Whitney were used to test the significance ($p < 0.05$) of spatial variations between environmental variables on the one hand and the abundances of the MIB taxa, on the other hand, using the XLSTAT version 2007 software. The Self Organizing Map (SOM), produced from Matlab software, version 6.1 (Alhoniemi *et al.*, 2000) applied to the matrix of 208 samples (13 campaigns X 16 stations) and 202 MIB taxa allowed the stations to be grouped according to their grain size and taxonomic composition. The 208 samples are considered vectors of the 202 taxonomic variables. The application of the SOM on this starting matrix generated after learning (Kohonen, 2001), a map of $N = 63 = 9 \times 7$ neurons. An Ascending Hierarchical Classification (CAH) based on the Ward method and the Euclidean distance as an aggregation criterion highlighted the actual assemblies of the

stations on the exit map (Park *et al.*, 2003). The structure of the MIB stand has been described from taxonomic richness, relative abundance, the frequency of occurrence (Dajoz, 2000) and classical ecological indices (Shannon index, Piéou equitability, Simpson and the EPT index).

The Canonical Correspondence Analysis (CCA) made it possible to determine degree of affinity of main taxa to granulometric variables. The data of species and particles size were transformed according the formula $Y = \log(A * Y + B)$.

Results

Granulometrics parameters

The granulometric results show in all the streams, 5 types of mineral substrates distributed according to the size of the particles. So we distinguish the coarse mineral substrates consisting of pebbles, stones, and aggregates, which oppose the small mineral substrates including coarse sand and fine sand.

The Hierarchical Ascending Classification (CAH) ordered the 208 soil samples into 4 groups and their projected contribution to neuron cells (Fig 2A, 2B and 2C). Group GI located at the top left of the Kohonen map is composed of samples of MAC01, MAC02, MAC08 and MAC14 stations characterized by pebbles. Group GII, in the center of the map, consists of samples belonging to a single MAC03 station distinguished by blocks stones, rocks and a rocky slab. The third group agglomerates essentially sandy samples belonging to the MAC04, MAC06, MAC07, MAC09, MAC10, MAC12, MAC13, MAC15 and MAC16 stations, mostly located mainly in the lower reaches of their respective streams and sub-basins. Group GIV is characterized by an aggregate type substrate from samples from MAC05 (Mayombo River) and MAC11 (Bordamur). The Wilk Lambda () test was highly significant at the 5%, threshold for stone blocks (= 0.046, $p < 0.0001$), aggregates (= 0.041, $p < 0.0001$) and coarse sand (= 0.098, $p < 0.0001$).

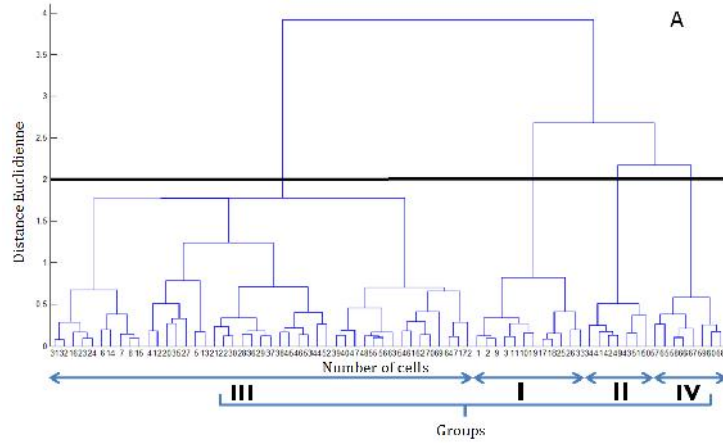


Figure 2A: Results of the Hierarchical Ascending Classification with 1 to 72 like cell number; Roman number I to IV = Groups.

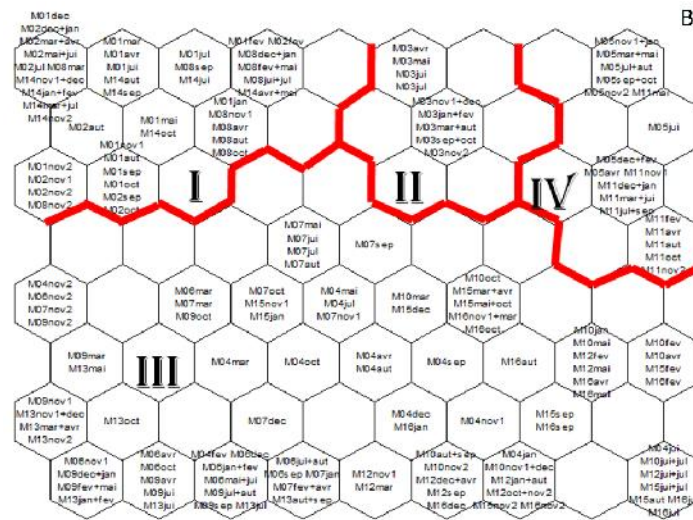


Figure 2B: SOM results, sample ordination and group identification. M01 to M16: station code; nov1 = November 2015 and nov2 = November 2016.

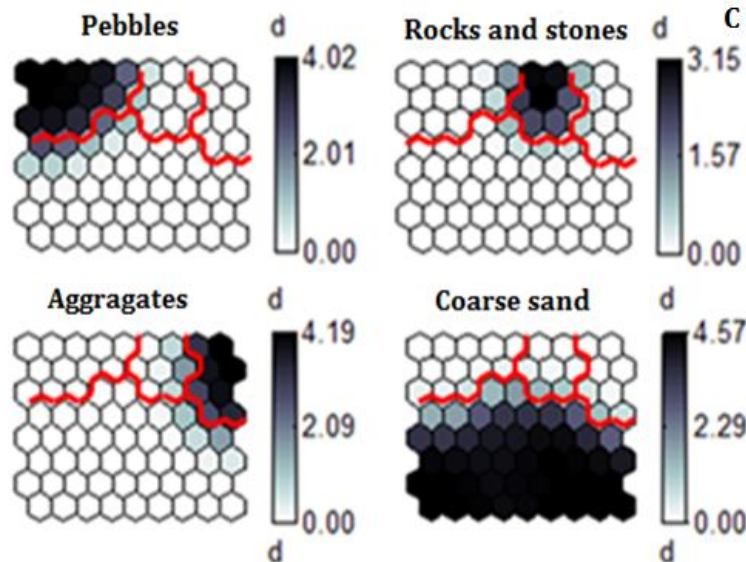


Figure 2C: SOM results, contribution of granulometric parameters

Taxonomic richness and relative abundance of benthic macroinvertebrates

The inventory of the benthic macroinvertebrates of the Mabounié basin watercourses made it possible to count 29 444 individuals divided into 4 Phylum (Arthropoda, Annelida, Platyhelminthes and

Mollusca), 6 class, 16 orders, 91 families, 182 genera and 202 taxa. The class of insects (Figure 3) predominates with 87.11% relative abundance, followed by crustacea (12.28%) and Turbellaria (0.41%), Oligochaeta (0.11%), Gastropoda (0.04%) and Acheta (0.03%) whose accumulated less than 1% of the relative abundance of a total of 178 organisms.

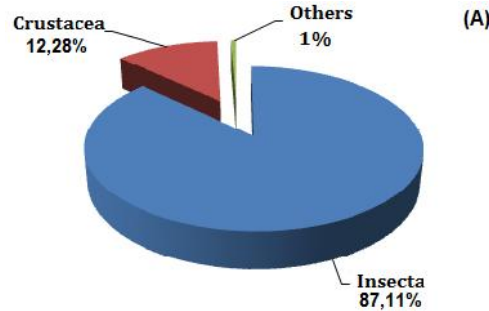


Figure 3: Relative abundance of MIB classes harvested during the study period

The order of Coleoptera is the most diversified with 17 families representing 19% of the taxonomic richness, followed by the Ephemeroptera with 14 families or 16% of the taxonomic richness, Diptera with 13 families (15% of the taxonomic richness), Trichoptera and Odonata with 10 families each (11% of taxonomic richness), Heteroptera with 9 families (10% of taxonomic richness), Gastropoda with 4 families (5% of taxonomic richness) and Rynchobdellida with 2 families (3% of taxonomic wealth). The other orders (Plecoptera, Tricladida, Lepidoptera, Dictyoptera,

Orthoptera, and Haplotaxida) count 1 family each or 7% of the taxonomic richness (Figure 4A).

The order of Ephemeroptera predominates with 49.04% relative abundance, followed by Decapoda (12.28%), Trichoptera (11.02%), Plecoptera (8.59%), Diptera (7.97%), Coleoptera (7.18%) and Odonata (2.78%). The other group consisting of Heteroptera, Lepidoptera, Orthoptera, Rynchobdellida, Gasteropoda, Haplotaxida, Tricladida, and Dictyoptera accumulate 5.36% relative abundance (Figure 4B).

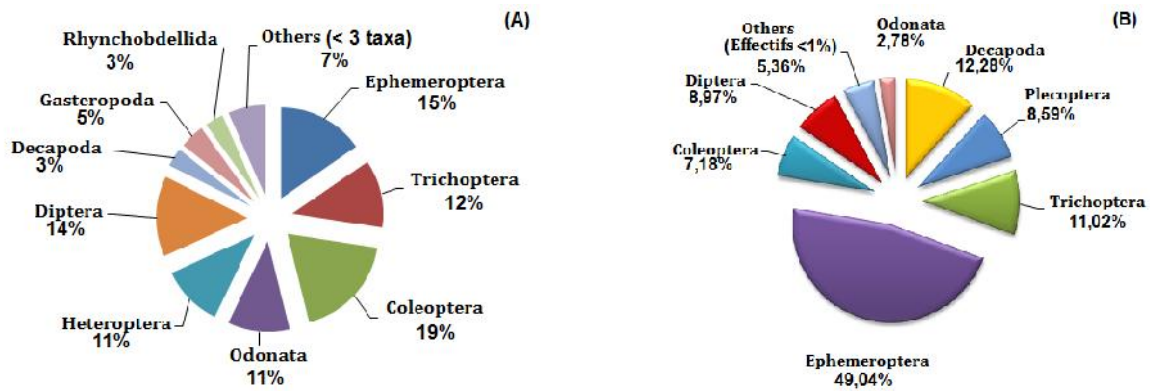


Figure 4: Relative abundance of Benthic Macroinvertebrate Orders harvested during the study period in the Mabounie watershed.

The taxonomic richness of the benthic Macroinvertebrates of the Mabounié Basin and the abundances of each order are presented in Table I.

Table 1: Taxonomic richness and abundance of benthic macroinvertebrates in streams of the Mabounié watershed

| Class | Order | Family | Genus/Species | Abundance |
|-------------|-----------------|----------------|---------------|-----------|
| Crustacea | Decapoda | 3 | 3 | 3616 |
| | Plecoptera | 1 | 7 | 2537 |
| Insecta | Ephemeroptera | 14 | 29 | 14445 |
| | Trichoptera | 11 | 27 | 3242 |
| | Coleoptera | 17 | 48 | 2117 |
| | Odonata | 10 | 24 | 819 |
| | Heteroptera | 10 | 15 | 107 |
| | Diptera | 13 | 34 | 2349 |
| | Dictyoptera | 1 | 1 | 6 |
| | Lepidoptera | 1 | 4 | 26 |
| | Orthoptera | 1 | 1 | 1 |
| | Gasteropoda | Basommatophora | 4 | 4 |
| Acheata | Rhynchobdellida | 3 | 3 | 12 |
| Oligochaeta | Haplotaxida | 1 | 1 | 34 |
| Turbellaria | Tricladida | 1 | 1 | 121 |
| Total | 15 | 91 | 202 | 29444 |

Biotypology of sampling stations

The extension of Artificial Neurons or Self Organizing Map (SOM) network grouped 208 benthic macroinvertebrate samples into 4 groups (Figure 5). This ordination distinguishes group GI, composed of threshold of MAC01, MAC02, MAC03, MAC07, MAC08 and MAC14 stations dominated by pebbles, stones and rocks, where *Tricorythus sp* is the most characteristic taxa to the group GIV grouping the stations with the abundant coarse sand substrate characterized by the absence this taxa. In addition, Group GI is recruited from the tributaries of the left bank while that of the group GIV is organized around the tributaries of the right bank. In addition, Group GII has aggregated and cobble-dominated substrate stations (M5, M11) leaning on the left bank and Group GIII dominated by sandy-bedded stations on the right bank (M10, M12, M15, and M16). Group GI represents 18.26% of the relative taxonomic richness and has 6 class, 14 orders, 81 families and 142 taxa. Group GII follows with 20.49% taxonomic richness, divided into 6 classes, 14 orders, 33 families and 91 taxa. Next is Group GIII with 38.96% taxonomic richness, distribute on 6 class, 15 orders, 81 families and 173 taxa, then group IV with 22.29% of taxonomic richness, comprising 6 class, 14 orders, 51 families, and 99 taxa. The benthic macroinvertebrates of EPT group predominate overall and represent respectively 72.87%, 64.05%, 63.75%, and 66.16% of individuals in groups I, II, III and IV.

The Chironomid group composed of Chironomidae, Tanyptodinae and Orthoclaudiinae is weakly represented with respectively 1.79%, 2.33%, 2.15% and 2.04% relative abundance in groups I, II, III, and IV; the other Diptera (Tipulidae, Tabanidae, Simuliidae, Limoniidae, Dixidae, Culicidae, Ceratopogonidae, Athericidae and Ephydriidae) having respectively 3.13%, 14.75%, 6.06% and 6.36% relative abundances.

Odonata have 2.38%, 6.54%, 2.24% and 4.01% and decapoda of 10.5%, 10.85%, 12.21% and 15.07% of relative abundances respectively in the groups GI to GIV. Coleoptera showed respective relative abundances of 6.70%, 5.05%, 6.75% and 7.06% in groups GI to GIV. Heteroptera, Gasteropoda, Rhynchobdellida, Haplotaxida, Tricladida, Lepidoptera, Orthoptera and Dictyoptera have less than 1% relative abundance in all four groups. The Kruskal-Wallis test ($p > 0.05$, $H = 1.22$) shows no significant difference between the groups. On the other hand, significant differences are observed between the taxa constituting these groups (Kruskal-Wallis, $p < 0.0001$) notably between the EPT and the other orders. Particularly between the Group GI samples consisted of pebble and block-type substrate stations (77.63%) and those of Group GII aggregate substrate stations (38.3%), and among Group GIII includes sandy substrate stations (67.56%) and those of group GIV, constitute of sandy substrate stations (Figure 4). The faunistic list of each group is presented in Table 2.

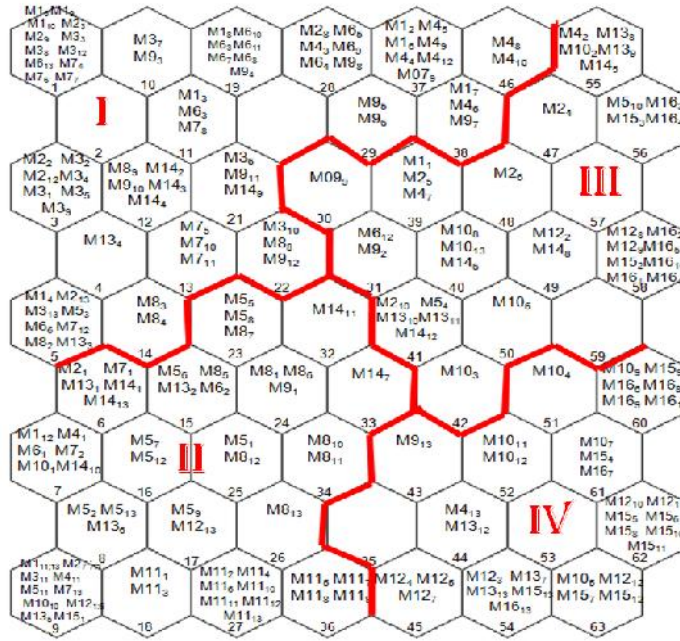


Figure 5: Distribution of samples on the Kohonen SOM map from the taxonomic composition. I to IV = groups defined by the SOM; number at the base of each hexagon = cell number (from 1 to 63); M1 to M16 = station code and station code number = sampling month (1 = November 2015, 2 = December 2015, to 13 = November 2016).

Table 2: Faunistic composition of the benthic macroinvertebrates of the groups defined by the SOM.

| Phylum | Class | Order | Family | Genus/Species | Cluster of the SOM | | | | Total |
|------------|-----------|---------------|------------------|-------------------------------|--------------------|----|-----|----|-------|
| | | | | | I | II | III | IV | |
| Arthropoda | Crustacea | Decapoda | | | | | | | |
| | | | Atyidae | <i>Atyaephyra desmarestii</i> | * | * | * | * | 3586 |
| | | | Paleomonidae | <i>Macrobrachium sp</i> | * | * | * | * | 6 |
| | | | Potamonidae | <i>Potamon sp</i> | * | * | * | * | 24 |
| | Insecta | Ephemeroptera | Amaletidae | <i>Amaletus sp</i> | * | * | * | * | 128 |
| | | | Ametropodidae | <i>Ametropus</i> | | | * | * | 2 |
| | | | Baetidae | <i>Acentrella sp1</i> | * | * | * | | 37 |
| | | | | <i>Acentrella sp2</i> | * | * | | | 4 |
| | | | | <i>Baetis rhodani</i> | * | * | * | * | 4370 |
| | | | | <i>Baetis sp2</i> | * | * | * | * | 60 |
| | | | | <i>Baetis sp3</i> | * | | * | | 3 |
| | | | | <i>Baetopus tenellus</i> | * | | | | 1 |
| | | | <i>Cloeon sp</i> | | * | | | 9 | |
| | | | Metropodidae | <i>Metropodus sp</i> | * | * | * | * | 12 |
| | | | Caenidae | <i>Caenis sp</i> | * | * | * | * | 508 |
| | | | | <i>Caenodes sp</i> | * | | * | | 10 |
| | | | | <i>Caenomedeia sp</i> | * | | * | | 61 |
| | | | Diceromyzinae | <i>Diceromyzon femorale</i> | * | * | * | * | 2296 |
| | | | | <i>diceromyzon sp2</i> | * | * | * | * | 243 |

| | | | | | | | | | | |
|--|-----------------------|---|-------------------|--------------------------------|---|---|----|---|------|------|
| | | | Ephemerythidae | <i>Ephemerythus kibohensis</i> | * | * | * | * | 1080 | |
| | | | Ephemeridae | <i>Ephemera sp</i> | | | * | | 10 | |
| | | | | <i>Pentagenia sp</i> | | * | | | 1 | |
| | | | Heptageniidae | <i>Ecdyonurus sp</i> | * | * | | * | 268 | |
| | | | | <i>Electrogena sp</i> | * | | | * | 7 | |
| | | | | <i>Epeorus sp</i> | * | | | | 1 | |
| | | | | <i>Rhitrogena sp</i> | * | | | | 6 | |
| | | | Isonychidae | <i>Isonychia sp</i> | * | * | * | * | 145 | |
| | | | Leptophlebiidae | <i>Adenophlebia sp</i> | * | * | * | * | 1044 | |
| | | | | <i>Adenophlebiodes sp</i> | * | * | * | * | 731 | |
| | | | | <i>Neochoroterpes sp</i> | * | * | * | * | 1675 | |
| | | | | <i>Thraululus belus</i> | * | * | * | * | 71 | |
| | | | Polymitarcidae | <i>Ephoron sp</i> | * | * | * | | 58 | |
| | | | Prosopistomatidae | <i>Prosopistoma sp</i> | | * | | | 1 | |
| | | | Tricorythidae | <i>Tricorythus sp</i> | * | * | * | * | 1604 | |
| | Plecoptera | | Perlidae | <i>Neoperla spio</i> | * | | * | * | 40 | |
| | | | | <i>Neoperla sp0</i> | * | * | * | * | | 96 |
| | | | | <i>Neoperla sp1</i> | * | * | * | * | | 137 |
| | | | | <i>Neoperla sp2</i> | * | * | * | * | | 299 |
| | | | | <i>Neoperla sp3</i> | * | * | * | * | | 1296 |
| | | | | <i>Neoperla sp4</i> | * | * | * | * | | 488 |
| | | | | <i>Neoperla sp5</i> | * | | * | * | | 171 |
| | | | | <i>Neoperla sp6</i> | * | | * | * | | 10 |
| | Trichoptera | | Calamoceratidae | <i>Anisocentropus sp</i> | * | * | * | * | 97 | |
| | | | | <i>Phylloicus sp</i> | * | * | * | * | | 184 |
| | | | Philopotamidae | <i>Chimara sp</i> | * | * | * | | 409 | |
| | | | | <i>Wormaldia sp</i> | * | * | * | * | 10 | |
| | | | | <i>Dolophilodes sp</i> | * | * | * | * | 607 | |
| | | | Ecnomidae | <i>Ecnomus sp</i> | | | * | * | 29 | |
| | | | Glossosomatidae | <i>Glossosoma sp</i> | * | | | | 1 | |
| | | | Goeridae | <i>Goeracea sp</i> | | * | | | 1 | |
| | | | Hydropsychidae | <i>Hydropsyche betteni</i> | * | * | * | * | 668 | |
| | | | | <i>Arctopsyche sp</i> | * | * | * | * | 33 | |
| | | | | <i>Polymorphanus sp</i> | * | * | * | * | 15 | |
| | | | | <i>Parapsyche sp</i> | * | * | * | * | 302 | |
| | | | | <i>Macrostemum sp</i> | * | * | * | * | 545 | |
| | | | Hydroptilidae | <i>Hydroptila sp</i> | * | | | | 1 | |
| | | | Lepidostomatidae | <i>Lepidostoma sp</i> | * | * | * | * | 56 | |
| | | | Leptoceridae | <i>Leptocerus sp</i> | | * | * | * | 124 | |
| | | | | <i>Triaenodes tardus</i> | * | * | * | * | 112 | |
| | | | | <i>Ceraclea sp</i> | * | | | | 1 | |
| | <i>Athripsodes sp</i> | * | | * | * | | 30 | | | |
| | <i>Nectopsyche sp</i> | | | * | | * | 2 | | | |
| | <i>Non déterminé</i> | * | | | | | 1 | | | |

| | | | | | | | |
|-----------------------|-------------------|------------------------------------|---|---|---|---|-----|
| Coleoptera | Polycentropodidae | <i>Neuroclipsis sp</i> | * | * | | | 3 |
| | | <i>Polycentropus sp</i> | * | * | | * | 7 |
| | | <i>Heteroplectron sp</i> | * | | | | 2 |
| | | <i>Polyplectropus sp</i> | | | | * | 1 |
| | | <i>Non déterminé</i> | | * | | | 1 |
| | Sericostomatidae | <i>Sericostoma sp</i> | | * | | | 1 |
| | Dytiscidae | <i>Africodytes sp</i> | * | | | | 2 |
| | | <i>Yola sp</i> | | * | | | 1 |
| | | <i>Neptosternus sp1</i> | * | * | * | * | 131 |
| | | <i>Neptosternus sp2</i> | | * | | | 4 |
| | | <i>Neptosternus sp3</i> | | * | | | 10 |
| | | <i>Neptosternus sp4</i> | * | * | | | 14 |
| | | <i>Neptosternus sp5</i> | * | | * | | 4 |
| | Laccophiinae | <i>Laccophilus sp</i> | | | * | * | 13 |
| | Hydroporinae | <i>Non déterminé</i> | * | * | | | 6 |
| | Copelatinae | <i>Copelatus sp</i> | * | * | | | 2 |
| | Colymbetinae | <i>Platambus sp</i> | * | * | * | * | 26 |
| | | <i>Rhantus sp</i> | * | * | * | | 3 |
| | Notoridae | <i>Noterus sp</i> | | * | * | * | 2 |
| | Scirtidae | <i>Cyphon sp</i> | * | | * | * | 10 |
| | | <i>Hydrocyphon sp</i> | | * | * | * | 104 |
| | | <i>Elodes sp</i> | * | * | * | * | 42 |
| | | <i>Microcara sp</i> | * | | | | 1 |
| | Chrysomelidae | <i>Donacia sp</i> | | | | * | 1 |
| | Dryopidae | <i>Dryops sp</i> | * | * | * | * | 109 |
| | Elmidae | <i>Non déterminé</i> | * | * | | * | 76 |
| | | <i>Lara Sp</i> | | * | | | 1 |
| | | <i>Dupophilus sp</i> | * | | * | * | 8 |
| | | <i>Limnius sp</i> | * | * | * | * | 125 |
| | | <i>Elmis sp</i> | * | * | * | * | 76 |
| | | <i>Esolus sp</i> | * | | | | 2 |
| | | <i>Microcylloepus sp</i> | | | | * | 1 |
| | | <i>Oulimnius sp</i> | * | * | * | * | 63 |
| | | <i>Pseudomacronychus decoratus</i> | * | * | * | * | 799 |
| | | <i>Stenelmis sp</i> | * | * | * | * | 45 |
| | | <i>Riolus sp</i> | | | * | * | 2 |
| | | <i>Neocylloepus sp</i> | * | * | | | 5 |
| | Hydrophilidae | <i>Enochrus sp</i> | * | * | * | * | 4 |
| | | <i>Helobata sp</i> | * | * | * | * | 37 |
| | | <i>Helochares sp</i> | * | * | | * | 5 |
| | | <i>Hydrobiomorpha sp</i> | | | | * | 1 |
| | | <i>Hydrobius sp</i> | * | * | * | * | 37 |
| <i>Sperchopsis sp</i> | | * | | | | 1 | |
| <i>Esolus sp</i> | | * | | * | | 2 | |

| | | | | | | | | | |
|----------------|--------------|----------------|---|-------------------------|---|---|---|-----|-----|
| | | | <i>Non déterminé</i> | * | | * | * | 23 | |
| | | Staphyllinidae | <i>Euvira sp</i> | * | * | * | * | 3 | |
| | | Gyrinidae | <i>Gyretes sp</i> | * | * | * | * | 193 | |
| | | Haliplidae | <i>Haliplus sp</i> | | | * | | 1 | |
| | | | <i>Non déterminé</i> | | | | * | 1 | |
| | | Lutrochidae | <i>Lutrochus sp</i> | * | * | * | * | 40 | |
| | | Curculionidae | <i>Non déterminé</i> | * | * | * | | 11 | |
| | | Psephenidae | <i>Psephenus sp</i> | * | | * | | 66 | |
| Heteroptera | Gerridae | | <i>Gerrus sp</i> | | | | * | 10 | |
| | | | <i>Metrobates trux infuscatus</i> | | | * | | 3 | |
| | | | <i>Trepobates becki</i> | | | | * | 2 | |
| | Hebridae | | <i>Hebrus sobremus</i> | | | * | | 1 | |
| | Veliidae | | <i>Rhagovelia distincta</i> | * | | | | | 1 |
| | | | <i>Rhagovelia sp</i> | * | * | | * | | 32 |
| | | | <i>Carayonelle hutchinsoni</i> | | | | | | 1 |
| | | | <i>Microvelia sp</i> | | * | * | * | | 5 |
| | | | <i>Shouteni sp</i> | | | * | | | 1 |
| | Mesoveliidae | | <i>Mesovelia furcata</i> | | * | | * | 5 | |
| | Belostomidae | | <i>Belostoma sp</i> | * | * | * | * | 13 | |
| | Corixidae | | <i>Corixa sp</i> | * | * | * | * | 3 | |
| | Cymatiinae | | <i>Cymatia sp</i> | * | * | * | * | 8 | |
| | Naucoridae | | <i>Naucoris sp</i> | * | * | * | * | 4 | |
| | Nerthrinae | | <i>Nerthra grandicollis</i> | * | | | | 1 | |
| | Pleidae | | <i>Plea sp</i> | * | * | * | * | 19 | |
| | Odonata | Aeshnidae | | <i>Non déterminé</i> | * | * | * | | 8 |
| | | Calopterygidae | | <i>Calopteryx virgo</i> | * | * | * | * | 80 |
| Chlorocyphidae | | | <i>Chlorocypha sp</i> | * | * | * | * | 45 | |
| Coenagrionidae | | | <i>Nehalennia speciosa</i> | * | * | | | 66 | |
| Corduliinae | | | <i>Cordulia sp</i> | * | | * | * | | 5 |
| | | | <i>Epithea sp</i> | * | | | | | 9 |
| | | | <i>Somatochlora fonscolombei</i> | * | | * | | | 3 |
| | | | <i>Somatochlora metallica metallica</i> | * | * | * | * | | 144 |
| Gomphidae | | | <i>Aphylla williamsoni</i> | * | * | * | * | | 26 |
| | | | <i>Gomphus sp</i> | * | * | * | * | | 161 |
| | | | <i>Onychogomphus forcipatus</i> | | | * | | * | 3 |
| | | | <i>Onychogomphus sp</i> | * | * | * | * | | 29 |
| | | | <i>Onychogomphus uncatus</i> | * | * | | * | | 6 |
| | | | <i>Ophiogomphus sp</i> | * | * | | | | 10 |
| | | | <i>Progomphus sp</i> | * | * | * | * | | 37 |
| Hageniinae | | | <i>Hagenius sp</i> | * | * | * | * | 109 | |

| | | | | | | | | | |
|--|-------------|--|-----------------|---------------------------------|---|---|---|---|-----|
| | | | Libellulinae | <i>Leucorrhinia caudalis</i> | | * | | | 1 |
| | | | | <i>Libellula fulva</i> | * | | | | 1 |
| | | | | <i>Libellula quadrimaculata</i> | | | | | 1 |
| | | | | <i>Libellula sp</i> | * | * | * | * | 42 |
| | | | | <i>Orthetrum sp</i> | | | * | | 2 |
| | | | Sympetrinae | <i>Brachytermis leucostica</i> | | | | * | 3 |
| | | | | <i>Leucorrhinia caudalis</i> | | | * | | 1 |
| | | | | <i>Sympetrum sp</i> | * | | * | | 4 |
| | | | Macromiidae | <i>Macromia splendens</i> | * | * | * | * | 23 |
| | Dictyoptera | | Blaberidae | <i>Epilampra sp</i> | * | * | * | * | 6 |
| | | | Athericidae | <i>Atherix sp</i> | * | * | * | * | 130 |
| | | | Ceratopogonidae | <i>Bezzia sp</i> | * | * | * | * | 26 |
| | | | | <i>Cullicoïdes sp</i> | * | | * | * | 5 |
| | | | Chironomidae | <i>Chironomus sp</i> | | * | | * | 11 |
| | | | | <i>Glyptochironomus sp</i> | * | | | | 1 |
| | | | | <i>Endochironomus sp</i> | * | | | | 2 |
| | | | | <i>Glyptotendipes sp</i> | * | * | * | | 28 |
| | | | | <i>Non déterminé</i> | * | * | | * | 4 |
| | | | | <i>Polypedilum sp</i> | * | * | * | * | 440 |
| | | | | <i>Stenochironomus sp</i> | * | * | * | | 8 |
| | | | Dixidae | <i>Tanytarsus sp</i> | | * | | | 6 |
| | | | | <i>Dixa sp</i> | * | * | | * | 5 |
| | | | | <i>Dixella sp</i> | | * | | | 3 |
| | | | Limoniidae2 | <i>Scleroprocta sp</i> | * | * | * | * | 88 |
| | | | Ephydriidae | <i>Ephydra riparia</i> | * | * | | | 3 |
| | | | Dolichopodidae | <i>Rhaphium sp</i> | * | | | | 1 |
| | | | Orthoclaadiinae | <i>Brilla sp</i> | * | | | | 1 |
| | | | | <i>Corynoneura sp</i> | * | * | * | * | 15 |
| | | | | <i>Non déterminé</i> | * | * | | | 8 |
| | | | | <i>Rheosmittia sp</i> | | * | | | 1 |
| | | | Rhagionidae | <i>Chrysopilus sp</i> | * | | | | 2 |
| | | | Simuliidae | <i>Simulium bracteatum</i> | * | * | * | | 45 |
| | | | | <i>Simulium venustum</i> | * | * | * | * | 915 |
| | | | | <i>Stegoterma mutata</i> | * | * | * | | 187 |
| | | | Tabanidae | <i>Tabanus sp</i> | * | | * | | 23 |
| | | | Tanypodinae | <i>Apsectrotanypus sp</i> | | | | | 1 |
| | | | | <i>Clynotanypus sp</i> | * | | | | 1 |
| | | | | <i>Conchapelopia sp</i> | * | * | * | * | 53 |
| | | | | <i>Cryptotendipes sp</i> | * | | | | 4 |
| | | | | <i>Procladius sp</i> | * | * | * | * | 26 |

| | | | | | | | | | | |
|---------------|-------------|--------------------|-----------------|------------------------------|-----|-----|-----|-----|-------|-----|
| | | | | <i>Cryptochironomus sp</i> | * | | | | | 1 |
| | | | Tipulidae | <i>Hexatoma spinosa</i> | * | * | * | * | * | 250 |
| | | | | <i>Yamatotipula furca</i> | * | * | * | * | * | 55 |
| | | Lepidoptera | Crambidae | <i>Petrophila confusalis</i> | * | * | | | * | 22 |
| | | | | <i>Synchita occidentalis</i> | | * | | | | 4 |
| | | Orthoptera | Gryllidae | <i>Anaxipha sp</i> | | | | | * | 1 |
| Mollusca | Gasteropoda | Basomm atophora | Ampullariidae | <i>Pila ovata</i> | | | | * | | 1 |
| | | | Limneidae | <i>Stagnicola sp</i> | * | * | * | | | 2 |
| | | | Physidae | <i>Physa acuta</i> | * | | | | | 1 |
| | | Mesogasteropoda | Thiaridae | <i>Potadoma freethi</i> | * | | | * | | 8 |
| Annelida | Oligocheta | Haplotaxida | Haplotaxidae | <i>Haplotaxis sp</i> | * | * | * | * | * | 34 |
| | Acheta | Rhychob delliforma | Glossiphoniidae | <i>Glossiphonia sp</i> | * | * | | | * | 6 |
| | | | | <i>Haementeria sp</i> | * | * | | | | 4 |
| | | | | <i>Helobdella sp</i> | * | | | | | 1 |
| | | | Hirudidae | <i>Non déterminé</i> | | | * | | | 1 |
| Plathelmintha | Turbellaria | Tricladia | Dugesidae | <i>Dugesia lugubris</i> | * | * | * | * | 121 | |
| Totals | 6 | 16 | 91 | 202 | 154 | 132 | 121 | 115 | 29444 | |

* Presence

On the other hand, abundances and taxonomic richness are high in groups GI and GII dominated respectively by pebbles, blocks and aggregates, and relatively low in group GIV dominated by the sandy substrate. However, there is no significant difference between taxonomic richness values from one group to another (Kruskal-Wallis, $p > 0.05$).

The Shannon-Weaver (H') index takes relatively low values in group GII at MAC11 station (2.46 bits) and high values in group GI at MAC14 station (4.16 bits).

Similarly, Pielou's evenness values are close to average in group GII at MAC11 (0.47) and rise substantially in group GI at MAC12 (0.74). In addition, Simpson's dominance index fluctuated between 0.086 in group I at MAC07 and 0.30 in group GII at MAC11. The spatial value of the ecologic index at each station is represented in Figure 6. From a spatial standpoint, no significant difference was observed between the values of these three ecological indices from one station to another (Kruskal-Wallis, $p > 0.05$).

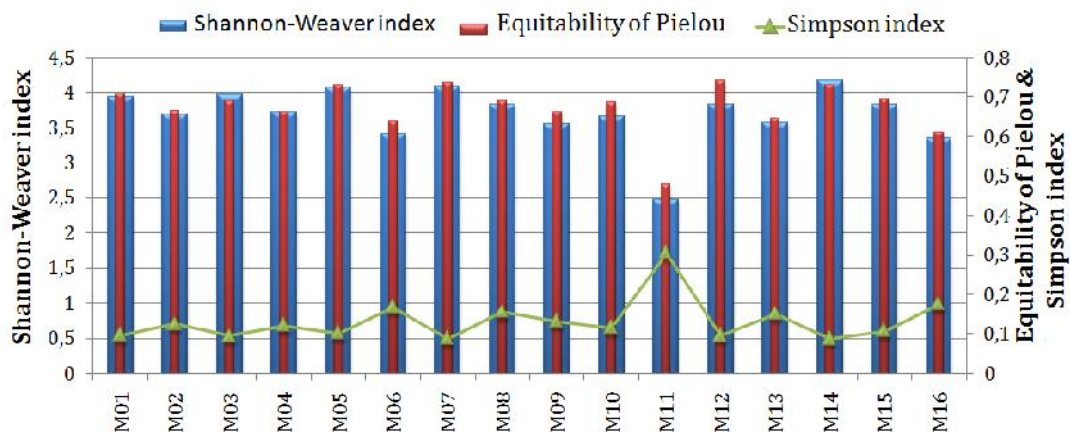


Figure 6: Spatial variation of Shannon indices, Pielou equitability and Simpson's index.

Table 3 shows relatively high values of taxonomic descriptors in the different stations. These values range between 11 and 19 taxa for the EPT index, between 17 and 29 taxa for the EPTC index, between 12 and 23 taxa for the EPTH index and between 12

and 21 taxa for EPTD index. The same is true for the density index EPT / density of chironomidae whose values oscillated between 09.67 and 117.70 individuals per m².

Table 3: Spatial Variation of Water Quality Indicator Descriptors for Good Water Quality

| Indices | EPT | EPTC | EPTH | EPTD | Average density EPT (Ind / m ²) | Average density Chironomidae (Ind, / m ²) | Average density EPT / Density Chironomidae (Ind / m ²) |
|---------|-----|------|------|------|---|---|--|
| M01 | 16 | 26 | 19 | 17 | 14,7 | 0,2 | 72,5 |
| M02 | 18 | 26 | 19 | 19 | 18,2 | 0,2 | 94,8 |
| M03 | 19 | 28 | 23 | 20 | 23,8 | 0,9 | 27,9 |
| M04 | 18 | 28 | 22 | 19 | 16,5 | 0,3 | 49,7 |
| M05 | 17 | 24 | 19 | 18 | 7,3 | 0,5 | 14,2 |
| M06 | 16 | 24 | 20 | 17 | 24,0 | 0,7 | 34,6 |
| M07 | 18 | 28 | 21 | 19 | 10,5 | 0,4 | 28,1 |
| M08 | 18 | 27 | 21 | 19 | 6,7 | 0,4 | 15,7 |
| M09 | 17 | 26 | 19 | 18 | 20,0 | 0,4 | 45,7 |
| M10 | 17 | 25 | 18 | 18 | 14,2 | 0,5 | 29,4 |
| M11 | 11 | 18 | 12 | 12 | 8,6 | 0,9 | 9,7 |
| M12 | 11 | 17 | 12 | 12 | 7,8 | 0,2 | 34,8 |
| M13 | 19 | 29 | 20 | 20 | 12,5 | 0,4 | 29,9 |
| M14 | 18 | 27 | 21 | 19 | 11,4 | 0,3 | 38,1 |
| M15 | 12 | 22 | 19 | 13 | 9,6 | 0,1 | 69,5 |
| M16 | 15 | 22 | 18 | 16 | 11,3 | 0,1 | 117,7 |

EPT=Ephemeroptera, Plecoptera and Trichoptera; EPTC= EPT with Coleoptera; EPTH= EPT with Heteroptera and EPTD= EPT with Decapoda.

Influence of grain size on abundance dynamics of major taxa

The first two axes of the Canonical Correspondence Analysis (CCA), explain 79.0% (F1 = 55.9% and F2 = 23.1%) of the affinity of the main taxa chosen on the basis of their abundance. relative greater than 1% at each station and granulometric variables (Figure 7). The F1 axis contrasts sandy substrates with large substrates. On F1 axis, *Hydropsyche Betteni*, *Parapsyche sp*, *Atyaephira desmarestii*, *Polypedilum*

sp, *Simulium venustum* and *Macrostemum sp* taxa are positively correlated with coarse-sand, while *Neoperla spp*, *Neochoroterpes sp*, and *Pseudomacronychus decoratus* are negatively correlated on the same axis.

On the F2 axis, *Tricorythus sp*, *Ephemerythus kiboensis* and *Adenophlebia sp* (Ephemeroptera) are positively correlated with the rocks, pebbles, and stones like substrate while *Baetis rhodani*, *Dicercomyzon femorale* and *Neoperla sp0* are found in fine sandy substrates.

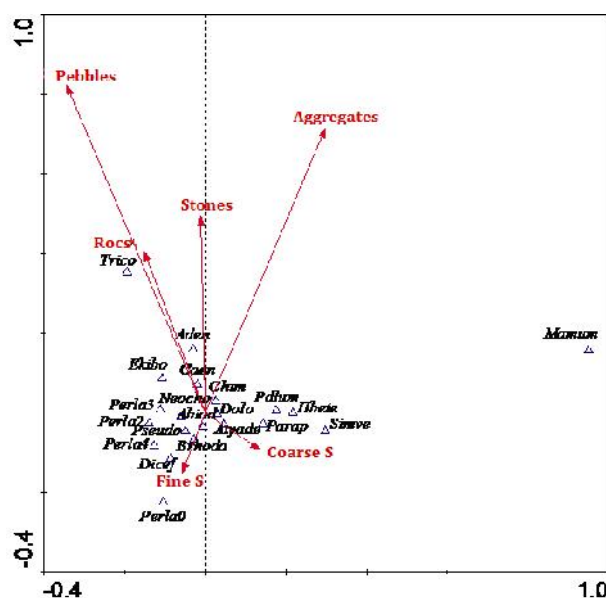


Figure 7: Canonic Correspondence Analysis (CAC) of major benthic macroinvertebrate taxa and grain size variables. (Sand F. = fine sand, Sand G. = Coarse sand, Blocks P. = Stone blocks, *Trico* = *Tricorythus sp*, *Ekibo* = *Ephemerythus kiboensis*, *Perla0*, *Perla2*, *Perla3* and *Perla4* (Perla morphotype 0, 2, 3 and 4), *Caen* = *Caenis sp*; *Neocho* = *Neochoroterpes sp*; *Dolo* = *Dolophilodes sp*; *Aden* = *Adenophlebia sp*; *Abiod* = *Adenophlebiodes sp*; *Dicel* = *Diceromyzon femorale*; *Brhoda* = *Baetis rhodani*; *Parap* = *Parapsyche sp*; *Mamum* = *Macrostemum sp*; *Hbete* = *Hydropsyche Betteni*, *Simve* = *Simulium venustum*, *Atyade* = *Atyaephyra desmarestii*, *Pdlum* = *Polypedilum sp*, *Chim* = *Chimara sp*, *Pseudo* = *Pseudomacronychus decoratus*.

Discussion

Environmental parameters

The role of the taxa-substrate relationship in the distribution of organisms has been established by illustrating differences in the distribution of benthic macroinvertebrates (MIBs) between biotopes (Ward 1992; Jowett 1993, Crosa *et al.*, 2002, De Crespín of Billy & Usseglio-Polatera, 2002).

As pointed out by Ward (1992), the majority of MIBs show a marked preference for one or more types of substrate, the latter appearing as variables having the most influence on taxonomic richness and abundance. As a result, unlike the results of Linhart *et al.* (2002) or Graça *et al.* (2004), the grain size is known to significantly influence the composition of MIB (Wohl *et al.* 1995).

Indeed, diversity and taxonomic abundance increase with substrate stability (Giller and Malmqvist, 1998) and thus with the grain size (Bravard *et al.*, 1997, Foto Menbohan *et al.*, 2017). Thus, the mineral substrates greater than 64 mm are quite stable and thanks the numerous irregularities of their surface, which constitute caches and points of attachment for the taxa, they are particularly biogenic. These grains

preferentially accommodate large individuals, with larvae essentially confined to the hypogeous zone where they find more stable environmental conditions, the water renewal time being quite long (Gayraud & Philippe, 2003; Datry *et al.*, 2007). Many pollutant-sensitive taxa such as Perla, Isoperla, Perlodes, etc. favor these coarse substrates (Fenoglio *et al.*, 2007).

Biological parameters

The fauna of the benthic macroinvertebrates of the Mabounié Basin watercourse, 94.17% insects, is rich and diversified. This important proportion of insects is close to that observed in other forest streams in the tropics. Thus, the population of benthic macroinvertebrates in the Nga stream is dominated by 99.9% insects (Foto Menbohan *et al.*, 2010 and 2013), and 88.59% in Nsapè (Tchakonté *et al.*, 2014), in Agneby in Ivory Coast (Diomandé *et al.*, 2009) by 68% insects, in the Kalengo River by 62.5% insects (Ndakala Mukungilwa *et al.*, 2015) and in New Caledonia by 75% insects (Mary, 1999). In Mabounié Basin, this class of insects is organized around 23.76% Coleoptera, 16.83% Diptera with 9.22% of Chironomidae, 14.35% Ephemeroptera, 13.10% of Trichoptera, 11.88% of Odonata, 7.42% of Heteroptera, 3.46% of Plecoptera and 1.94% of Lepidoptera.

The benthic macroinvertebrate population of tributaries of the right bank of Mabounié is distinct from that of tributaries of left bank due to the absence in all samples of the taxa *Tricorythus sp* (Ephemeroptera). This absence would result from the lack of coarse mineral substrates (pebbles, blocks of stones, etc.) and weak slopes, the main physical difference observed between the left and right tributaries of Mabounié watershed. In this vein, Richards *et al.* (1993) noted that hydraulic regime and bedrock are physical conditions that affect the composition, abundance, and distribution of benthic macroinvertebrate communities. Our results corroborate this observation.

In terms of affinity to one type of substrate, the *Diceromyzon femorale* (Ephemeroptera) and *Neoperla* morphotype *sp0* (Plecoptera) taxa would prefer fine sand as *Atyaephyra desmarestii* would prefer coarse sand. In addition, CCA shows that *Macrostemum sp*, *Hydropsyche betteni* (Hydrpsychidae, Trichoptera), *Simulium venustum* (Simuliidae, Diptera), *Polypedilum* (Chironomidae, Diptera) and *Neoperla spp* (Perlidae, Plecoptera) taxa have not affinity for the specific substrate; they would seem to accommodate any form of the mineral substrate provided that the physicochemical conditions lend themselves to it.

The rich and heterogeneous organizational structure of the stand is certainly inherent in the low variation of environmental conditions in the Mabounié basin watercourses, as many studies show that the taxonomic richness is influenced by the prevailing environmental conditions in the basin. Medium and a stable environment is a home to high taxonomic richness (Arab *et al.*, 2004; Foto Menbohan *et al.*, 2012). In the Mabounié Basin, this environmental stability results in a high abundance of organisms, a Shannon index greater than 3.5 bits/ind., an equidistribution of the stand greater than 0.6 and an absence of dominant taxa in 15 of the 16 stations. Only the M11 station has low ecological indices and a high Simpson index compared to other stations. The singularity of the results of the M11 station is to be put in relation with the forest track that overlooks it and the fragility of the soils in this sector, conducive to high erosion. These disturbance conditions appear to be responsible for the abundance of *Hydropsyche betteni*, *Macrostemum sp* and *Simulium venustum* at this station. Our observations are supported by those of several authors including Alhou *et al.* (2009).

Macroinvertebrates stand being structured in the short rainy season because the Simpson and Pielou equitability evenness shows a profile of instability, varying respectively from 0.1 to 0.6 and from 0.5 to 0.7. It would then reach maturity in the long dry season where the Simpson's evenness only varies by 0.2 units between stations and seasons and Pielou's equitability by 0.1 units. The water quality of rivers was also assessed from the proportion of Ephemeroptera, Trichoptera, Plecoptera and Decapoda commonly used in Hydrobiology as indicators of water quality (Alhou *et al.*, 2009, Tchakonté *et al.*, 2015). The high values of the rate of the EPT on the Chironomidae and those of classical ecological indices give watercourses in the Mabounié basin a status of good biological and ecological quality.

Conclusion

This first faunistic inventory constitutes a first important database for the Mabounié basin and Gabon. The taxonomic composition of this fauna varies little according to the type of substratum and the physicochemical quality of the streams. It also reveals that the *Tricorythus sp* taxa, which is subjugate to coarse mineral substrates (pebbles, blocks of stones and slabs), can constitute a biological marker of substrate change in watercourse. The high proportion of EPT (68.61%), EPTC (75.79%), the value of classical ecological indices (Shannon, Equitability and Simpson) as well as the low EPT / Chironomidae ratio show that, the Mabounié basin still have reference watercourse characteristics for forest hydrosystems.

The fauna inventoried in this study consists of 15 orders, 90 families, 182 genera and 202 taxa for a total of 29,444 specimens. These stands are dominated by insects (87.11%), including Coleoptera (23.76%), Diptera (16.83%), of which 9.22% belong to the Chironomidae group, and the Ephemeroptera (14.35%), Trichoptera (13.10%), Odonata (11.88%), Heteroptera (7.42%), Plecoptera (3.46%), Lepidoptera (1.94%) and, other orders (Decapoda, Rhynchobdellida, Tricladida, Dictyoptera) accounting for less than 3% of overall taxonomic richness.

Acknowledgments

We thank the Maboumine Company for its multifaceted support, the laboratories of Pedology and Hydrobiology and Ichthyology of Agronomic and Forestry Research Institute (IRAF) of Gabon as well as the laboratory of Hydrobiology and Environment of


the University of Yaoundé 1 in Cameroon, for their scientific and technical contributions in the processing and analysis of data.

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| DOI: 10.22192/ijarbs.2018.05.07.020 | |

How to cite this article:

Blaise Rollinat MBOYE, Samuel FOTO MENBOHAN, Jean Daniel MBEGA, Eric Belmont BIRAM à NGON. (2018). Influence of the Granulometric parameters on the Diversity and Distribution of Benthic Macroinvertebrates in the Mabounié Watershed (Central West Gabon). *Int. J. Adv. Res. Biol. Sci.* 5(7): 252-270.

DOI: <http://dx.doi.org/10.22192/ijarbs.2018.05.07.020>