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Influence Steeping of the Cassava Tubers on the Physico-Chemical Quality of Water and the Population of the Benthic Macroinvertebrates of River Pala in Central African Republic (CAR)

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Abstract: ***The aim of this study was to determine the influence of steeping of cassava tubers on the structure of Benthic Macroinvertebrates (BM) community in Central African Republic (CAR) in relation to the physicochemical quality of the water of Pala stream. The data were collected from May 2015 to April 2016 on a monthly frequency in 5 selected sampling stations of the upstream towards the downstream on the river. The physicochemical analyses were carried out using standard methods while the benthic macro fauna was collected using a net with a mesh size of 150 µm on a total surface of approximately 6 m^2 per station. The physicochemical analyses revealed a satisfactory water quality of the stations not located downstream from the point of steeping of the cassava tubers and a deterioration of the ecological quality in the stations located downstream from the point of steeping. A total of 2982 Benthic Macroinvertebrates, belonging to 79 taxa were identified and counted. Arthropods were the most diversified with 54 taxa and more abundant (53.11%), followed by Molluscs (23 taxa, 37.79% of abundance) and Annelids (2 taxa, 9.10% of abundance). The station P5in the potamal area, which is the only station not directly located downstream from the steeping of the cassava tubers harbours the majority of Arthropods, dominated by Insects. In fact, the presence of oligotrophic characteristic crustaceans is confirming the auto purification capacity of the river due to a weak disturbance related to anthropic activities. In the rhythral and potamalstations downstream from the steeping of the cassava tubers, the strong abundance of Molluscs and the presence of Annelids, all polluotolerants, indicate the water quality degradation due to this practice of steeping.***

Keywords: Benthic Macroinvertebrates, water quality, steeping of cassava tubers, PalaRiver, Central African Republic.

1. Introduction

Continental aquatic environments have a large variety of advantages and services for man, conferring them an incommensurable economic value (Gleick, 1993; Costanza et al., 1997). Among these aquatic environments, rivers are probably the most impacted aquatic ecosystems of the planet due to the multiple threats they are exposed to (Allan & Flecker, 1993; Malmqvist & Rundle, 2002; Allan, 2004). According to Leynaud & Verrel (1980), river pollution is not referred to water purity or to their aptitudes, but to the modifications of their characteristics due to human actions, hence the need to put in place programs to monitor these hydrosystems.

Among the sustainable management tools of aquatic environments, biological evaluation methods (biological monitoring) based on living organisms have played a very significant role as they make it possible to give a global view of the conditions and environmental pressures (Armellin, 2010). In these biological control systems of lotic medium, Benthic Macroinvertebrates are most commonly used as bioindicators of aquatic medium status (William & Smith, 1996; WFD, 2003; Archaimbault & Dumont, 2010). These organisms are present and abundant in all the types (small or large) of rivers (Chessman, 1995; Camargo et al., 2004). They are easy to collect and moreover, their collection has less perturbation on the aquatic community (Barbour *et al.*, 1999).

In Central African Republic (CAR), the situation on water quality and management are preoccupying. Despite its enclavement, this country represents a water tower for Central African countries which is made up of a hydrographic network with two large watersheds (the watershed of Oubangui and that of Chari). This highly dense hydrographic network is subjected to two major problems: the regular drop of water volume and the degradation of surface water quality (rivers, springs, and ponds) and water of traditional wells which provide portable water for more than 60% of the population (Kozo, 1999; FAO, 2005; PNUE, 2011). Even though mining activities, poor fishing practices using toxic products in aquatic ecosystem, are regularly applied; the last military-political crises came and exacerbated this situation to more than alarming.

Beyond all these concerns, agriculture in CAR is based on the cultivation of cassava, which is the basic food of the country. This plant is cultivated on all the territory with a cassava productive yield in the form of 7.373.000/year cossets for the year 2015 (FAO/PAM, 2014). Cassava consumption in the form of cossets requires steeping of the tubers. In CAR the steeping starts directly in the hydrosystems. In fact, steeping of cassava tubers leads to the release of toxic cyanide which can also associate to other chemical elements of water to form more toxic compounds. Moreover, the peels of abandoned tubers at the bottom of streamsafter the extraction of softened starch constitute a high load of organic matter. Up till present, few studies have been conducted on the impact of steeping of cassava tubers on the physicochemical status of water (Louembé *et al.*, 2002). Also, to our knowledge, no study has been carried out on benthic fauna of lotic medium in CAR. The purpose of the present study is to evaluate the influence of steeping of cassava tubers on physico-chemistry of water status and the structure of Benthic Macroinvertebrates of Pala Forest River. The specific objectives assigned to this study consist of: (1) to determine the physico-chemical characteristics of water from some physico-chemical parameters; (2) to establish the structure of Benthic Macroinvertebrates community of Pala Riverand (3) to identify the abiotic parameters involved in the settlements of these community in relation with the steeping of cassava tubers.

2. Material and Methods

Presentation of the study area

This study was conducted in the Bimbo council of CAR, located at the western part of Bangui which is the capital town of the country. The Bimbocouncil is a forest zone with the same climatic and edaphic characteristics as Bangui. There is relatively abundance of hot rain which favours specific alteration called ferrallitisation. Majority offerrallitic soil type are characterized by an intensive alteration of primary minerals and by the accumulation of their less soluble chemical elements like the trivalent cations (iron and alumina hydroxide) (Doyémet, 2006). The climate is of soudano-oubanguien type characterized by two seasons: a rainy season which extends from April to October and a dry season which goes from November to March. Precipitations vary from 1200 to 1600 mm/year (Tambashe *et al.*, 2008). The average annual temperatures vary between 23°C and 27°C with a maximum in March and the lowest in July, which is the period of heavy rainy season (Tambashe *et al.*, 2008).

Description of sampling stations

River Pala is an affluent of river M'poko of the Oubangui basin. The Pala water shed (4°11'29'' and 4°19'07'' latitude north; 18°26'01'' and 18°30'52'' longitude east) has a surface area of 80.03 km^2 (**figure 1).** It is located in a periurbain zone at approximately 2 km from the west part of Bimbo town. The watershed is found entirely in the Botambiforest of the Bimbocouncil. This watershed area is located in a zone of traditional agriculture dominated by cassava cultivation where water from the river is highly used throughout by farmers for the steeping of the cassava tubers. One also finds in the watershed of Pala, a large Zila cemetery and the Central African Company of cement factory (SOCACIM), which is still nonfunctional at the level of the potamal (**figure 1).**

The Pala River with a length of 11.61 km (IGN, 1988) takes its source from a marshy area called Lake Ngbongo which is constantly covered with plants that empties in M'Poko River, a tributary of Oubangui. The river flows from west towards the east and has two tributaries; Ngaïna and Sakaba, all on right bank at the level of the rhithral, where many dead branches and marshy zones are found (**figure 1).**

For this study, 5 sampling stations were chosen. Station P1 (4°17'546"N, 18°26'108" E, 359 m of altitude) is located in the marshy area called "Lake Ngbongo" (**figure 1 A** and **B**).

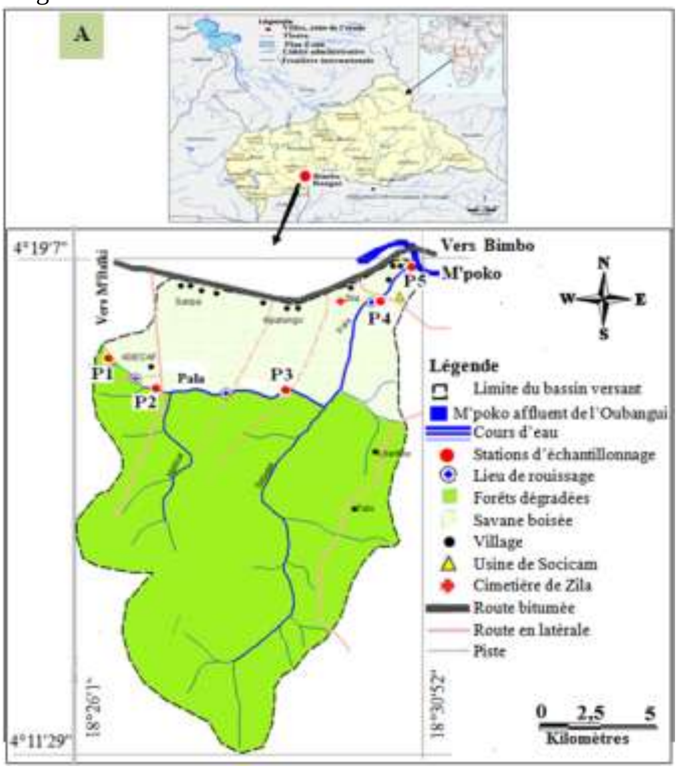

Figure 1: Map of the Pala watershed (A) and sampling Stations: P1 (B), station P2 (C), station P3 (D), station P4 (E), station P5 (F).

Station P2 (4°17'230" N, 18°27'222" E, 356 m of altitude) found at the level of the crenon is located at 1.82 km from station P1 (**figure 1 A** and **C**). At about 0.7 km upstream to station P2 is found a site for steeping of cassava tubers in the river. Station P3 (4°17'243" N, 18°28'857" E, 351 m of altitude) situated at the site of the rhithron is located at the level of the Maka bridge, at 5.32 km from station P1 (**figure 1 A** and **D)** and at about 1 km downstream to the site of steeping of cassava tubers. Station P4 (4°18'688" N, 18°30'270" E, to 348 m of altitude) is located in the potamon at the level of the Zila bridge at 10.05 km from station P1 (**figure 1 A** and **E).** At the upstream of station P4, is found a large cemetery of Zila. Station P5 (4°19'111" N, 18°30'634" E, to 340 m of altitude) situated at the level potamon is located at 11.4 km from station P1 (**figure 1 A** and **F**).

Sampling procedure

Collection of water samples for physico-chemical analysis and Benthic Macroinvertebrates samples were done monthly from May 2015 to April 2016. Samples were not collected in the month of September because of political crises in Bangui. Water was collected against the flow of water current in labelled 1000 ml polyethylene tubes for analysis in the laboratory. Dissolved oxygen and carbon dioxide gases were fixed *in situ* respectively by the Winkler method, NAOH N/40 and phenolphtaleine indicator followed by their fixation in 250 ml tubes and transportation in a cooler to the laboratory. Benthic Macroinvertebrates were collected using a 1.5m long and 30 x 30 cm kick-net with a 150 µm mesh size on a distance of 100m. Care was taken to include all possible habitats over representative sections of the stream (100m samples), according to sampling procedure proposed by Stark et al. *(*2001). In each station, 20 collections were made in different micro-habitats, each one corresponding to a surface of 0, 3 m^2 (30 cm × 100 cm). In the laboratory, samples collected with the net were rinsed through a sieve of 150 µm and all Benthic Macroinvertebrates were handpicked and preserved in 90% alcohol.

Measurement of environmental variables

Environmental variables were measured at the different sampling points according to Rodier et al. *(*2009) and APHA (1998). Temperature (°C), pH, Total Dissolved Solids (TDS), Electric Conductivity (µS/cm) were measured *in situ* using respectively analcohol thermometer and a mark ExStik® IIpH/Conductivity/TDS multimeter. In the laboratory, Dissolved Oxygen was measured by volumetry using PhenylArsine Oxide (PAO) with starch as the coloured indicator in accordance with the standard method of AFNOR NF T 90-106. Percentage saturation was obtained using the Mortimerabacus (1956). Alkalinity, Dissolved Carbon Dioxide and Oxydability were measured by volumetry using appropriate reagents in accordance with the standard of AFNOR NF T 90.

Identification Benthic Macroinvertebrates

In the laboratory, the specimens were rinsed with water then preserved in 96°alcohol. Identification and counting were done using a stereoscopic microscope MOTIC Sfc-11. The identification keys of Durand & Levêque, (1981); Mouthon, (2001); De Moor *et al. (*2003); Moisan, (2006); Stals & De Moor (2007); Tachet et al. *(*2010) and Moisan & Pelletier (2013) were used.

The Taxonomic richness, abundance and taxa occurrence frequency were used to describe the Benthic Macroinvertebrate community. The occurrence frequency denoted F and expressed in percentage, provides information on the consistency of a species or taxon in a given habitat without any indication of its quantitative importance (Dajoz, 2000). Results interpretation would indicate omnipresent species if there are in all surveys (F = 100%); regular species in 75≤ F≤ 100% of the surveys;

constant species in 50≤ F≤ 75% of surveys; accessories species in 25≤ F≤ 50% of surveys and rare species in 0≤ F≤ 25% of surveys (Dufrêne & Legendre, 1997). This index is based on the presence/absence matrix and is calculated following the formula below:

$$F = \frac{P_i \times 100}{P_t}$$

Where *Pt* is the total number of samples and *Pi* is the number of samples where species *i* is present.

The indices of diversity (H ') of Shannon-Weaver ($H' = -\sum_{i=1}^{n} P_i \log_2 P_i$), with Pi= relative abundance of the taxon i, S = the total number of taxons in the sample) and that of equitability (E) of Pielou (E= $\frac{H'}{Log_2 S}$ where H' is the diversity index of Shannon and Weaver and S the number of species) permitted the estimation of the total diversity and the study of the regularity of species distribution.

The similarity index of Sörensen (H) was used to determine the level of resemblance between the Benthic Macroinvertebrates community collected in the different sampling stations. This index is calculated by the formula: $S = \frac{2c}{a+b} x100$, with S = coefficient of similarity of Sörensen; a = number of taxons present in station 1; b = number of taxons present in station 2; c = number of taxons common to both stations.

Software SPSS 20.0 was used to carry out the nonparametric ANOVA of Kruskal-Wallis and the U test of Mann Whitney used to test the differences between the abiotic parameters and the taxonomic richness. In order to study the link between the environmental variables and the dynamics of abundance of Benthic Macroinvertebrates, the correlation coefficient of Spearman and the Canonical Analysis of Redundancy (CAR) were carried out using two data bases, the abundances matrix of taxons (additional, constant, regular and omnipresent) and the matrix of physico-chemical parameters, using the same Software and CANOCO for Windows 4.5 respectively (Ter Braak & Smilauer, 2002).

3. Results

Environmental variables

The minimal, average and maximum values of environmental variables measured are presented in table 1. The average Temperature of water varied from 23, 8 ± 0, 9°C in station P1 to 26, 8 ± 0, 9°C in station P5 with mean values of 24.7±0.9°C, 25, 5 ±1.1 and 26, 2 ± 1.1°C respectively at stations P2, P3 and P4. The average values of pH do not vary between stations. These values were 6.97 ± 0.2 (stations P1 and P4) and 6.98 ±0.02 at the other stations. The values of Alkalinity was generally low in all stations with average values of 5, 4±2, 02 mg/L. Electric Conductivity and Total Dissolved Solids were generally high in all stations with average values being between 52.2±15.3mg/L and 66.8±11.2 mg/L at station P2 and 150.4±35.4 mg/L and 221.6±46.7mg/L at station P4. The mean values of saturated Dissolved Oxygen varied from 63.8 ±4.4% at station P2 to 80.9 ±3.5% at station P5 with average values of 71.4±5.3%; 68.5 ±5.2% and 75.4 ± 3.8% respectively at stations P1, P3 and P4. Dissolved Carbon Dioxides and Oxydability presented respective mean values of 5.6 ± 1.52 mg/L at station P5, 4.2 ± 0.7 mg/L at station P1 and 13.2 ± 2.3 mg/L and 7.8 ± 1.2 mg/L at station P3.

The test of Kruskal-Wallis showed significant differences from one station to other for Dissolved Oxygen (P= 0.01), Total Dissolved Solids (P = 0.03), Dissolved Carbon Dioxides (P=0.04) and Alkalinity (P=0.02). For the other measured variables, significant difference was observed (p>0.05) from one station to other.

Table 1: Mean values and standard deviation environmental variables measured at each sampling station during the study period

Environemental variables		**Sampling stations**				
		P 1	**P 2**	**P 3**	**P 4**	**P 5**
Temperature (°C)	Max	25.9	26.1	26.9	27.7	27.8
	Mea	23.77±0.99	24.7±0.94	25.52±1.09	26.2±1.12	26.8±0.98
	Min	22.50	23.20	23.40	23.90	24.90
pH	Max	6.99	7.01	7.01	6.99	7.01
	Mea	6.97±0.02	6.98±0.02	6.98±0.02	6.97±0.02	6.98±0.02
	Min	6.94	6.94	6.95	6.95	6.95
Electric Conductivity (µS/cm)	Max	280	83.4	93.7	303	301
	Mea	164.7±100.3	66.8±11.2	76.9±12.4	221.6±46.7	206.6±47.4
	Min	51.6	50.2	57.7	168.3	139.2
Total Dissolved Solids (mg/L)	Max	197	85.4	78.1	209	203
	Mea	112.2±7	52.2±15.3	56.4±11.7	150.4±35.4	142±30.9
	Min	36.6	35.9	40.1	109	99.8
Dissolved Oxygen (% saturation)	Max	76.9	71.25	76.02	79.8	85.2
	Mea	71.4±5.3	63.8±4.4	68.5±5.2	75.4±3.8	80.9±3.5
	Min	61.9	57.8	61.8	70.8	76
Alcalinity (mg/L)	Max	8	6	6	8	6
	Mea	4±1.79	4.2±1.4	4.2±1.4	5.4±2.02	3.3±1.85
	Min	2.00	2.00	2.00	2.00	2.00
Oxydability (mg/L)	Max	5.5	10	9.9	7.5	6.5
	Mea	4.2±0.72	7.4±1.73	7.8±1.24	6±1.17	5±0.99
	Min	3.2	4.4	6.5	3.8	3.6
Dissolved Carbon Dioxide (mg/L)	Max	8.6	13.6	15.8	11.1	8.4
	Mea	6.6±1.3	10.2±2.02	13.2±2.26	8.6±1.87	5.6±1.52
	Min	5	6.3	8.8	4.9	3.5

Legend: Max = Maximum; M = Mean; Min = Minimum

Composition, distribution and frequency of occurrence of different taxons

During the study period a total of 79 taxons of Benthic Macroinvertebrates were collected with 77 identified up till the rank of genus/or species, one at the rank of subfamily and one at the rank of family. Benthic Macroinvertebrate identified belong to 3 phyla (Arthropods, Mollusksand Annelida), 6 classes (Crustaceans, Insecta, Bivalves, Gastropoda, Achaeta and Oligochaeta), 11 orders and 42 families (**Table 2**). In terms of abundance, a total of 2982 individuals were collected. The phylum Arthropoda was the most abundant with 1584 individuals (53.11%) followed by the phylum of Mollusca with 1127 individuals (37.79%) and that of Annelida with 271 individuals (9.08%) (Table 2). Among the 1584 Arthropoda counted, insects were the most abundant with 1508 individuals representing 95.20% of relative abundance, followed by crustaceans represented by 62 individuals (4.80%). Hemiptera and Diptera were the most represented among the group of insects with 576 individuals (38.20%) and 448 individuals (29.71%) respectively. They were followed by the Orders of Coleoptera with 290 individuals (19.23%) and Odonata with 193 individuals (6.47%). Ephemeroptera were represented by one individual (0.07%). Crustaceans were represented by Decapoda with 76 individuals. Bivalves, with 857 individuals representing 75.15% relative abundance were the most abundant of the class of Mollusca. Gastropods are made up of 280 individuals, 24.85% relative abundance of Mollusks. The Class of Bivalves represented by the order of Eulamelli branches was dominated by *Sphaerium* sp. species with 837 individuals making up 98.92% of relative abundance of Bivalves. In the class of Gastropoda, Basommatophora dominated with 191 individuals representing 68.21% of relative abundance, followed by Mesogastropoda with 89 individuals (31.790%). Annelida were represented by the Classes of Achaeta belonging to the Order of Rhynchobdellida and was sampling station made up of *Helobdella*sp. species with 221 individuals (81.54%) of relative abundance of Annelids and the Classes of Oligochaeta constituted of the order Haplotaxida with the unique family of Enchytraeidae with 50 individuals (18.46%) (**Table 2).**

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Table 2: Abundance of the different Benthic Macroinvertebrate taxons identified at each sampling station of river Pala

Benthic Macroinvertebrates			Sampling stations					Total abundance (R. abundance %)
Famillies	**Taxons**	**Acronyms**	**P1**	**P2**	**P3**	**P4**	**P5**	
		Arthropods						**1584 (53.11)**
Atyidae	*Cardina africana*	Cafr	0	0	0	0	64^{Co}	64 (2.14)
	Caridina indistincta	Cind	0	0	0	0	4^{Ac}	4 (0.13)
	Caridina nilotica	Cnil	0	0	0	0	7^{Ac}	7 (0.23)
Gecarcinucidae	*Afrithelphusa afzeli*	Afaf	0	0	0	0	1^{Ra}	1 (0.03)
Chironomidea	*Chironomus* sp.	Cisp	0	197^{Co}	92^{Co}	131^{Ac}	0	420 (14.08)
Ceratopogomidae	Ceratopogoninae*	Cera	0	4^{Ra}	0	0	0	4 (0.13)
Culcidae	Anophelinae*	Anop	0	0	9^{Ra}	0	0	9 (0.30)
	Culicinae*	Culi	0	1^{Ra}	15^{Ra}	0	0	15 (0.50)
Notonectidae	*Microanisop apicalis*	Mapi	5^{Ra}	0	0	0	0	5 (0.16)
	Anisop sp.	Ansp	2^{Ra}	1^{Ra}	0	0	0	3 (0.10)
	Notonecta sp.	Nosp	2^{Ra}	0	1^{Ra}	0	0	3 (0.10)
	Nychi asp.	Nysp	1^{Ra}	3^{Ra}	3^{Ac}	0	1^{Ra}	8 (0.26)
Geridae	*Gerris* sp.	Gesp	11^{Ac}	12^{Co}	6^{Ac}	0	2^{Ra}	31 (1.03)
Veliidae	*Velia* sp.	Vesp	2^{Ra}	4^{Ra}	0	0	6^{Ra}	12 (0.40)
Belostomidae	*Lethocerus* sp.	Lesp	1^{Ra}	6^{Ac}	20^{Co}	0	0	27 (0.90)
Saldidae	*Saldula* sp.	Sasp	0	4^{Ra}	19^{Ac}	0	8^{Ra}	31 (1.03)
Naucoridea	*Loccocoris* sp.	Losp	11^{Co}	21^{Co}	137^{Re}	24^{Co}	44^{Co}	237 (7.94)
	Naucoris sp.	Nasp	2^{Ra}	19^{Co}	53^{Re}	8^{Ac}	5^{Ac}	87 (2.91)
Nepidae	*Nepa* sp.	Nesp	1^{Ra}	2^{Ra}	0	2^{Ra}	2^{Ra}	7 (0.23)
	Ranatra linearis	Rlin	3^{Ra}	9^{Ac}	30^{Co}	5^{Ra}	44^{Re}	91 (3.05)
Pleidea	*Plea leachi*	Plea	3^{Ra}	8^{Ac}	2^{Ra}	^{Ra}	8^{Ra}	24 (0.80)
Hydrometridae	*Hydrometra* sp.	Hysp	1^{Ra}	6^{Ra}	1^{Ra}	1^{Ra}	1^{Ra}	10 (0.33)
Aeshnidae	*Boyeria irene*	Bire	0	0	14^{Ac}	0	4^{Ra}	18 (0.60)
Corduliidae	*Epitheca bimaculata*	Ebim	0	2^{Ra}	8^{Ac}	0	21^{Co}	31 (1.03)
	Oxygastra curtsii	Ocur	3^{Ra}	3^{Ra}	1^{Ra}	0	0	7 (0.23)
	Stomatochlora sp.	Stsp	3^{Ra}	2^{Ra}	11^{Ac}	5^{Ac}	0	21 (0.70)
Cordulegasteridae	*Cordulegaster* sp.	Cosp	0	0	4^{Ra}	1^{Ra}	3^{Ra}	8 (0.26)
Gomphidae	*Gomphus* sp.	Gosp	0	0	3^{Ra}	0	1^{Ra}	4 (0.13)
	Paragomphus sp.	Pgsp	0	0	0	0	5^{Ra}	5 (0.16)
Libellulidae	*Diplacodes lefebvrii*	Dlef	0	0	7^{Ra}	0	0	7 (0.23)
	Brachythemis leucosticta	Bleu	0	0	6^{Ac}	0	0	6 (0.20)
	Orthretum sp.	Orsp	0	5^{Ra}	8^{Ac}	0	0	13 (0.43)
Coenagrionidae	*Coenagrion* sp.	Cnsp	0	0	0	0	6^{Ac}	6 (0.20)
Synlestidae	*Chlorolestes fasciatus*	Cfas	0	3^{Ra}	33^{Ac}	0	31^{Co}	67 (2.24)
Chrysomelidae	*Macroplea* sp.	Mcsp	1^{Ra}	0	0	2^{Ra}	0	3 (0.10)
Dytiscidae	*Cybister* sp.	Cysp	6^{Ac}	1^{Ra}	8^{Ra}	0	0	15 (0.50)
	Hydraticus sp.	Hdsp	0	2^{Ra}	0	0	0	2 (0.06)
Dryopidae	*Dryops* sp.	Drsp	5^{Ra}	0	0	0	1^{Ra}	6 (0.20)
Elmidae	*Normandia* sp.	Nrsp	0	1^{Ra}	0	1^{Ra}	0	1 (0.03)
	Potamophyilus sp.	Posp	0	1^{Ra}	0	0	0	1 (0.03)
Hydrophilidae	*Amphios* sp.	Amsp	30^{Ac}	18^{Co}	87^{Co}	8^{Ac}	0	143 (4.79)
	Berosus sp.	Besp	0	5^{Ra}	0	0	1^{Ra}	6 (0.20)
	Chaetarthria sp.	Chsp	0	1^{Ra}	0	0	4^{Ra}	5 (0.16)
	Coelostoma sp.	Cesp	0	4^{Ac}	5^{Ac}	2^{Ra}	2^{Ra}	13 (0.43)
	Enochrus sp.	Eosp	2^{Ra}	0	0	0	0	2 (0.06)
	Hydrochara sp.	Hhsp	0	0	5^{Ac}	2^{Ra}	2^{Ra}	9 (0.30)
	Hydrophilus sp.	Hrsp	0	0	1^{Ra}	0	1^{Ra}	2 (0.06)
Hydroscaphidae	*Hydroscapha* sp.	Hosp	1^{Ra}	2^{Ra}	1^{Ra}	5^{Ac}	0	9 (0.30)
Hygrobidae	*Hygrobia* sp.	Hgsp	1^{Ra}	0	1^{Ra}	0	0	2 (0.06)
Noteridae	*Néohydrocoptus* sp.	Nhsp	0	0	1^{Ra}	0	0	1 (0.03)
	Noterus sp.	Ntsp	11^{Co}	6^{Ac}	45^{Co}	4^{Ra}	1^{Ra}	67 (2.24)
Scirtidae	*Hydrocyphon* sp.	Hcsp	0	1^{Ra}	1^{Ra}	0	0	2 (0.06)
Sperichenidae	*Eubria* sp.	Ebsp	0	1^{Ra}	0	0	0	1 (0.03)
Baetidea	*Baetis* sp.	Basp	0	0	1^{Ra}	0	0	1 (0.03)
		Mollusks						**1127 (37.79)**
Sphaeridae	*Pisidium* sp.	Pisp	0	8^{Ra}	0	0	2^{Ra}	10 (0.33)
	Sphaerium sp.	Spsp	1^{Ra}	653^{Co}	163^{Re}	8^{Ra}	12^{Ac}	837 (28.06)
Hydrobiidae	*Bytthinella* sp.	Bysp	0	0	3^{Ra}	0	0	3 (0.10)
	Bythynia sp.	Btsp	0	0	26^{Ac}	0	0	26 (0.87)
	Horatiini sp.	Htsp	0	0	3^{Ra}	1^{Ra}	0	4 (0.13)
	Lithoglyphus naticoïdes	Lnat	0	0	0	0	3^{Ra}	3 (0.10)
	Marstoniopsis sp.	Masp	0	0	3^{Ac}	0	3^{Ra}	6 (0.20)
	Pseudamnicole sp.	Pssp	0	0	30^{Co}	6^{Ra}	0	36 (1.20)

Valvatidae	*Valvata* sp.	Vasp	0	0	0	10 Ac	0	10 (0.33)
Viviparidea	*Viviparus* sp.	Visp	0	1 Ra	0	0	0	1 (0.03)
Ancylidae	*Ancylus* sp.	Acsp	0	10	0	0	0	10 (0.33)
Lymnaeidae	*Galba* sp.	Gasp	0	6 Ra	8 Ra	6 Ra	0	14 (0.46)
	Lymnaea sp.	Lysp	1 Ra	3 Ra	2 Ra	1 Ra	2 Ra	9 (0.30)
	Myxas glutinosa	Mglu	0	0	0	0	3 Ra	3 (0.10)
	Radix sp.	Rdsp	1 Ra	3 Ac	7 Ac	10 Co	8 Ac	29 (0.97)
Physidae	*Physa* sp.	Phsp	1 Ra	3 Ra	49 Ac	2 Ra	7 Ac	62 (2.07)
Planorbidae	*Anisus* sp.	Aisp	1 Ra	0	0	0	0	1 (0.03)
	Bathyomphalus contortus	Bcot	4 Ra	0	0	0	0	4 (0.13)
	Gyraulus sp.	Gysp	10 Ac	0	0	0	0	10 (0.33)
	Hippeutis sp.	Hisp	19 Ra	1 Ra	1 Ra	0	0	21 (0.70)
	Planorbarius sp.	Plsp	21 Ac	0	0	0	0	21 (0.70)
	Planorbis sp.	Pasp	3 Ra	0	4 Ra	0	0	3 (0.10)
	Segmentina sp.	Sesp	3 Ra	1 Ra	0	0	0	4 (0.13)
Annélids								**271 (9.10)**
Glossiphoniidae	*Helobdella* sp.	Hbsp	0	2 Ra	1 Ra	218 Ac	0	221 (7.41)
Enchytraeidae	nd	Ench	0	2 Ra	48 Ra	0	0	50 (1.67)
Abundance			**173**	**1047**	**983**	**459**	**320**	**2982 (100)**

0 =absenttaxons.1.2…. = abundance of taxons, Ra =rare taxons, Ac = accessory taxons, Co = constant taxons, Re = regular taxons, Om = omnipresent taxons, * = taxons identified up to the rank of family or sub family & R. =Relative.

With regards to the frequency of occurrence of taxons, station P1 is dominated by *Amphios sp* (17.34%) followed by *Planorbarius* sp. (12.14%) and *Hippeutis* sp. (10.98%). In stations P2 and P3 located downstream from the steeping points of cassava tubers, the species *Sphaerium* sp. (62.37%) and *Chironomus* sp. (18.82%) dominated the community of station P2. Species present in station P3 were *Sphaerium* sp. (16.58%) , *Lococcoris* sp. (13.94%) and *Chironomus* sp. (9.36%). The family of Enchytraeidae was specific to stations P2 and P3. At station P4. Benthic Macroinvertebrates were dominated by *Helobdella* sp. (47.49%) and *Chironomus* sp. (28.54%). *Cardina africana* was the most abundant at station P5 with 64 individuals (20.01%) followed by *Ranatra linearis* (13.75%), *Lococcoris* sp. (13.75%) and *Chlorolestes fasciatus* (13.75%).

Moreover, spatial variation of Benthic Macroinvertebrates showed that the greatest average values of taxonomic richness were recorded in stations P2 (13.4± 21.6 taxa) and P3 (12.6± 19.9 taxa) located downstream from the steeping points of cassava tubers. At station P5, the only point which is not located directly after steeping point, the average taxonomic richness is 4.1±5.4 taxons, whereas the lowest taxonomic richness is observed at station P1 with 2.4±1.2 taxons located at the level of marshy area (**figure 2).** It is thus observed that the rhithron with stations situated downstream from the steeping points of cassava tubers is the most diversified bioecological zone of Pala. The U test of Mann Whitney showed significant differences (P<0.05) between the stations located downstream from the steeping points of cassava tubers (stations P2 and P3) from the other stations.

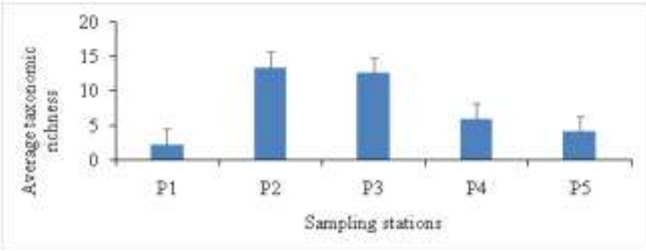

Figure 2: Spatial variation of the mean and standard deviation of taxonomic richness during the study period

Specific diversity and Equitability

The highest values of the index of diversity of Shannon and Weaver (3.06 bits/ind) and that of Equitability of Pielou (0.80) were recorded at station P3 located downstream from steeping points. These values were followed by those of station P5 (2.43 bits/ind and 0.78), not situated downstream from the steeping points of cassava tubers in the potamal. The lowest values were observed at station P1 (1.62 bits/ind and 0.54) at the marshy area. The values of Equitability index of Pielou were above 0.80 at all stations (**Table 3**).

Table 3: Descriptive parameters of the structure of Benthic Macroinvertebrates

Matrix	Sampling stations				
	P1	**P2**	**P3**	**P4**	**P5**
Total abundace (ind.)	173	1047	983	459	320
Relative abundance (%)	5.80	35.11	32.96	15.39	10.73
Taxonomic diversity	34	44	50	25	35
Shannon and Weaver index (bits/ind.)	1.62	1.82	3.06	1.54	2.43
Equitability index of Pielou	0.54	0.56	0.80	0.68	0.78
Water flow rate (m/s)	0.56	0.32	0.15	0.83	0.24

Index of Similarity of Sörensen

The values of the index of similarity of Sorensen are above 50 %, showing that specific diversity is similar in the different stations of river Pala (**Table 4).** Exception was observed for the communities of stations P1 and P4 which are not similar (S=40.44%).

Table 4*:* Matrix of the index of Similarity of Sörensen (%) between the communities of Benthic Macroinvertebrates of the different stations during the study period

	P1	P2	P3	P4
P2	**54.53**			
P3	**55.17**	**57.13**		
P4	40.44*	**53.73**	**53.73**	
P5	**51.35**	**51.28**	**55.28**	**51.28**

*Value (<50%) does not refer to the cases of resemblance

Relation between water quality and dynamics of abundances and the Canonical Analysis of Redundancy (CAR)

The correlation of Spearman showed links between environmental variables and dynamics of abundances of Benthic Macroinvertebrates in the different stations (Table 4). The chosen species for this correlation present each at least 1% of the total abundance. The test showed negative and significant correlations between Dissolved Oxygen contents and *Sphaerium* sp. (r = -0.413**), *Pseudamnicole* sp. (r = -0.591**) and *Helobdella* sp. (r = -0.311**). Moreover, positive and significant correlations were recorded between Dissolved Carbon Dioxide contents and *Chironomus* sp. (r = 0.351**) and *Loccocoris* sp. (r = -0.351**) and significant negative correlations between Dissolved Carbon Dioxide contents and *Gerris* sp. (r = -0.411**), *Epithecabimaculata sp.* (r = -0.496**) and *Chlorolestes fasciatus (*r = -0.304*). Oxydability showed positive and significant correlations on the one hand, with *Sphaerium* sp. (r = 0.418**) and *Pseudamnicole*sp. (r = 0.385**), *Hydrometra*sp. (r = 0.385**), *Orthretum*sp. (r = 0.447**), *Chlorolestesfasciatus (*r = 0.442**) and significantly negative correlation on the other hand, with *Gerris* sp. (r = -0.493**) and *Epithecabimaculata*sp. (r = -0.519**). Temperature showed positive and significant correlations with *Loccocoris* sp. (r = 0.397**) and significantly negative correlation with *Gerris* sp. (r = -0.429**), *Epithecabimaculata (*r = -0.517**) and *Chlorolestes fasciatus (*r = -0.275*).

The Canonical Analysis of Redundancy (CAR) showed that the environmental variables have some influence on the distribution of the 35 composite species made up essentially of accessory, constant, regular and omnipresent taxons of Benthic Macroinvertebrates in the different stations. Organization of data in the factorial designs 1 and 2 (F1xF2=63.7%) enable to clearly divide the communities into four groups (**Figure 3**). The group I discriminates in the positive X-coordinate *Naucoris* sp., *Epithecabimaculata*, *Chlorolestes fasciatus*, *Coenagrion* sp., *Loccocoris* sp., *Boyeria Irene*, *Orthretum* sp., *Noterus*sp., *Marstoniopsis* sp., *Bithynia*sp., *Radix* sp. and *Physa* sp.; species whichare influenced by pH and temperature. The group II discriminates in the positive X-coordinate and negative Y-coordinate the species *Caridina africana*, *Caridinaindistincta*, *Caridinanilotica*, *Nychia*sp., *Gerris* sp., *Hydrometra*sp., *Plealeachi. Ranatralinearis* and *Brachythemis leucosticta*. This second group is characterized by a well oxygenated medium. The group III discriminates in the negative X-coordinate and positive Y-coordinate the species *Amphios* sp., *Chironomus* sp., *Lethocerus* sp., *Cordulegaster* sp., *Stomatochlora pro partes*, *Cybister*sp. , *Sphaerium* sp., *Pseudamnicole* sp. and *Planorbarius* sp. The species found in this group are influenced by Dissolved Carbon Dioxide and Oxydability. The group IV shown in the negative X-coordinate and negative Y-coordinate *Hydroscapha*sp., *Hydrochara* sp., *Saldula* sp., *Valvata* sp. and *Helobdella* sp. which are distinguished by a medium influenced by Electric Conductivity, Total Dissolve Solidsand Alkalinity.

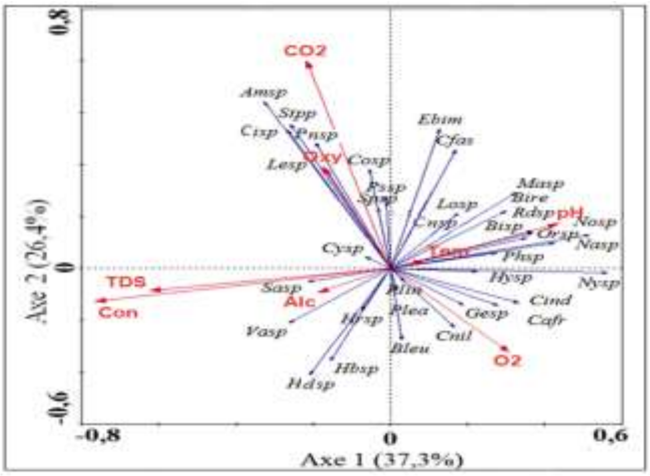

Figure 3: Canonic Analysis of Redondancy (CAD) of accessories, constant, regular and omnipresenttaxons of Benthic Macroinvertebrates of Pala and environmental variables

(Alc = Alcalinity, Con = Conductivity, O_2 = Dissolved oxygen, Oxy = Oxydability, TDS =Total Dissolve Solids, Tem = Temperature, CO_2= dissolved carbod dioxide gas). Acronyms of taxa Cafr = *Caridina africana*, Cind = *Caridina indistincta*, Cisp = *Chironomus* sp., Lesp = *Lethocerus* sp., Sasp = *Saldula* sp., Olsp = *Loccocoris* sp., Nasp = *Naucoris* sp., Nysp = *Nychia* sp., Gesp = *Gerris* sp., Hysp = *Hydrometra* sp., Plea = *Plea leachi*, Rlin = *Ranatra linearis*, Bleu = *Brachythemis leucosticta*, Ebim = *Epitheca bimaculata*,, Cesp = *Coenagrion* sp., Cosp = *Cordulegaster* sp., Stpp = *Stomatochlora pro parte*, Bire = *Boyeria irene*, Orsp = *Orthretum* sp., Cfas = *Chlorolestes fasciatus*, Amsp = *Amphios* sp., Cysp = *Cybister* sp., Hdsp = *Hydroscapha* sp., Hrsp = *Hydrochara* sp.,, Nosp = *Noterus* sp., Masp = *Marstoniopsis* sp., Bisp = *Bithynia* sp., Rdsp = *Radix* sp., Phsp = *Physa* sp., Spsp = *Sphaerium* sp., Pssp = *Pseudamnicole* sp., Pnsp = *Planorbarius* sp., Vasp = *Valvata* sp. and Hesp = *Helobdella* sp.)

4. Discussion

Physico-chemical characteristics of Pala

The low water temperature of Pala (22.5 – 27.8°C) could be due to the forest zone that covers most of the watershed area. The canopy produced by this forest prevents solar radiations which is the principal source of energy of the hydrosystems (Webb and Zhang, 2004). In the same line, Qiu (2013) showed that the rivers situated at the beginning of a watershed found in forest zones have low temperatures which vary very little. The temperature range obtained in the forest zone of this study is similar to that obtained by Diomande *et al.* (2009) in the river Agnéby in a forest zone (25.5 – 28.05°C) in Ivory Coast, Nyamsi Tchatcho et *al.* (2014) and Tchakonté (2016) in periurban streams in Yaoundé and Douala respectively in forest zones (22 – 26°C et 24 - 27°C) in Cameroon.

The water of Pala is slightly acidic with mean values of pH varying from 6.97±0.02 to 6.98±0.02. This could be attributed to the nature of the substrate and the effect of steeping of cassava tubers. Indeed, the soil of Bangui and its surroundings is in majority ferralitic and is characterized by an intensive weathering alteration of primary minerals (Doyémet, 2006). These observations are in line with the suggestions of Nola *et al.* (1999) who suggested that the pH of water is tributary to the layers of the ground crossed during percolation.

Low values of Electric Conductivity and Total Dissolved Solids were observed in stations P2 and P3 located downstream from the steeping points of cassava tubers. These low values could be explained by the steeping of cassava tubers which could have a reducing effect on the mineralization of organic matter. High values of saturated Dissolved Oxygen (> 71.4%) observed in stations P1, P4 and P5 could reflect good water content in Dissolved Oxygen according to the classification of Nisbet & Verneaux (1970). The satisfactory contents of Dissolved Oxygen in water could be explained by the high photosynthetic activity of aquatic plants and the dissolution of atmospheric oxygen of these natural environments in water (Müller & Weise, 1987; Fernandes et *al.*, 2014). Also, the mean rate of saturation Dissolved Oxygen less than 70% in stations P2 and P3 located downstream from the steeping points of cassava tubers shows extreme doubtful situation of water (Nisbet & Verneaux.1970; Onana *et al.*, 2016), probably due to the steeping effect of cassava tubers. Indeed, these low mean values of the percentages of oxygen in stations P2 and P3 could be, on the one hand due to fermentation during softening of cassava tubers, thus Louembé et al. (2002) showed a reduction in Dissolved Oxygen content after three days of steeping; and on the other hand due to significant degradation of cassava tubers peelings abandoned in the bottom of water, leading to dissolved oxygen consumption during oxidation process by micro-organisms. The mean values of the seven physico-chemical parameters measured (Temperature, pH, percentage of Dissolved Oxygen, Electric Conductivity, Total Dissolved Solids, Alkalinity, Dissolved Carbon Dioxide and Oxydability) shows in accordance with the evaluation norms of water status proposed by Nisbet & Verneaux. (1970) and WHO (2011), that the water has satisfactory to good status in the stations which are not located directly downstream from the steeping of cassava.

Benthic Macroinvertebrates Fauna

The total taxonomic richness of Benthic Macroinvertebrates observed in the river Pala is low compared to the results obtained by FotoMenbohan *et al.* (2012; 2013) and Tchakonté (2016) in urban and Periurban Rivers of Douala and Yaounde in Cameroon. This taxonomic richness is higher than that observed in three hydrosystems of Kinshasa (Kamb Tshijik *et al.*, 2015) and that of Soudano-saharian zone in the North region of Cameroon (Madomguia *et al.*, 2016). This could be due to the different environmental conditions and to the nature of different substrates, thus lotic hydrosystems have much physical diversity at the level of geographical areas same as from upstream towards the downstream (Haouchine, 2011). In this line, Illies & Botosaneanu (1963) showed that local factors (flow, width of the bed, flow rate, etc.) which are linked to the assembly of river shapes of channelequally influence Benthic Macroinvertebrates communities. The composition of benthic macrofauna observed during this study is typical to African fresh waters (Durand & Lévêque, 1981) and corroborates with the results obtained by Diomandé *et al.* (2009) in Ivory Coast, FotoMenbohan *et al.* (2010) and Tchakonté (2016) in Cameroon. Sanogo *et al.* (2014) in Burkina Faso and Kamb Tshijik et *al.* *(*2015) in the Democratic Republic of Congo. The predominance of Arthropods (54 taxons out of 79) on the other taxonomic groups and thepredominance of insects in terms of taxonomic richness (50 taxons) confirm their cosmopolitanismand thus their aptitude to colonize heterogeneous ecological niches (Monique, 1987; Caryou *et al.* .2000; Tchakonté. 2016). From the spatial point of view, the station at the marshy area (station P 1) is the least abundant station and less equilibrated (Index of Equitability of Pielou= 0.54). Taxonomic diversity is made up of insects, Bivalves and Gastropods with the order of Basommatophora representing up to 28.57% of the taxonomic richness.

This strong diversity of Basommatophora which are considered as polluo-resistant organisms (Mouthon, 2001) could reflect a medium of poor ecological quality. In fact, stations P2 and P3, located downstream from the steeping points of cassava tubers have high taxonomic richness and high abundances with the rate of taxonseach other similarity up to 57.13%. Station P3 is more diversified compared to station P2due to high abundance of *Chironomus*sp. and *Sphaerium* sp. at station P2. Moreover, taxons of these stations are in majority made up of organisms considered as polluo-resistant with high abundances of organism such as *Chironomus*sp. and *Sphaerium*sp. Which belong respectively to the families of Chironomidae and Sphaeridae; *Physa*sp., *Hippeutis*sp. and *Radix*sp. of the Basommatophora order; Hydrobiidae, Valvatidae and Oligochaeta (Hilsenhoff, 1988; Armitage *et al.*, 1994; Mouthon, 2001; Bode *et al.*1996, 2002; Moisan & Pelletier, 2013; Onana, 2016; Tchakonté, 2016). These results could be linked to the steeping of cassava tubers which could cause a deterioration of water quality downstream from their production points, favoring thus the colonization of many polluo-resistant taxons and might lead to the disappearance of polluo-sensitive taxons.

Station P4 is the least in terms of taxonomic richness. This may be explained by high flow rate of water at the level of this station which could have a negative impact for the colonization of many taxons. At the level of this station, the presence of *Chironomus* sp., *Valvata*sp., *Radis* sp. and *Helobdella*sp. groups of polluo-resistant organisms (Hilsenhoff, 1988; Mouthon, 2001; Bode *et al.*, 1996; Bode *et al.*2002; Moisan & Pelletier, 2013 and Onana, 2016), might equally explain poor ecological waterquality and could be attributed to the steeping effect from upstream from station P3. On the other hand, the structure of Benthic Macroinvertebrates at the level of station P5 which is not directly located downstream from the steeping points of cassava tubers showed a taxonomic diversity with the predominance of Arthropods. The index of Shannon and Weaver (4.03 bits/ind) and that of equitability of Pielou (0.79) reflect a more diversified community with equal repartition of taxons. The taxonomic richness of insects (71.05%) groups of organisms which disappear during the disturbance of water quality, with that of the species *CaridinaAfricana*, *Caridina indistinca* and *Caridinanilotica* of the order of Decapoda belonging to polluo-sensitive groups (Tachet *et al.*2010**,** Tchakonté et al., 2014 and Nyamsi Tchatcho et *al.*, 2014) could indicate the water has good ecological quality at the level of this station. This could be confirmed by the percentage of Dissolved Oxygen higher than 80% (Nisbet & Verneaux, 1970) and might be attributed to good auto purification capacity of streams in forest areas (Charvet, 2010).

The Canonical Analysis of Redundancy showed that the benthic communities are influenced by environmental variables in general. Dissolved Carbon Dioxide, Oxydability, Electric Conductivity, Total Dissolved Solids and Alkalinity influence taxons situated at downstream from the steeping points of cassava tubers, whereas Temperature, pH, the Dissolved Oxygen contents influence polluo-sensitive taxons present at station P5 which is not located downstream from the steeping points of cassava tubers at the level of the potamon (water with oligotrophic quality).

5. Conclusion

The physico-chemical analyses carried out on the Pala watershed showed that this water is of satisfactory to good ecological quality in the stations which do not have direct impact of the steeping of cassava tubers and indicate an eutrophication in the medium situated downstream from the steeping points of cassava tubers. This study also equally permitted to make the first inventory of Benthic Macroinvertebrates in the Central Africa Republic (CAR) which corresponds typically to the structure of these communities in fresh waters of Africa and characterized by a predominance of Arthropods. The obtained result clearly showed the peculiarity of the stations situated directly downstream from the steeping points of cassava tubers and characterized by high abundance of polluo-resistant species. Station P5 which is further from the steeping points of cassava tubers at the potamal level is characterized by the presence of polluo-sensitive species. The environmental parameters measured during this study influenced the dynamics of Benthic Macroinvertebrates.

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