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Diversity and seasonal variation of zooplankton of Lake Hlan, Republic of Bénin (West Africa)

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ABSTRACT

Objective: This study is the first assessment of zooplankton community of the Lake Hlan. It aims to assess zooplankton diversity through hydrological season.

Methods and Results: It was carried out from May to December 2012. Monthly plankton harvesting were performed, using plankton net of 30-µm mesh. Three vertical samplings through the Lake body depth were done at each station and mixed to have a composite sample. Environmental parameters were also assessed at the same time. The zooplankton diversity founded was composed of 45 species (33 rotifers, 6 cladocera and 6 copepods). The community was highly diversified and characteristic of balanced ecosystem. The Shannon diversity index values were ranged between 4.4 bit.ind^{-1} and 5.1 bit.ind^{-1}. The taxonomic composition and the species abundance are affected by the flood coming, when the upstream station is different from the two other at the biological level.

Conclusion: The zooplankton community of Lake Hlan has low specific richness, but has very good diversity index across hydrological seasons. Its ecosystem is then lowly affected by anthropological factors. The Lake Hlan currently continues to be a reference ecosystem in ecological status evaluation in Benin republic, since its localization has low accessibility.

Keywords: Biodiversity; Community structure; Hydrological season; Zooplankton

Diversité et variation saisonnière du zooplancton du lac Hlan, République du Bénin

RÉSUMÉ

Objectif: Cette étude est la première évaluation de la communauté zooplanctonique du lac Hlan. Il vise à évaluer la diversité du zooplancton au travers des saisons hydrologiques.

Méthodes et résultats: L'étude a été réalisée de Mai à Décembre 2012. Le plancton a été mensuellement échantillonné sur trois stations représentants le plan horizontal du lac. Un filet à plancton conique de 30 µm de vide de maille a été utilisé. Un échantillonnage vertical sur toute la colonne du plan d'eau a été réalisé à chaque station. Les paramètres environnementaux ont également relevés. Un total de 45 espèces de zooplancton était identifié (33 rotifères, 6 cladocères et 6 copépodes). La communauté était très bien diversifiée

et caractéristique d'écosystème équilibré. La valeur de l'indice de Shannon a varié entre 4,4 $bit.ind^{-1}$ et 5,1 $bit.ind^{-1}$. La composition taxinomique et l'abondance des espèces ont été affectées par la venue de la crue, alors que la station en amont était différente des deux autres au niveau biologique.
Conclusion: La communauté zooplanctonique du lac Hlan a une faible richesse spécifique, mais a un bon indice de diversité à travers les saisons hydrologiques. L'écosystème est alors faiblement affecté par des facteurs anthropologiques. Le lac Hlan continue actuellement d'être un écosystème de référence dans l'évaluation de l'état écologique en république du Bénin, sa localisation étant faiblement accessible.
Mots-clés: Biodiversité; Saison hydrologique; Structure d'assemblage; zooplancton

INTRODUCTION

The ecological state assessment of an aquatic system, needs prior knowledge on it biodiversity at different level of food web. Plankton communities are excellent indicators of the ecological state as well as the pollution state of an aquatic area. Several studies worldwide have used these communities for environmental assessment (Cottenie *et al*., 2001; Barinova *et al*., 2006; Morgado *et al*., 2007; Barinova *et al*., 2010; Barinova *et al*., 2011). They give a rapid knowledge as well, as they are close to the basis of the food web. In Benin continental waters, the studies on plankton communities are very rare, limiting the efficiency of aquatic environment management process. The Lake Hlan is a small permanent flood Lake with an ecosystem lowly affected by anthropological factors. The African environment, currently being under many stressors, searching for reference workplaces (not polluted or very low affected), must begin with an assessment of the biodiversity of the available systems. Thus, the Lake Hlan is now under study of this issue, some studies have started to assess it itchyological state (as Montchowui *et al*., 2008). However, any knowledge does not exist on the diversity of the zooplankton community. This study aims to give a first knowledge on zooplankton of the Lake Hlan, to provide more data available for future assessment of it quality at ecological health level. It assessed the zooplankton diversity and provided information on the ecological state, prior to a complete assessment of the issue.

MATERIALS AND METHOD

Study area and sampling site: The Lake Hlan is located at Toffo town in the south of Benin republic. It is a widening of the Hlan River at Kpomè. It is situated between 6°56.88' North latitude and 2°19.48' longitude East. Its area covers 165 ha. During floods, its water is influenced by that of the rivers Samion, Da, Hoho and Hlan. Those rivers flow into the Lake starting from the swamp of Adogbé and Hon village. Two other great Rivers influence the Lake during flood events; these are Zou and Ouémé Rivers respectively through Zounga and Agbagbé tributary. Three stations (Figure 1) with different levels of anthropogenic activities and composed different habitats were chosen as representative of the water map for sampling plankton. So from upstream to downstream, the sampling stations were: Houvènou (06°57'49.6" N, 002°19'04.4" E, latitude 53 m), Awayamey (06°56'29.2" N,002°19'57.4" E, latitude 25 m) and Dezinmey (06°55'57.3' N, 002°20'17.3" E, latitude 35 m).

Zooplankton harvesting: Zooplankton was harvested according to the hydrological seasons of Benin Republic. It was carried out from May to December in the year 2012. The low water season was represented by May to July, while August to November was the period of flood. The month of December was the period just after the flood (transition time). All samples were collected by using plankton net of 30 µm mesh. A composite sample of three vertical sampling (full depth) was taken monthly at each station. Samples were then immediately preserved with formaldehyde at final concentration of 5%. Environmental parameters include: Conductivity, Total Dissolved Solid (TDS) and pH were measured with a Hanna multi-parameter (HI991300) probe. Dissolved oxygen, and temperature were measured a Voltcraf oxymeter (DO-100) probe. The Secchi depth and Body depth of the Lake were also recorded using a Secchi disc (30 cm of diameter) and a weighted rope respectively.

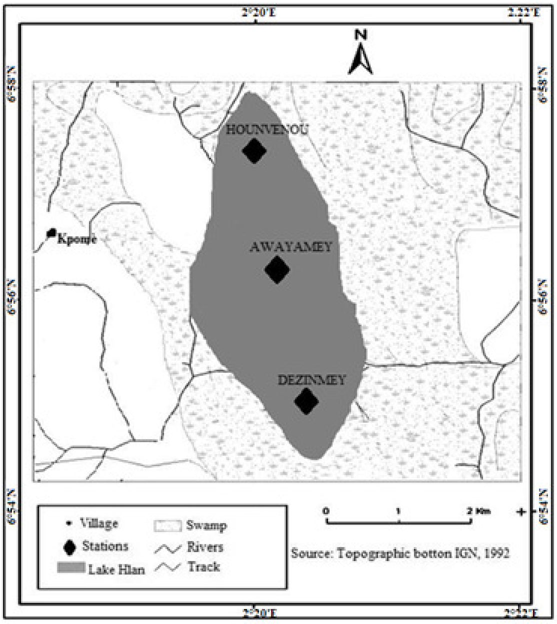

Figure 1: Geographical map of Lake Hlan and sampling stations.

Laboratory procedure: Samples were treated according to Houssou *et al* (2015). They were all concentrated to the same volume of 100 ml. Then the species were identified under photonic microscope (OLYMPUS B102). Systematic analysis was done with several guides as Beauchamp (1965), Smith and Fernando, (1978), Pourriot and Francez (1986), Shiel (1995), Lynne (2004) and LaMay *et al*. (2013). The abundance of each identified species was estimated after counting of individual using a type of Sedgewick rafter per chamber. Individuals were counted in all the compartments on the counting chamber. During the counting, only the individuals having a whole structure were considered. The species abundance in the Lake was calculated by using the following formula:

$$Dsp = \frac{100}{3n * Ld * S} * \sum_{i=1}^{n} Ni$$

Where Dsp is the Density of the species, n is the total number of observed aliquot of 1 ml each, Ld is the depth of the Lake, S is the surface of the plankton net and Ni is the total number per observed ml.

Data analysis: All biological data were transformed by using Log (x+1) according to Frontier (1973). The Principal Component Analysis (PCA) and the Cluster Analysis were used to discriminate the typology of distribution of founded zooplankton species. The monthly variations between data were tested with the one way ANOVA test, followed by the LSD of Ficher post-hoc test. PCA and ANOVA 1 tests were performed in Statistica v7 software, when the cluster analysis was done with PAST program. The biological diversity was also studied using the Shannon diversity index, calculated by:

$$H' = -\sum[(\frac{ni}{Ni}) * log2(\frac{ni}{Ni})]$$

Where H' is the index of diversity expressed in bit/individual, ni the number of the species, N is the total number of individual constituting for all the species, log2 is the logarithm on base 2.

RESULTS

Environmental parameters: The mean values of the recorded environment parameter are presented in table 1. No significant variation was observed through the study period, in terms of temperature, dissolved oxygen, pH, and secchi depth. The mean values respectively ranged between 27.2±0.3°C and 29.8±0.1°C; 3.5±0.2 mg.l^{-1} and 5.0±0.9 mg.l^{-1}; 6.3±0.2 and 7.0±0.2; 64.0±32.3 cm and 95.7±25.4 cm. Significant variations were then observed for the conductivity, the total dissolved solids, and the body depth of the Lake. The mean values were ranged between 71.7±6.7 µS.cm^{-1} and 92.5±6.8 µS.cm^{-1} (Conductivity), 37.2±4.2 ppm and 48.5±4.5 ppm (TDS) and between 2.4±0.4 m and 5.9±1.3 m (Lake Body depth).

Table 1: Seasonal change in recorded environmental parameters

	May	June	July	August	September	October	November	December
Temperature	29.8±0.1^{a}	27.8±0.8^{b}	27.3±0.5^{c}	27.2±0.3^{d}	27.4±0.2^{e}	28.1±0.2^{f}	28.1±0.4^{g}	28.6±0.01^{h}
Dissolved Oxygen (mg.l^{-1})	5.0±0.9^{a}	4.5±0.4^{b}	4.2±0.8^{c}	3.5±0.2^{d}	4.0±0.3^{e}	4.3±0.2^{f}	4.2 ±0.1^{g}	4.6±0.5^{h}
pH	6.9±0.1^{a}	6.8±0.2^{b}	6.8±0.1^{c}	6.3±0.2^{d}	6.4±0.3^{e}	6.9±0.2^{f}	6.8±0.4^{g}	7.0±0.2^{h}
TDS (ppm)	37.2±4.2^{a}	39.8±1.9^{b}	48.5±4.5$^{a\,b\,c}$	42.2±3.3$^{c\,d}$	45.0±2.7$^{a\,e}$	36.2±3.1$^{c\,d\,e\,f}$	42.3±0.8$^{c\,f\,g}$	46.3±1.9$^{a\,b\,f}$
Conductivity (µS.cm^{-1})	71.7±6.7^{a}	83.2±11.6^{b}	92.5±6.8$^{a\,c}$	82.0±6.0^{d}	87.0±5.5$^{a\,e}$	72.5±6.0$^{c\,e\,f}$	82.2±2.3^{g}	90.2±3.4$^{a\,f}$
Transparency (cm)	95.7±25.4^{a}	76.0±5.3^{b}	67.0±33.8^{c}	65.0±5.0^{d}	76.0±1.7^{e}	64.0±32.3^{f}	81.0±13.9^{g}	93.5±14.3^{h}
Depth (m)	2.4±0.4^{a}	2.6±0.2^{b}	3.0±0.4^{c}	3.9±0.5^{d}	5.9±1.3$^{a\,b\,c\,d\,e}$	4.3±0.4$^{a\,f}$	3.5±0.8^{e}	2.8±0.3^{e}

The values of the same line with one or several common letters as power are significantly different One way *ANOVA, Post-hoc: LSD of Fisher, p<0.05*

Checklist of zooplankton species: A total of 45 zooplankton species were identified (Table 2). The rotifers were mostly dominant with 33 species in 29 genera. They were followed by copepods and Cladocera, which both were constituted of 6 species, respectively ranged in 5 and 6 genera. Except *Brachionus patulus* and *Brachionus calyciflorus*, all species were found during the low water season. *Brachionus patulus* and *Brachionus calyciflorus* had appeared in the samples with flood coming, while *Platyias sp, Mytilina sp, Trichotria sp, Scaridium longicaudum, Diaphanosoma excisum* and *Leptodora kindtii* had disappeared. Any species has not presented a net dominance in term of percentage of dominance.

Table 2: Distribution of zooplankton species according to hydrologic seasons; the values in square bracket are the percentage of dominance (%).

Zooplankton	Hydrodynamic			
	Code	Low depth	Flood	After flood
ROTIFERA				
Filinia opoliensis Zacharias, 1898	R1	+ *(3.8)*	+ *(3.8)*	+ *(3.9)*
Hexarthra intermedia Wiszniewski, 1929	R2	+ *(0.2)*	+ *(0.8)*	+ *(0.7)*
Testudinella sp Bory de St. Vincent, 1826	R3	+ *(4.4)*	+ *(4.9)*	+ *(5.7)*
Ploesoma truncatum Levander, 1894	R4	+ *(1.9)*	+ *(3.7)*	+ *(4.6)*
Brachionus patulus Müller, 1786	R5	- *(0.0)*	- *(0.0)*	+ *(2.4)*
Brachionus falcatus Zacharias, 1898	R6	+ *(5.2)*	+ *(6.2)*	+ *(3.7)*
Brachionus angularis Gosse, 1851	R7	+ *(2.5)*	+ *(0.7)*	+ *(3.5)*
Brachionus plicatilis Muller,1786	R8	+ *(0.5)*	- *(0.0)*	+ *(0.7)*
Brachionus calyciflorus Pallas, 1766	R9	- *(0.0)*	+ *(0,4)*	- *(0.0)*
Brachionus dimidiatus Beauchamp, 1932	R10	+ *(3.4)*	+ *(3.6)*	+ *(3.9)*
Brachionus sp Pallas, 1766	R11	+ *(2.6)*	+ *(2.1)*	- *(0.0)*
Keratella cochlearis Gosse, 1851	R12	+ *(1.2)*	+ *(0.5)*	- *(0.0)*
Keratella quadrata Müller, 1786	R13	+ *(4.7)*	+ *(4.4)*	+ *(2.2)*
Keratella tropica Apstein, 1907	R14	+ *(3.0)*	+ *(2.7)*	- *(0.0)*
Anuraeopsis navicula Rousselet, 1911	R15	+ *(5.5)*	+ *(5.6)*	+ *(4.8)*
Notholca squamula Müller, 1786	R16	+ *(1.9)*	+ *(0.8)*	- *(0.0)*
Platyias sp Harring, 1913	R17	+ *(0.2)*	- *(0.0)*	+ *(0.8)*
Asplanchna brightwellii Gosse, 1850	R18	+ *(2.4)*	+ *(3.0)*	+ *(2.7)*
Asplanchna girodi de Guerne, 1888	R19	+ *(2.7)*	+ *(1.9)*	+ *(3.8)*
Asplanchna sp Gosse, 1850	R20	+ *(2.0)*	+ *(2.5)*	- *(0.0)*
Proales sp Gosse, 1886	R21	+ *(4.8)*	+ *(5.4)*	+ *(5.9)*
Cephalodella giba Ehrenberg, 1832	R22	+ *(3.5)*	+ *(3.8)*	+ *(3.8)*
Cephalodella sp Bory de St. Vincent, 1826	R23	+ *(2.5)*	+ *(1.1)*	+ *(2.3)*
Lecane sp Nitzsch, 1827	R24	+ *(3.1)*	+ *(4.0)*	+ *(2.9)*
Mytilina mucronata Müller, 1773	R25	+ *(1.2)*	+ *(0.9)*	- *(0.0)*
Mytilina sp Bory de St. Vincent, 1826	R26	+ *(1.0)*	- *(0.2)*	- *(0.0)*
Euchlanis dilatata Ehrenberg, 1832	R27	+ *(2.2)*	+ *(2.8)*	+ *(1.1)*
Lepadela patella Müller, 1786	R28	+ *(2.9)*	+ *(3.6)*	+ *(1.8)*
Colurella uncinata Müller, 1773	R29	+ *(1.6)*	+ *(1.1)*	+ *(0.7)*
Trichotria sp Bory de St. Vincent, 1827	R30	+ *(0.5)*	- *(0.0)*	- *(0.0)*
Philodina sp Balvay, 1996	R31	+ *(0.3)*	+ *(1.2)*	+ *(3.6)*
Polyarthra vulgaris Carlin, 1943	R32	+ *(3.9)*	+ *(4.4)*	+ *(4.5)*
Scaridium longicaudum Muller, 1786	R33	+ *(0.4)*	- *(0.0)*	+ *(0.9)*
COPEPODS				
Tropodiaptomus incognitus Dussart & Gras, 1966	COP1	+ *(3.5)*	+ *(3.9)*	+ *(4.5)*
Tropodiaptomus lateralis Kiefer, 1932	COP2	+ *(1.6)*	+ *(1.7)*	+ *(2.7)*
Afrocyclops gibsoni Brady, 1904	COP3	+ *(2.5)*	+ *(1.8)*	+ *(2.5)*
Ectocyclops hirsutus Kiefer, 1930	COP4	+ *(1.6)*	+ *(2.0)*	+ *(0.5)*

Mesocyclops sp Sars, 1914	COP5	+	*(1.9)*	+	*(2.2)*	+	*(3.8)*
Diacyclops bicuspidatus Claus, 1857	COP6	+	*(1.2)*	+	*(0.6)*	+	*(2.1)*
CLADOCERAN							
Moina sp Baird, 1850	CL1	+	*(3.5)*	+	*(4.4)*	+	*(4.0)*
Guernella sp Richard, 1892	CL2	+	*(2.4)*	+	*(1.7)*	+	*(3.0)*
Daphnia sp Müller, 1785	CL3	+	*(2.9)*	+	*(3.7)*	+	*(2.8)*
Diaphanosoma excisum Sars, 1885	CL4	+	*(0.4)*	+	*(0.3)*	-	*(0.0)*
Bosmina sp Baird, 1845	CL5	+	*(2.3)*	+	*(1.6)*	+	*(3.1)*
Leptodora kindtii Focke, 1844	CL6	+	*(0.2)*	+	*(1.6)*	-	*(0.0)*

+ Present; - Absent; Numeric italic scores in bracket: occurrence percentage (%)

Seasonal dynamic of zooplankton groups: The seasonal dynamic of found zooplankton groups is showed Figure 2. Throughout the study, Rotifers were largely dominant with high abundance during low water season and after the flood season. A significant variation was observed among sampling periods. The Copepods, Cladocera and Nauplii of Copepod were lowly abundant without significant change among seasons.

ANOVA one way; post-hoc: LSD of Fisher					
Rotifera	S	Ma, Ju, Jl ≠ Se, Oc, No	Ma, Jl ≠ Au	Au, Se, Oc, No ≠ Dec	*P<0.05*
Copepods	NS				*p>0.05*
Cladoceran	NS				*P>0.05*
Copepods nauplii	NS				*p>0.05*

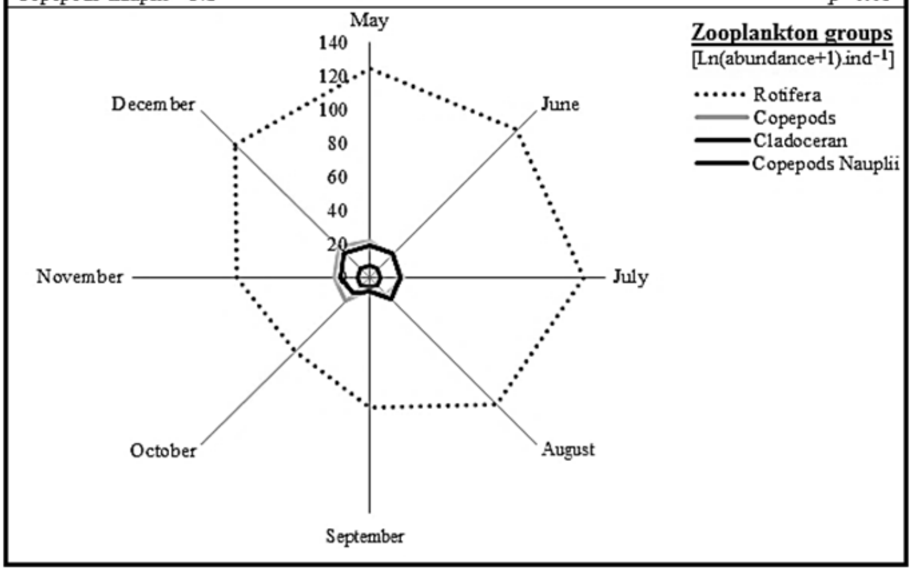

Figure 2: Monthly variation of zooplankton groups abundance. S: significant variation, NS: no significant variation, ≠: Different location symbol among months.

Monthly variation of zooplankton abundance and diversity index: The total zooplankton abundance and the Shannon diversity index are showed on figure 3. Zooplankton abundance had same profile with the Shannon diversity index. The high diversity and abundance was observed during low water season. H' is ranged between 4.4 bit.ind^{-1} and 5.1 bit.ind^{-1}. Significant variations were observed both in the total abundance and H' seasonality.

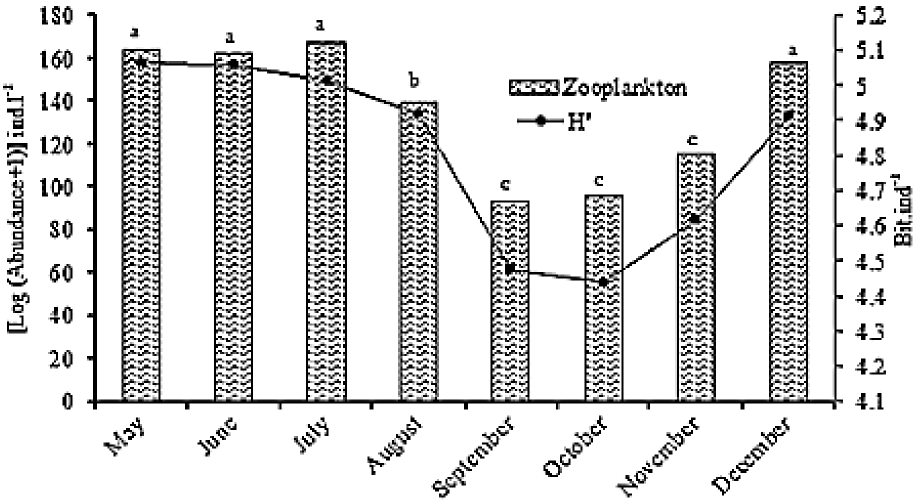

Figure 3: Compared variation of Shannon index (H') and total recorded zooplankton abundance. Histogram with different letter are significantly different (One way ANOVA, LSD post-hoc of Fisher, $p<0.05$)

Zooplanktonic typology: The zooplankton individuals, projected on factorial designs of Principal Components Analysis (PCA) are presented on figure 4. The first axis explains 72.39 % of the results and was composed by both low water season (May to July) and the flood season up to September (see annex). All this period was selected negatively. The second axis also negatively selected composed the flood period (October to November) and after flood period (December) (see annex). It explains 14.64% of the result. The rotifer species as *Testudinella* sp*, Brachionus falcatus, Keratella quadrata, Anuraeopsis navicula, Proales* sp*, Cephalodella giba and Polyarthra vulgaris*, the copepod *Tropodiaptomus incognitus* and the cladocera *Moina dubia* highly correlated with the low water and starting of flood, was opposed to the rotifer as *Brachionus patulus, Brachionus plicatilis, Brachionus calyciflorus, Platyias* sp*, Mytilina* sp*, Trichotria* sp and *Scaridium longicaudum* and the cladocera *Diaphanosoma excisum* and *Leptodora kindtii*. Regarding the second period (flood times and first month after flood), the rotifers *Hexarthra intermedia, Testudinella* sp*, Asplanchna girodi* and *Philodina* sp, the copepods *Tropodiaptomus lateralis*, *Afrocyclops gibsoni* and *Mesocyclops* sp and the cladocera *Guernella* sp highly selected, was opposed to *Brachionus* sp, *Keratella quadrata*, *Keratella tropica, Asplanchna* sp and *Euchlanis dilatata* (rotifers). It was observed that *Testudinella* sp and *Keratella quadrata* was both selected by the low water and flood time. But according to their quality of representation, both are badly represented during the flood season (see annex). The cluster analysis of zooplankton species is showed on figure 5.

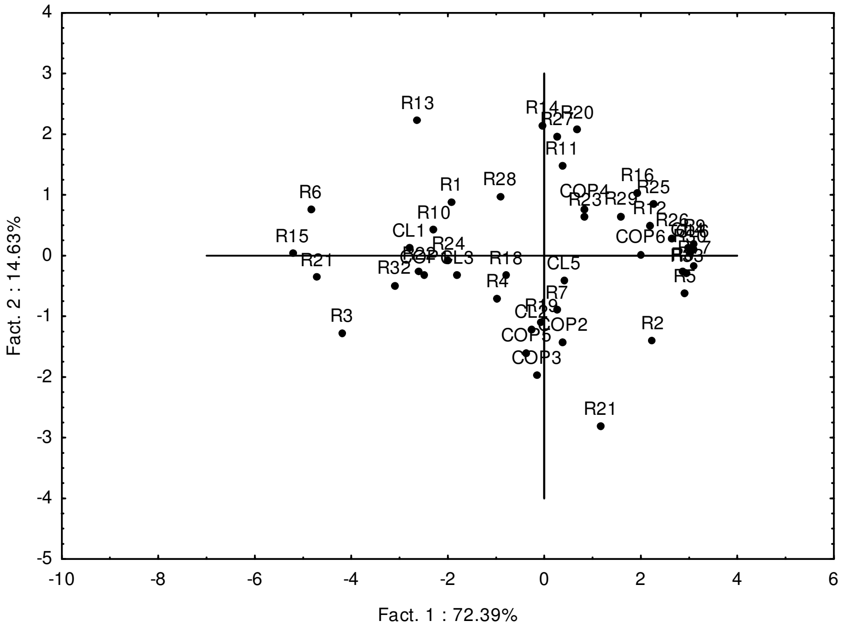

Figure 4: Principal component Analysis (PCA) of recorded zooplankton species.

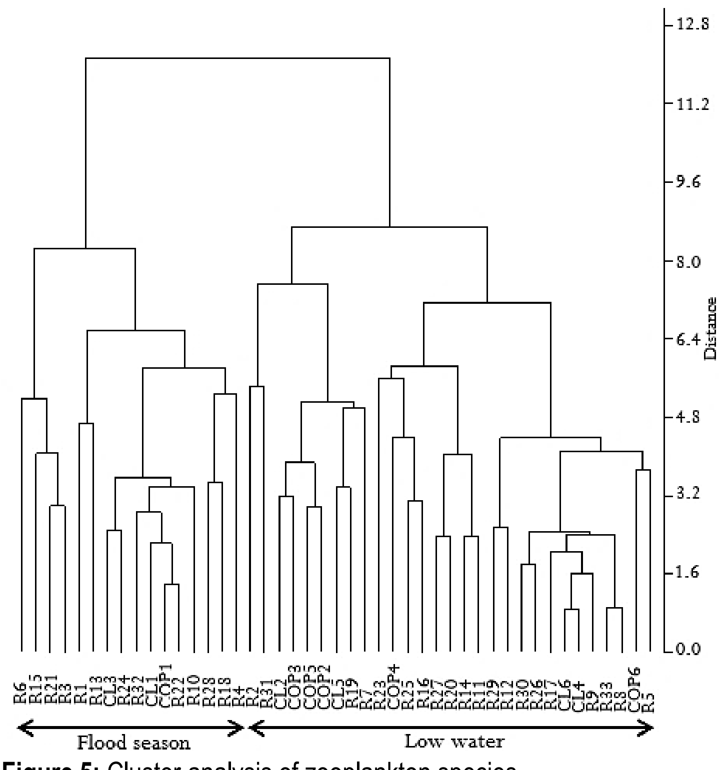

Figure 5: Cluster analysis of zooplankton species

Biological typology of sampling stations: The cluster classification of the sampling stations is represented on figure 6. Zooplankton abundance distribution classified the sampling sites in two groups. HOUVENOU is net different to AWAYAMEY and DEZINMEY. Zooplankton was more abundant in the last two stations.

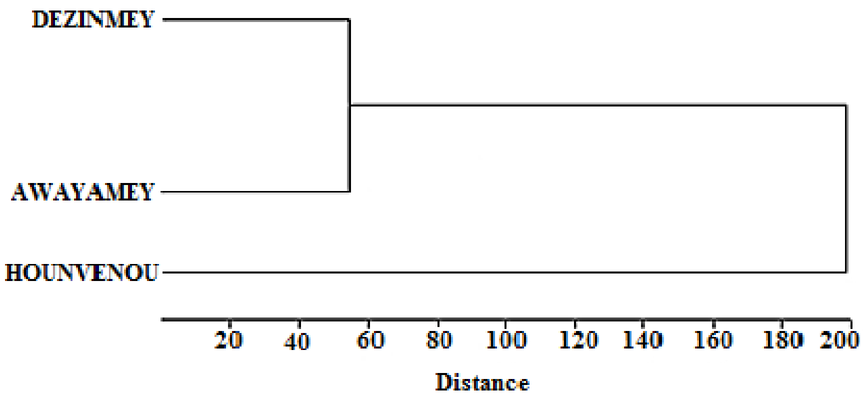

Figure 6: Cluster analysis of sampling stations (based on Euclidean distance measure for abundance of 45 zooplankton taxa).

DISCUSSION

The balance of natural ecosystems is dependent on its quality in terms of both biological component and physico-chemical parameters. These two factors are mutually dependents. The environmental descriptors are many; within them, temperature, conductivity, dissolved oxygen, total dissolved solids, secchi depth, the pH and the water body depth are largely use to have a first knowledge on the ecosystem quality (Bricha *et al.,* 2007; Ghazali et Zaid, 2013; N'Diaye *et al.,* 2013; Lagnika *et al.,* 2014; Abboudi *et al.,* 2014). The temperature recorded in this study, did not significantly vary during both low water flood season. The values were characteristic of tropical water environment. The temperature in aquatic systems, highly affects all biological process, as well as reproduction, growth and life duration (Fernandez de purelles *et al*., 2003; Cartes *et al*., 2007; Souissi *et al*., 2008). The values recorded are allowed for tropical aquatic life. The dissolved oxygen values recorded are also allowed for aquatic life (IBGE, 2005). The lowest values are caused by the resuspension of decaying matter during the flood coming. As the pH, the values are in the quality standards and are characteristic of water with optimal biological growth (IBGE, 2005). According to Dupont (2004), the first hazard occurs within 5.5 and 6.5, when the most sensitive species disappear. Regarding the conductivity of the water, the recorded values are in the recommended norm of surface waters (< 200 µS.cm^{-1}) (OBV, 2012). These values showed less impact of Human activities on the Lake. According to CREL (2009-2011), Human activities on surface water brought salts, which increase the conductivity more than 125 µS.cm^{-1}. As the conductivity, the TDS showed a low ionization of the water. The values were those of excellent quality of surface water. About the Secchi depth, the Lake Hlan had generally relatively low transparency (< 1 m). The herbal cover on the surface of the water regulates ingress of light. The lowest values during the flood season are due to supply of exogenous sediment conveyed by tributaries (Gonzàlez *et al*., 2004).

In several samples from the Lake Hlan during flood and recession seasons, 45 zooplankton taxa were recorded. This study is one of the first investigations of zooplankton community in Lakes of the Oueme Rivers' basin in Benin republic. The 45 recorded species are representative of the diversity during the two hydrological seasons, which season was composed here by 8 month. This diversity is more than that of Lake Azili (36 species, Houssou *et al*., 2015). The environment conditions in the Lake Hlan are then suitable to their distribution contrary to the Lake Azili which is influenced by anthropogenic factor (Houssou *et al*., 2015). Like Azili, the Lake Hlan presents a zooplankton diversity of tropical surface waters with the dominance of the rotifers group.

The Lake Hlan has low accessibility; limiting Human activities to fisheries and some rare nearness agricultural area. So, the organic matters are present in minimal amount. That could justify a low specific richness of the zooplankton community, even ichtyofauna (37 fish species, Montchowui *et al.,* 2008). This community is nevertheless dominated by rotifer group as knew for most of surface freshwater ecosystems in tropical area.

The classification of the ecological state based on the Simboura and Zenetos (2002) scale, using Shannon diversity index of zooplankton showed that the Lake Hlan has a good ecological state. The species are much diversified through the study period. During the low water season, according to these criteria, the Lake Hlan had the characteristic of a reference site; while during the flood season, it reached a characteristic of transition (good ecological state) to the polluted condition. Soil leaching at high water period so contributed to pollution of the Lake. The typology of zooplankton species had showed that the diversity is highly influenced by flood coming. All found species are endemic to the Lake, except *Brachionus patulus* which appear only during flood events. The abundance of all other species is then affected by the exogenous supply from the tributaries (like observed in Azili, Houssou *et al.*, 2015). Regarding the spatial typology, the three sampling sites were grouped in two, isolating HOUNVENOU. This station is a particular biotope on the Lake with the characteristic of swamp. It has high herbal cover. All found species have presented a low abundance in comparison to the two other stations.

CONCLUSION

The Lake Hlan at the current knowledge state of it zooplanktonic biodiversity, has 45 species. Its ecosystem is influenced by the incident of flood, affecting the diversity of the zooplanktonic communities. Based on this diversity and the environmental parameters measured, the ecosystem of Lake Hlan can be used as reference in ecological state evaluation in Benin republic. A complementary study is then needed on its quality to confirm this issue. During the low water season, this Lake had generally a very good ecological state, while during the flood its state is moderately good.

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Annex: Zooplankton PCA values

Factorial coordinates of species			
	Fact. 1	**Fact. 2**	**Fact. 3**
R1	-1.92953	0.88261	1.08946
R2	2.24250	-1.39469	-1.03331
R3	-4.19823	-1.28362	0.02370
R4	-0.96546	-0.70524	-0.44523
R5	2.91634	-0.62723	-0.05538
R6	-4.84661	0.76089	-0.67128
R7	0.26144	-0.90105	1.28672
R8	2.86750	-0.26642	0.36185
R9	3.11074	0.19554	-0.60869
R10	-2.28547	0.42476	-0.29944

R11	0.36531	1.48040	-0.00182
R12	2.18302	0.49594	0.38522
R13	-2.62571	2.22518	0.73260
R14	-0.03932	2.15082	0.27819
R15	-5.22324	0.03419	0.41723
R16	1.93051	1.03917	0.11639
R17	3.11016	-0.15773	-0.19089
R18	-0.79478	-0.32779	-0.23671
R19	-0.05995	-1.11120	1.61936
R20	0.68496	2.07053	-0.67754
R21	-4.69880	-0.36176	0.33780
R22	-2.59052	-0.25875	-0.28555
R23	0.84851	0.63442	0.99567
R24	-1.98333	-0.08763	-0.61263
R25	2.26342	0.84440	-0.31708
R26	2.65537	0.29623	0.24864
R27	0.26483	1.95827	-0.54809
R28	-0.91864	0.97895	-0.11649
R29	1.59115	0.65447	0.44771
R30	3.02237	0.03250	0.07093
R31	1.16827	-2.80972	-0.76588
R32	-3.10667	-0.49032	-0.02935
R33	2.95806	-0.29031	0.16939
COP1	-2.47624	-0.30923	-0.55414
COP2	0.38944	-1.42845	-0.09906
COP3	-0.15643	-1.96701	0.56201
COP4	0.83969	0.77435	-1.08838
COP5	-0.36872	-1.60355	-0.27643
COP6	2.00051	0.02238	0.38628
CL1	-2.79730	0.12504	-0.53251
CL2	-0.26438	-1.21162	0.31052
CL3	-1.80201	-0.32139	-0.92175
CL4	2.97325	0.14071	-0.19454
CL5	0.40797	-0.41725	1.05400
CL6	3.07603	0.11023	-0.33153

Contributions of species			
	Fact. 1	**Fact. 2**	**Fact. 3**
R1	1.46116	1.51223	7.12033
R2	1.97362	3.77601	6.40529
R3	6.91720	3.19853	0.00337
R4	0.36582	0.96551	1.18921
R5	3.33791	0.76371	0.01840
R6	9.21878	1.12389	2.70324
R7	0.02683	1.57606	9.93235
R8	3.22704	0.13778	0.78548
R9	3.79772	0.07422	2.22267
R10	2.04998	0.35025	0.53789
R11	0.05237	4.25436	0.00002

R12	1.87031	0.47746	0.89024
R13	2.70578	9.61191	3.21970
R14	0.00061	8.98020	0.46425
R15	10.70722	0.00227	1.04432
R16	1.46265	2.09630	0.08127
R17	3.79632	0.04830	0.21859
R18	0.24791	0.20858	0.33613
R19	0.00141	2.39695	15.73153
R20	0.18413	8.32226	2.75394
R21	8.66504	0.25406	0.68456
R22	2.63372	0.12997	0.48914
R23	0.28256	0.78132	5.94714
R24	1.54379	0.01491	2.25155
R25	2.01060	1.38412	0.60313
R26	2.76724	0.17035	0.37088
R27	0.02752	7.44426	1.80214
R28	0.33120	1.86037	0.08140
R29	0.99361	0.83150	1.20250
R30	3.58503	0.00205	0.03018
R31	0.53565	15.32517	3.51890
R32	3.78781	0.46670	0.00517
R33	3.43408	0.16361	0.17212
COP1	2.40649	0.18563	1.84215
COP2	0.05952	3.96104	0.05887
COP3	0.00960	7.51089	1.89482
COP4	0.27671	1.16401	7.10623
COP5	0.05336	4.99166	0.45840
COP6	1.57064	0.00097	0.89514
CL1	3.07097	0.03035	1.70110
CL2	0.02743	2.84978	0.57845
CL3	1.27442	0.20052	5.09697
CL4	3.46944	0.03843	0.22704
CL5	0.06532	0.33797	6.66447
CL6	3.71347	0.02359	0.65935

Quality of species representation on factorial axis			
	Fact. 1	**Fact. 2**	**Fact. 3**
R1	0.558700	0.116901	0.178113
R2	0.589166	0.227891	0.125092
R3	0.913906	0.085436	0.000029
R4	0.185241	0.098844	0.039396
R5	0.845566	0.039113	0.000305
R6	0.939693	0.023161	0.018027
R7	0.017894	0.212549	0.433446
R8	0.915236	0.007900	0.014574
R9	0.930935	0.003678	0.035644
R10	0.761714	0.026311	0.013075
R11	0.044271	0.727035	0.000001
R12	0.816157	0.042122	0.025415

R13	0.553998	0.397873	0.043127
R14	0.000300	0.897344	0.015011
R15	0.965231	0.000041	0.006159
R16	0.505745	0.146542	0.001838
R17	0.977136	0.002513	0.003681
R18	0.649762	0.110526	0.057635
R19	0.000755	0.259446	0.551004
R20	0.087559	0.800071	0.085672
R21	0.977224	0.005793	0.005051
R22	0.912219	0.009101	0.011084
R23	0.239532	0.133907	0.329821
R24	0.875962	0.001710	0.083579
R25	0.783029	0.108979	0.015367
R26	0.928711	0.011558	0.008143
R27	0.014816	0.810121	0.063462
R28	0.343407	0.389978	0.005522
R29	0.651501	0.110225	0.051582
R30	0.974976	0.000113	0.000537
R21	0.137198	0.793576	0.058964
R32	0.966321	0.024071	0.000086
R33	0.951730	0.009167	0.003121
COP1	0.897910	0.014003	0.044967
COP2	0.055393	0.745239	0.003584
COP3	0.004312	0.681776	0.055656
COP4	0.219135	0.186361	0.368158
COP5	0.043432	0.821456	0.024411
COP6	0.832548	0.000104	0.031041
CL1	0.929432	0.001857	0.033681
CL2	0.031538	0.662394	0.043508
CL3	0.691319	0.021991	0.180881
CL4	0.969001	0.002170	0.004148
CL5	0.069107	0.072287	0.461264
CL6	0.957920	0.001230	0.011127

Factorial coordinates of sampling periods

	Fact. 1	Fact. 2	Fact. 3
May	-0.871941	-0.049873	0.395414
June	-0.893313	0.255198	0.179515
July	-0.899502	0.356952	-0.007934
August	-0.895139	0.355241	-0.151728
September	-0.868868	0.373231	-0.213313
October	-0.774254	-0.450966	-0.303723
November	-0.784473	-0.538107	-0.081261
December	-0.807767	-0.466163	0.151107

Contributions of the sampling periods

	Fact. 1	Fact. 2	Fact. 3
May	0.131288	0.002125	0.412704
June	0.137803	0.055627	0.085062
July	0.139719	0.108830	0.000166
August	0.138366	0.107790	0.060766
September	0.130364	0.118984	0.120107
October	0.103518	0.173707	0.243495
November	0.106269	0.247325	0.017430
December	0.112673	0.185612	0.060270

Quality of sampling periods representation on factorial axis			
	With F1	**With F2**	**With F3**
May	0.760281	0.762768	0.919121
June	0.798009	0.863135	0.895361
July	0.809103	0.936518	0.936581
August	0.801274	0.927470	0.950492
September	0.754931	0.894233	0.939735
October	0.599470	0.802840	0.895087
November	0.615398	0.904958	0.911561
December	0.652487	0.869795	0.892628