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Structure of zooplanktonic communities in Lakes Ossa and Mwembe at Dizangue (Cameroun, Central africa)

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Key words: Physicochemestry, Zooplankton, Community structure, Ossa Lake complex, Cameroon

Abstract

The structural composition of zooplankton of two lakes (Ossa and Mwembe) of the Ossa complex, a UNESCO' protected site located in Dizangue, Cameroon, was studied. Monthly sampling was conducted from September 2009 to February 2010. The physicochemical characteristics of the water lakes, the characteristics of the area around the lakes were documented and their influence on zooplankton communities assessed. The two lakes were closes in accord to their physicochemical characteristics: temperature (27.70±0.87°C and 28.85±0.66°C), pH (6.57±0.06 and 6.52±0.07), Suspended Solids (7.00±2.39mg.L^{-1} and 10.66±3.12mg.L^{-1}), electric conductivity (28.91±5.25µS.cm^{-1} and 28.18±7.33µS.cm^{-1}). In fact, no significant difference was found, compare to each other. Thirty seven and 41 species of zooplankton were recorded in the Ossa and Mwembe lakes respectively. The seasonal variation appeared to be the fundamental factor that regulates the presence and abundance of these species in the lakes. *Lecane* sp., *Polyarthra vulgaris*, *Epiphanes clavulata, Lepadella* sp., *Brachionus dimidiatus* and *Plationus patulus* were mostly abundant during the dry season whereas *Bosminopsis macaguensis*, *Bosminopsis deitersi*, *Keratella tecta*, *Hexarthra mira* and *Lecane bulla* were abundant during the rainy season. When taking into consideration the contents of phosphorus and Secchi disc disappearance, these lakes were found to be eutrophic. In addition, the Sanaga River brings sporadic zooplankton species such as *Scaphaloberis kingi* and *Streblocerus* sp., contributing to the accumulation of crustacean eggs on the river banks during floods, and therefore to increase the density of organisms. In conclusion, the effluents from SAFACAM Company increase some physicochemical parameters values such as, electric conductivity, dissolved carbon dioxide and pH.

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Introduction

Zooplankton is obviously considered as a major component of aquatic ecosystem. It transfers more than 60% of the lake primary production to alevin fishes (Habermann, 1998), thus justifying the fact that fish production does not just depend on physical conditions (day light, temperature) but also on biological factors (nutrients). Zooplankton is also consider being good bio-indicators (Angeli, 1980; Pourriot *et al.*, 1982; Pinel-Alloul *et al.*, 1990; Moss, 1998; Taylor, 2002; Patoine *et al.*, 2002; Holyńska *et al.*, 2003) because they are highly linked with their media and are equally very sensitive to changes in the environmental conditions. I`ndeed, in reaction to modifications of characteristics of their biotope, zooplankton organisms can change in size, abundance, biomass and community structure. The zooplankton can even disappear from the medium due to variations in biotope characteristics and nutrients availability.

Many studies have revealed the important role of several factors on zooplankton community structure. Besides pressure of predation carried on by some zooplanktonic organisms and by fishes, several environmental factors govern the structure of zooplankton in hydrosystems. These include: temperature (Green, 1981), eutrophication (Sprules and Munawar, 1986), acidity of the medium (Schindler, 1990) and chemical contamination (Havens and Hanazato, 1993).

The study of the structural composition of zooplankton is necessary for a pertinent understanding of the hydrosystem. It brings important news' for the elaboration of efficient strategy of their management. Currently, numerous studies have been conducted in Europe and America, but data from Africa in general and Cameroon in particular are scarce (Gopal and Wetzel, 1995; Johnson *et al.*, 1999). If in Cameroon, some data such as those of Gras and Dussart (1966) and Pourriot (1968) from the Chad Lake, Green (1972, 1973, 1977) from the crater lakes of West Cameroon, and more recently Zébazé Togouet (2000), Zébazé Togourt *et al.* (2005), Nziéleu Tchapgnouo (2006) and Zébazé Togouet (2008) in lakes and ponds in Yaoundé, Nziéleu Tchapgnouo *et al.* (2012, 2016) at Ossa Lake complex exist, much is yet to be done.

Most of these studies refer to the zooplankton and crustacean biodiversity, the polluted aspect of Yaoundé hydrosystem and the polymorphism of rotifers. The structure of the zooplankton is still to be done in this protected UNESCO hydrosystem. In fact, since the work of Kling (1988) and of Nziéleu Tchapgnouo *et al.* (2012, 2016) on the zooplankton of the Ossa Lake complex, no other research work has been carried out in this environment which is exposed to multiple anthropogenic activities. Ossa Lake complex harbors animal species such as soft-shell tortoise, dwarfish crocodile, python, many rodents, but especially west-african manatee "*Trichecus senegalensis*" (Johnson *et al.*, 1999). To keep this ecosystem healthy, it is necessary to understand how it functions entirely, hence this research aim to assess the environmental variables which justified the variation observed in the zooplankton community of Ossa and Mwembe Lakes.

Material and methods

Study area

The Ossa Lake Complex basin is located at about 40 km to the east of the Atlantic coast of the Gulf of Guinea (Fig. 1). It lies between latitude 3°45'42 " and 3°53' north and longitude 9°9' and 10°4'12 " east (Wirrmann and Elouga, 1998). The complex is made of two main basins; the Ossa basin (3103 000 m^2) and the Mevia basin (676 000 m^2) (Wirrmann, 1992). A third less important branch of the complex, the Lake Mwembe is located in Dizangue town. These three lakes submerge at the bottom of an ancient deep valley which was previously blocked by the alluvium of the Sanaga River, probably at the end of the latest glacial period. Located at an altitude of 8 m above the sea level, the lake complex has sides of 12 and 10 km (Wirrmann, 1992). The maximum depth of the lake is reported by Pourchet *et al.* (1991) who estimated it to be 10 meters. The lakes are supplied with water through precipitation (≈ 2.9m/year, data from

SAFACAM supplemented by the town of Dizangue 1930-1990) and the drainage of two watersheds which extend 55 km^2 and 110 km^2 respectively.

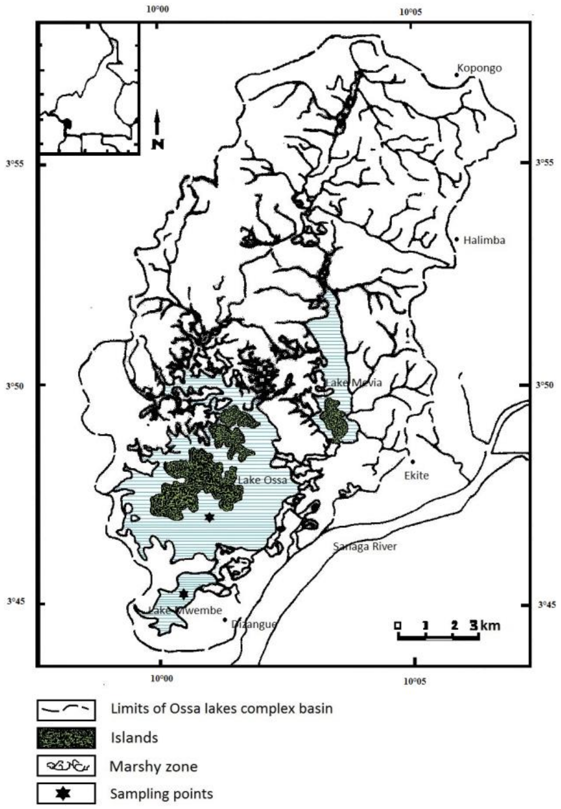

Fig. 1. Lake Ossa complex and different sampling stations on lakes Ossa and Mwembe.

The volume of water in the lakes is estimated at 3 779 000 m^2, for a total area of 4 507 000 m^2 including the islands. The edges of the lakes have been°Ccupied since 1897 by SAFACAM rubber plantation with an area of 95 ha in 1914 to 2.042 ha in 1929, then to 6.800 ha in 1967 (Anonymous, 1990; Wirrmann, 1992). Since 1974, SAFACAM has added, to the cultivation of rubber, palm oil plantation to over half of the total surface area planted (Wirrmann, 1992).

Sampling

The sampling was carried out from September 2009 to February 2010, a six months period which covers both the rainy season (April to°Ctober) and the dry season which extends from December to mid-March (Suchel, 1987). November is the month of seasonal transition between the rainy season and the dry season. Two sampling sites were chosen, one on the Ossa Lake and the second on Lake Mwembe (Fig. 1). Both stations are located in the centre of the lakes. The sampling frequency was monthly and samples were collected using a 03L bottle of VAN DORN. Samples were collected from three levels of depth: on the surface (between 0 and 0.5 m), above the area of disappearance of Secchi disc and 50 cm above the bottom. At each sample station, 1L water was sampled for physicochemical measurement whereas for biological sampling, thirty liters of water were collected at the level of each depth and passed through a sieve of 64 microns mesh. One hundred and fifty mL aliquot water was fixed in formalin 4% and another 150 mL were directly brought back to the laboratory.

Physicochemical analysis

The following parameters were measured *in situ*: temperature, pH, dissolved oxygen, electrical conductivity and total dissolved solids (TDS) by means of a mercury thermometer, a portable pH meter SCHOTT (CG 818), a portable oxygen meter YSI 52 and a portable TDS/conductivitimeter HACH, respectively, according to the calibration performed at 25 °C in the laboratory before each sampling. In the laboratory, the color settings, concentration of Suspended Solids (SS), forms of nitrogen (ammonium, nitrate and nitrite), orthophosphate and turbidity were measured using spectrophotometry (spectrophotometer HACH DR/2000). Dissolved carbon dioxide was measured using the volumetric methods (APHA, 1998).

Biological analysis

Biological samples fixed in 4% formalin permitted to identify and count zooplankton species. The species of rotifers, Cladocerans and copepod were identified by means of a stereoscopic microscope WILD M5, using the identification keys of Ruttner-Kolisko (1974), Koste (1978), Pourriot and Francez (1986), Nogrady *et al.* (1993, 1995), Segers (1994, 1995), Shiel (1995), Wallace and Snell (2001) and Kutikova (2002) for Rotifers, Amoros (1984), Korovchinsky (1992), Smirnov and Korovchinsky (1995), Smirnov (1996), Dodson and Frey (2001) and Korinek (2002) for Cladocerans and Lindberg (1957), Dussart (1980), Van De Velde (1984), Dussart and Defaye (1995) and Alekseev (2002) for Copepods.

The formalin samples, washed with distilled water, and the second sampler were used for identification and the counting of species. The listing of organisms present within each sample was made on the basis of counting two or three samples of 10 mL (Legendre and Watt (1972).

Data analysis

Correlations were sought between the physicochemical variables and biological variables to determine possible factors that could justify the zooplankton biomass and its distribution. Shannon and Weaver diversity index was used to appreciate the zooplankton diversity in both lakes. Equitability index of Pielou was used to examine the distribution of organisms and the dominance of some species in the lakes, whereas, the Sorensen index of similarity was used to compare the species richness of the two lakes.

Multiple Analysis of Variance (MANOVA) was used to determine which factor influence the zooplankton structure in both lakes. Then, Principal Component Analysis (PCA) was used to group the different sampling sites in relation with the environmental factor and to verify the effect of each factor on the distribution of zooplankton species, whereas Redundancy Analysis (RDA) was used to associate the different species to each characteristic sites and environmental parameters.

Results

Physicochemical characteristics of water

The values of the physicochemical parameters of water in both lakes, Ossa and Mwembe, are shown in Tables 1 and 2.

The average temperature in the Ossa and Mwembe lakes are respectively 27.70±0.86°C and 28.85±0.66°C. The amplitude of temperature variation in both media was low (less than 7). Generally, the temperature decreased between September and November and increased between December and February, regardless of their depth. There was no significant difference in the temperature values at the level of each depth ($p > 0.05$). The two lakes were slightly acidic with an average pH of 6.57±0.06 CU and 6.52±0.07 CU respectively. But the pH of water usually decreased between September and February.

Table 1. Values of physicochemical parameters of Lake Ossa between September 2009 and February 2010. (Bot = bottom, Dec = december, Feb = february, Jan = january, Nov = november,°Ct =°Ctober, Sep = september, Surf = surface, SS = suspended solids, Temp = temperature, Cond = electric conductivity, Turb = turbidity).

Month	Total Depth (m)	Sampling depth	Temp (°C)	pH (UC)	Cond (µS.cm^{-1})	Turb (FTU)	TDS (mg.L^{-1})	Color (Pt.Co)	SS (mg.L^{-1})	PO_4^{3-} (mg.L^{-1})	NO_2^- (mg.L^{-1})	NO_3^- (mg.L^{-1})	NH_4^+ (mg.L^{-1})	O_2 (mg.L^{-1})	CO_2 (mg.L^{-1})
		Surf.	27.2	6.74	44	19	22	85	3	0.014	0.005	0.05	0.2	1.4	14.08
Sep.09	11	1.50 m	28	6.56	39	20	16.5	97	5	0.01	0.005	0.04	0.16	1.6	14.08
		Bot	27.2	6.65	55	39	27.5	199	19	0.04	0.003	0.012	1.22	5.6	24.64
		Surf.	30.2	6.85	24.4	8	12.2	78	5	0	0.012	0.11	0	4.2	7.04
Oct.09	11	1.50 m	32	6.54	35.9	5	18.6	32	1	1.18	0.013	0.11	0	2.8	12.32
		Bot	29.4	6.79	12.3	9	24.6	45	0	0	0.013	0	0	5	1.76
		Surf.	26.7	6.82	38.2	9	18.8	23	0	0.03	0.002	0.03	0.06	2.6	8.8
Nov.09	11	1.50 m	26.6	6.58	27.6	10	13.7	39	4	0.05	0.002	0.12	0.09	0.8	10.56
		Bot	26.6	6.44	56.9	20	28.4	83	4	0.01	0.003	0.09	2.04	7.2	17.6
		Surf.	28.7	6.42	25.1	19	12.5	74	3	0.02	0.005	0.03	0.08	8.6	5
Dec.09	4	1.50 m	25.2	6.11	24.3	19	12.2	66	3	0.06	0.009	0.27	0.2	6.2	1.76
		Bot	25.5	6.52	22.8	27	11.3	180	9	0.54	0.009	0.11	0.18	6.4	1.76
		Surf.	25.5	6.62	23.2	22	11.6	111	13	0	0.007	1.3	0	7.8	5.87
Jan.10	3.5	1.15 m	25.6	6.6	18.3	17	8.8	84	14	0	0.007	1	0	10.4	2.9
		Bot	25.5	6.51	16.5	15	8.3	78	6	0	0.006	0.9	0	10.8	3.4
		Surf.	28.2	6.67	16	19	8	100	8	0	0	1.3	0.49	9	22.88
Feb.10	3.5	1.00 m	30	6.57	22	28	11	156	16	0.05	0.014	2	0.55	11.2	15.84
		Bot	30.5	6.34	19	24	9.5	131	13	0.14	0.012	1.6	0.75	10	15.84

Table 2. Values of physicochemical parameters of lake Mwembe between September 2009 and February 2010. (Bot = bottom, Surf = surface, SS = suspended solids, Temp = temperature, Cond = electric conductivity, Turb = turbidity).

Month	Total Depth (m)	Sampling Depth	Temp (°C)	pH (UC)	Cond ($\mu S.cm^{-1}$)	Turb (FTU)	TDS ($mg.L^{-1}$)	Color (Pt.Co)	SS ($mg.L^{-1}$)	PO_4^{3-} ($mg.L^{-1}$)	NO_2^- ($mg.L^{-1}$)	NO_3^- ($mg.L^{-1}$)	NH_4^+ ($mg.L^{-1}$)	O_2 ($mg.L^{-1}$)	CO_2 ($mg.L^{-1}$)
		Surf.	27.2	6.6	33.7	21	/	106	9	0.12	0.005	0.04	0.16	1	14.8
Sep 09	11	1.50 m	28	6.8	112.7	20	/	94	11	0.1	0.005	0.02	0.19	0.4	10.56
		Bot	27.2	6.07	26	30	/	153	14	0.04	0.003	0.012	1.22	4	12.32
		Surf.	30	6.56	28.5	17	14.2	84	12	0.01	0.017	0.03	0	4	15.84
Oct 09	11	1.50 m	29.2	6.86	25.6	15	12.9	73	5	0.01	0.007	0.02	0	12.6	40.48
		Bot	28.8	6.67	31.2	32	15.6	165	19	0.23	0.013	0	0	10	8.8
		Surf.	26.7	6.63	32.6	5	16.5	17	1	0.01	0.001	0.07	0.01	2.6	12.32
Nov 09	11	1.50 m	26.7	6.73	26.8	8	13.4	36	3	0.08	0.003	0.07	0.02	4.8	22.88
		Bot	26.7	6.2	26.81	15	13.1	72	7	0	0.001	0.05	0.09	3.8	5.28
		Surf.	30	6.74	31.1	15	15.5	69	3	0	0.005	0.04	0.16	4.8	5.28
Dec 09	4	1.50 m	28	6.68	25.5	17	12.8	68	0	0.02	0.008	0.05	0.11	4.6	0
		Bot	28	6.29	22.5	25	11.1	99	4	0.1	0.013	0.08	0.26	6.2	0
		Surf.	30.6	6.62	15.1	21	16.5	114	12	0	0.009	1.4	0.04	9	4.3
Jan 10	3.5	1.15 m	29.8	6.66	13.1	18	13.4	89	10	0	0.007	1.1	0.06	6.2	4.8
		Bot	30	6.43	13.2	22	13.1	128	14	0	0.01	1.7	0.14	7.6	5.86
		Surf.	31	6.41	15	30	7.5	181	16	0.13	0.016	2.2	0.58	10	19.88
Feb 10	3.5	1.00 m	30.5	6.31	14	35	7	197	17	0	0.023	2.6	0.88	11.2	10.84
		Bot	31	6.11	14	52	7	344	35	0.07	0.041	4.6	1.33	11	9.08

The electrical conductivity values of the water were low, with an average of $27.91\pm5.25\mu S.cm^{-1}$ and $28.18\pm7.33\mu S.cm^{-1}$ respectively in Ossa and Mwembe. Globally, they decreased gradually between September and February. However, it was observed that this parameter changes values between September and December. From a general point of view, the values of electrical conductivity had the same evolutional trend as those of TDS in Lake Ossa (the TDS of Lake Mwembe was not measured in the month of September).

Low values of dissolved oxygen were recorded in the rainy season. These values increased during the dry season. Unlike dissolved O_2, the values of dissolved CO_2 decreased during the rainy season and increased during the dry season, with the averages of $10.34\pm3.06 mg.L^{-1}$ and $11.29\pm3.40 mg.L^{-1}$ respectively.

Water samples from Lakes contained very low amounts of nutrients, PO_4^{3-} , NH_4^+, NO_3^- and NO_2^-. However, it can be observed that between December and February, the contents of NO_3^- and NO_2^- in the water rose. The values of the characteristic parameters of mechanical pollution (SS, turbidity, color) had a similar pattern of evolution; they decreased between September and November, and then increased until February. However, these values remained relatively low.

Biological characteristics of the mediums

Thirty seven and 41 species of zooplankton were collected in the Ossa and Mwembe lakes respectively. Rotifers were represented by 26 and 27 species, Cladocerans by 8 and 11 species and copepods by 3 species in each lake. This zooplankton composition fluctuates with time, with a significant participation of larval and copepodits stages. Indeed, considering the participation in abundance, different categories of organisms contribute according to data in Table 3.

Table 3. Percentage of temporal variations in the density of zooplankton organisms in lakes Ossa and Mwembe.

Lake	Period	Cladocerans	Copepodits	Nauplii	Copepods	Rotifers
Ossa	Sep 09	7.22	1.80	37.31	0.12	53.55
	Oct 09	22.61	7.66	19.54	3.01	47.17
	Nov 09	39.23	7.52	21.06	3.43	28.78
	Dec 09	9.68	9.62	46.86	3.96	29.89
	Jan 10	48.00	3.11	9.12	3.34	36.42
	Feb 10	9.65	1.48	16.19	0.99	71.70
Mwembe	Sep 09	7.34	11.51	26.16	0.64	54.33
	Oct 09	10.48	3.87	40.17	0.30	45.17
	Nov 09	28.48	17.42	24.06	1.37	28.67
	Dec 09	4.25	6.82	57.96	2.57	28.39
	Jan 10	0.09	0.69	25.71	0.46	73.05
	Feb 10	37.32	3.62	12.10	0.54	46.40

The evolution of the density of rotifers in both ecosystems was contrary to that of crustaceans between September and November (Fig. 2). When the number of rotifers decreased, that of crustaceans increased.

As one advances into the dry season, the density of copepods gradually decreased. The densities of rotifers and Cladocerans varied depending on the media. After a drop in the abundance of Cladocerans in both lakes in the month of December, their density in Lake Ossa increased in January, and later drop in February. Almost all Cladocerans of Mwembe disappeared in January but reappear in February.

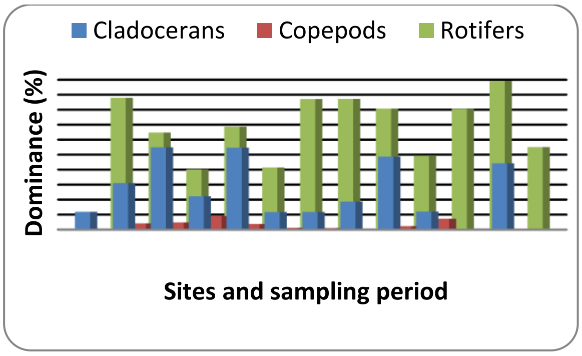

Fig. 2. Percentage of dominance of the different groups of zooplankton in lakes Ossa and Mwembè (Dec = december, D.S. = dry season, Feb = february, Jan = january, Nov = november,°Ct =°Ctober, R.S. = rainy season, Sep = September).

The diversity index of Shannon & Weaver varied between 0.87 (zone of disappearance of Secchi in January) and 2.68 (zone of disappearance of Secchi in February) in Lake Ossa and between 1.42 (surface area and zone of disappearance of Secchi in January) and 2.49 (area of disappearance of Secchi in°Ctober) in Mwembe lake. A variation in the faunal composition was mostly observed in the middle of the water. The value of the equitability index of Pielou was less than 0.6 in most of the water collection point (Table 4). The Sörensen similarity index between lakes had a very high value (82%).

Abundances of representative species were included in a multiple analysis of variance in conjunction with the fix factors (medium and depth) or random factors (Season and months) (Table 5). It appeared from these results that only the season had a probability lower than the threshold value considered (p = 0.05). It can be observed a probability p = 0.09 in lake Mwembe, closer to the threshold value, for their sampling point.

Table 4. Shannon & Weaver diversity index, Pielou equitability index in both water bodies Ossa and Mwembe.

Month	Sampling depth	Shannon and Weaver index		Equitability index of Pielou	
		Ossa	Mwembe	Ossa	Mwembe
Sep 09	surface	1.77	2.22	0.44	0.53
	1.50 m	2.3	2.44	0.55	0.61
	bottom	2.13	2.18	0.71	0.53
Oct 09	surface	2.17	1.96	0.56	0.51
	1.50 m	2.55	2.49	0.6	0.55
	bottom	2.58	2.46	0.6	0.62
Nov 09	surface	2.27	2.06	0.54	0.57
	1.50 m	2.08	2.19	0.5	0.56
	bottom	2.45	1.94	0.64	0.47
Déc 09	surface	2.07	1.74	0.55	0.48
	1.50 m	1.73	1.46	0.46	0.35
	bottom	1.69	1.98	0.53	0.55
Jan 10	surface	1.28	1.42	0.34	0.39
	1.15 m	0.87	1.42	0.43	0.39
	bottom	1.36	1.83	1.36	0.43
Feb 10	surface	1.87	2.16	0.46	0.47
	1.00 m	2.68	1.97	0.63	0.43
	bottom	2.44	2.27	0.56	0.48

Table 5. Results of the determination of the different explanatory variables on the abundance of zooplankton in Ossa and Mwembe lakes.

<table>
<tr><th></th><th></th><th colspan="6">Interaction between parameters</th></tr>
<tr><th></th><th></th><th colspan="2">Station and Season</th><th colspan="2">Depth and Station</th><th colspan="2">Depth and Month</th></tr>
<tr><th></th><th></th><th>Station</th><th>Season</th><th>Depth</th><th>Season</th><th>Depth</th><th>Month</th></tr>
<tr><td rowspan="2">Lake Ossa</td><td rowspan="2">Species abundance</td><td>P = 0.393</td><td>P = 0.0003</td><td>P = 0.568</td><td>P = 0.0155</td><td>P = 0.651</td><td>P = 1</td></tr>
<tr><td colspan="2">Cumulated P = 0.245</td><td colspan="2">Cumulated P = 0.426</td><td colspan="2">Cumulated P = 1</td></tr>
<tr><td rowspan="2">Lake Mwembe</td><td rowspan="2">Species abundance</td><td>P = 0.0958</td><td>P = 0.0004</td><td>P = 0.566</td><td>P = 0.012</td><td>P = 0.647</td><td>P = 1</td></tr>
<tr><td colspan="2">Cumulated P = 0.0956</td><td colspan="2">Cumulated P = 0.395</td><td colspan="2">Cumulated P = 1</td></tr>
</table>

Seasonal variation of physicochemical and biological characteristics of lakes water

The results of the Principal Component analysis based on the physicochemical data obtained from the different hydrosystem and depth are presented in Fig. 3. In general, different depth of the two lakes do not differed much from each other. At least the second axis explained 17.90% of this distribution and discriminated two groups of months: the dry season (A) and the rainy season (B). During the dry season, the major physicochemical parameters were: calcium hardness, SS, NO_2^-, NH_4^+, temperature, whereas those that characterized the rainy season were: pH, alkalinity, dissolved carbon dioxid, electrical conductivity and depth.

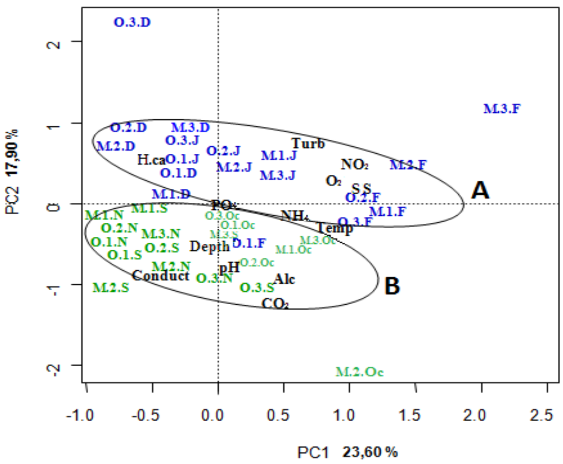

Fig. 3. Principal Component Analysis ordination biplot of the environmental variables and the sampling campaign in lakes Ossa and Mwembè, from September 2009 to February 2010 (D = December, F = February, J = January, M = Mwembè, N = November, O = Ossa,°C =°Ctober, S = September, 1 = surface, 2 = medium, 3 = bottom, O.3.S = Ossa bottom September, Alc = alkalinity, CO_2 = carbon dioxide, Conduct = conductivity, H.ca = calcium hardness, NH_4 = ammonium, NO_2 = nitritre, O_2 = Dissolved oxygen, PC1 = principal component 1, PC2 = principal component 2, PO_4^{3-} = orthophosphate, SS = suspended solids, Temp = temperature, turb = turbidity).

The grouping of stations based on biological properties (Fig. 4) allows identifying two main groups according to seasonality. Group A consists of the warmer months while Group B brings the rainy months. In group A, the surface water qualities of the two lakes were similar in January and February (Aα) while February in lake Mwembe and January at Ossa shown remarkable differences at the level of the middle and bottom (Aβ and Aσ).

The distribution obtained after the canonical redundancy analysis (Fig. 5) which combines the biotic and abiotic variables is explained at 52.81% by the first axis and at 25.21% by the latter. Axis 1 split the distribution into two : the months of December, January and February were characterized by warm, turbid water with high concentration of NO_2^-, and by the presence of periphytic species such as *Lecane* sp., *Lepadella* sp., *E. clavulata*, *B. dimidiatus* (Aα) in warm water, and the species *T. elongata*, *T. negletus* and *A. rectangula* that could be found in the murky waters rich of NO_2^- (Aβ), while the other sampling periods were marked by lots of rain and eutrophic species such as *B. macaguensis*, *B. deitersi*, *K. tecta*, *P. vulgaris*, *K. tropica* (B). The second axis presents a high abundance of crustacean, during the rainy season and turbid water, while rotifers thrive in warm waters.

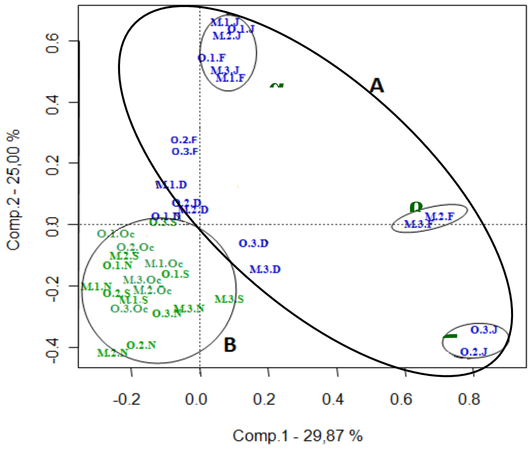

Fig. 4. Principal Component Analysis of the biological data in lakes Ossa and Mwembè, from September 2009 to February 2010 (Comp.1 = principal component 1, Comp.2 = principal component 2, D = December, F = February, J = January, M = Mwembè, N = November, O = Ossa,°C =°Ctober, S = September, 1 = surface, 2 = medium, 3 = bottom, M.1.Oc = Mwembè surface°Ctober).

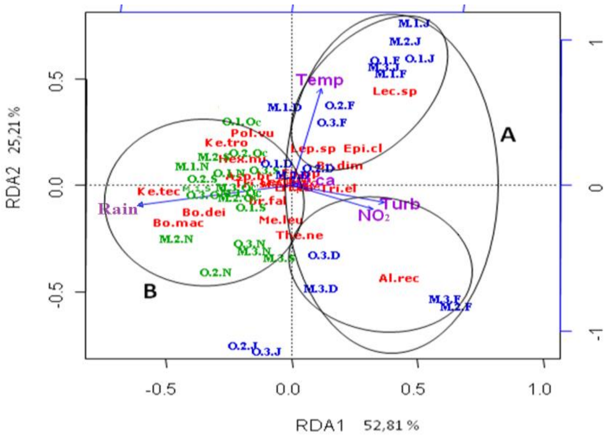

Fig. 5. Redundancy Analysis on the biological and environmental data of the sampling season, from September 2009 to February (RDA1 = redundancy 1, RDA2 = redundancy 2, D = December, F = February, J = January, M = Mwembè, N = November, O =

Ossa,°C =°Ctober, S = September, 1 = surface, 2 = medium, 3 = bottom, O.2.J = Ossa middle january).

Discussion

Physicochemical characteristics of water

In general, the two lakes were close to each other and there was no significant difference between the different parameters measured at each level (Nziéleu Tchapgnouo *et al.* (2012); water sampling for physicochemical characterization can therefore be made between the surface and 50 cm depth.

The temperature range of lakes Ossa and Mwembe corresponds to those found in lakes Kariba in Zimbabwe (29-30°C), Lanao in Phillipines (26-27°C), Victoria in Kenya (24-26°C), Tanganyika in Tanzania (26-27°C) and Ehoma in Nigeria (25-32 °C) (Okogwu, 2010). There was a regressive curve for temperature values between September and November. A gradual increase in this value could be seen from December to February. This was certainly in relation with the rise in the water and the low depth water as described by Suchel (1987). According to Suchel (1988), Lake Ossa is subject to a°Ceanic variant of the equatorial climate Guinean characterized by three months of dry season (December to February), a rainy season of seven months to which belong the months of September and°Ctober, two months of transition to the rainy season (March) and to the dry season (November). This might justifies the fact that water were cool in flood season and warm during the dry season. The low variation in temperature is a characteristic of most tropical lakes (Lewis, 1987).

For Ramade (2005), the pH of natural water is never lower than 6 even for aquatic biotopes located on very acidic rocks, except in the case of regular supply of atmospheric sulphuric acid by acid rain. This acidity of water could be attributed to the total hydrolisation of primary minerals resulting from sedimentary ferralitic yellow rocks found in lake Ossa. It could equally result from the elimination of the major part of the bases (Segalen, 1967; Vallerie, 1968). However, it is important to note that a strong acidity of water results to the setting into solution of the toxic metals trapped in the sediments.

Electrical conductivity decreases from September to February. It is known that the contribution of waste waters in the aquatic environment increases its content on ionizable salts and consequently its conductivity (Zébazé Togouet *et al.*, 2005). Mineralization would be thus more important during the rainy season because of the waste water coming from SAFACAM and the floods by Sanaga River. The evolution of this parameter goes from an average of 17.8µS.cm^{-1} in 1987 (Kling, 1987) to 27 µS.cm^{-1}.

The oxygen gradient observed in water corroborated that found in the lake Ehoma by Okogwu (2010) and marks also a significant seasonal variation. The rate of dissolved oxygen and those of CO_2 in the media showed that the two sites offered favorable conditions of mineralization to the micro-organisms, especially in January.

Values of parameters PO_4^{3-}, NH_4^+, NO_2^- and NO_3^-, taken inmg.L^{-1} explained the poor content of lakes in organic matter, according to the classification characteristics of the lakes, to confirm their oligotrophic character (Wirrmann, 1992; Nziéleu Tchapgnouo *et al.*, 2012). Taking into consideration phosphorus content of a biotope as suggested by Dunnette (1992) and Ramade (2005) these lakes could be estimated as eutrophic. This result corroborate that of Ryding and Rast (1994), coming with another statement of the trophic degree of water of a lentic biotope, according to their phosphorus content and that of disappearance of the Secchi disc. This makes it possible to say that water from lakes Ossa and Mwembe are eutrophics because of the PO_4^{3-} values which are higher than 100 µg.L^{-1} for an in-depth evaluated transparency of disappearance of the Secchi disc less than 1.5 m. The maximum depths of disappearance of Secchi disk in these two lakes were respectively 1.6 m and 1.5 m. The complex lakes were therefore subjected to eutrophication which is an artificial phenomenon that accelerates the natural process of eutrophication, resulting from various anthropogenic causes of water pollution. For Ramade

(2005), the eutrophication is sometimes caused by biodegradation of fermentable organic matter discharged with wastewater or from industries into lakes. Lakes of Ossa complex are classified, according to Ramade (2002), at Level 2, over 4 successive phases of eutrophication. At level 2, there is nutrient enrichment, mainly phosphate, which is often considered the limiting factor to productivity of aquatic ecosystems. This will bring out the proliferation of phytoplankton and aquatic plants. SAFACAM, on the outskirts of the complex, may have significantly contributed to the pollution of the lakes.

The Principal Component Analysis of physicochemical data allows identifying the influence of some environmental parameters depending on the season, despite the level of sampling. Variables such as pH, alkalinity, CO_2, conductivity, NH_4^+, temperature and depth characterized the rainy season (September,°Ctober, November), while variables such as Calcium Hardness, PO_4^{3-}, SS, NO_2^-, marked the dry season (December, January, February) (Fig. 3). The first axis explained 23.6%, while the second explained 17.9%. Grouping different depths sampling at the center of the graph obtained by PCA allow confirming the absence of significant difference between the levels of depth. Stations do not significantly differed from each other ($p > 0.05$), but the warming period were fairly well grouped around the parameters SS, NO_2^-, dissolved O_2, calcium hardness. Multiple Analysis of Variance (MANOVA) excluded indeed the influences of stations, depths and sampling month on the structure of the species. Only season can justify it ($p < 0.05$). However, p-value of 0.09 found in lake Mwembe for stations suggested that these two lakes are not equally exposed to the effects of pollution. Lake Mwembe indeed received wastewater from planting SAFACAM was also influenced by the flood water of the Sanaga River.

Biological characteristics of water

Tropical lakes are dominated by rotifers (Bidwell and Clarke, 1977; Mwebaza-Ndawula, 2005). According to the abundance of Cladocerans, Mergeay *et al.* (2006) thinks that population growth is due to a combination of factors such as the supply and the availability of nutrients and low temperatures, which accelerate hatching of durable eggs. Other authors, Dejen *et al.* (2004), suggested that the expansion of the river banks during floods favored eggs hatching.

Moreover, under good conditions, cladocerans and rotifers compete for nutrients (Gilbert, 1988). The density of Cladocera increased as a consequence of floods that enriched the nutrient medium.

Moreover, the affluent would bring new species such as *Alona protzi*, *Scaphaloberis kingi* and *Streblocerus* sp. which appeared briefly in the various lakes. A drop in the abundance and the density of the species in December was a seasonal succession which would be explained by the predation exerted by alevins fishes, the competition between the species and the degrading water quality. Indeed, Zébazé Togouet *et al.* (2005) estimates that with increasing temperature and lower water quality, populations and specific richness of zooplankton decreased. This is less observed for Rotifers which are more tolerant with the variations of the medium like the small Copepoda.

The low values of Shannon and Weaver index indicated that there exists dominating species in the medium. The minimal value observed in January in euphotic zone shown a broad domination of *Alona rectangula* (93%). This is appreciated better with the index of equitability which emphasized the imbalance of the ecosystem and the bad distribution of the species, to the sight of its values lower than 0.6 in most levels collection. The 1.36 value observed in January in the deep zone of Lake Ossa was explained by the presence of only two species in the medium. In general, the two lakes have a high similarity as indicated by the Sörensen similarity index (> 80%).

PCA on species also highlighted resemblance due to seasons regardless of the depths and media. The months of December, January and February were similar in terms of species distribution at any depth. Yet the depth interacted with biotic and abiotic components of lake systems with significant impact on their functioning. The lack of distribution of zooplankton in the water column would therefore be justified because there is no thermal stratification in lakes, due to its shallow depth, and the continuous mixing of waters is effective. The temperature and wind were the essential parameters for the distribution of species in lakes. In fact, Bertolo (1998) estimates that the combined action of wind and solar energy determine the phases of stratification and mixing, with different distribution patterns depending on whether the lakes are deep or not; Francisco and Tourenq (1997) argue that the absence of thermal stratification reduces the vertical variations in the distribution of zooplankton.

Redundancy Analysis (RDA) supporting the observation that the structures of the species were still strongly influenced by seasonality alone. It actually revealed the influence of seasonality (rain = 24.05%), temperature (11.48%), NO_2^- (4.65%), Calcium Hardness (3.69%) and turbidity (1.66%) on the distribution of species in the community. *Alona rectangula* found abundantly in February in Lake Mwembe characterized environments with high turbidity and high levels of NO_2^-. *Lecane* sp was influenced by a high temperature, as *Polyarthra vulgaris*, *Epiphanes clavulata* and *Lepadella* sp. These species characterized the warm season, as *Brachionus dimidiatus* and *Plationus patulus*.

The dominant species of the rainy season include *Bosminopsis macaguensis*, *Bosminopsis deitersi*, *Keratella tecta*, *Hexarthra mira* and *Lecane bulla*. The abundance of crustaceans in the rainy season may be related not only to the recruitment of durable eggs deposited on the lakes banks when removing the last flood lakes which offer favorable hatching environmental conditions (Dejen *et al.*, 2004; Mergeay *et al.*, 2006; Okogwu, 2010, but also the contribution of new species that cannot adapted to the waters of lakes and disappeared with the arrival of dry season (*Ilocryptus agilis*, *Scaphaloberis kingi*).

On leaving subgroups Aα and Aβ in Fig. 4 and associating these subgroups species *Lecane* sp. and *Alona rectangula* respectively in Fig. 5, the PCA and the RDA confirmed the low values of the diversity index of Shannon & Weaver and equitability of Pielou in both lakes in January, and to a lesser extent in February, and wide dominance of these species in these periods (Nziéleu Tchapgnouo *et al.*, 2012).

Conclusion

The following parameters PO_4^{3-}, NH_4^+, NO_2^- and NO_3, from the waters of lake Ossa and Mwembe have enabled us to do a classification of these hydrosystems. Mwembe Lake was more influenced by pollution. Water of the Ossa complex lakes was generally dystrophic. This eutrophication was linked to anthropogenic activities in the lake complex basins. These activities include rubber cultivation and oil production by the SAFACAM industry.

Seasonal changes remain the major factor which influenced the quality of lakes and the distribution of zooplankton species. Several physicochemical parameters characterized the dry season, these include, temperature, SS, dissolved oxygen, NO^{2-}. Others factors affected the rainy season (pH, electrical conductivity and dissolved carbon dioxid) with their values being more important during that period.

As for zooplankton, its distribution in lakes depends on seasonal changes. The presence of the following species was correlated to the rainy season: *B. macaguensis*, *B. deitersi*, *K. tecta*, *P. vulgaris*, *K. tropica*, whereas *Lecane* sp., *Lepadella* sp., *E. clavulata*, *B. dimidiatus* were observed during dry season.

However, there was no structure of the zooplankton community in the water column due to the absence of thermal stratification but also due to the continuous mixing of the lake water. The flooded waters of the lakes by the Sanaga River resulted in the high abundance of crustaceans in the rainy season and the presence of certain species of cladocerans whose adaptation to the water of the lakes remained difficult.

Conclusively, the Sanaga River and the agricultural exploitation by the SAFACAM Company had shown a great impact on the water quality within the Ossa

Complex lakes. Agriculture contributes to bring the lakes towards an important eutrophication.

Conflict of interest

The authors declare that they do not have any conflict of interest.

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