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Spatio-temporal variation of the zooplankton population in the Hana River in Taï National Park (West Africa)

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Abstract

This work aimed to determine the distribution of zooplankton in relation with abiotic parameters in Hana river of Taï National Park. Three stations situated in upper, lower and mid watercourses were defined on Hana River. From May 2016 to April 2017 a monthly sampled of zooplankton was collected with a cylindro-conical net of 64 µm mesh-size. The low values of physicochemical parameters showed that Hana River is oligotrophic to eutrophic. The zooplankton composition indicates 04 great groups dominated by Rotifers (47,70%) followed by Copepods (25,01%) and other organisms (25,01%), Cladocerans represented 2,27% only in all of zooplankton individuals. Zooplankton population increased during the dry season when nutrient concentrations are higher in the river. This work has allowed us to identify environmental parameters witch influence the distribution of zooplankton taxa in the Hana River. However agricultural and rural activity in the peripheral area constituted a threat to the ecological quality of this river.

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Introduction

Freshwater ecosystems provide a variety of goods and services to human societies (Bruno *et al.,* 2011), they are also habitats to aquatic fauna and flora. This aquatic ecosystem naturally has a purification capacity which makes the system maintains its biological balance between producers, consumers and decomposers. However, in most developing countries, human activities (such as the construction of hydroelectric and agropastoral dams, the use of chemicals as fertilizers in agriculture, the conversion of forest into agricultural farmland) constitute a real threat to the equilibrium of these aquatic environments. Indeed, these anthropogenic pressures causes physical and chemical changes that can alter the structure and functioning of the aquatic ecosystems (Ohrui and Mitchell 1998, Caraco and Cole 1999, Niyogi *et al.,* 2004). Unfortunately, very little attention by the decision-makers is given to the monitoring of water quality, which ought to be given priority as it constitute essential support to the socio-economic development of any country. We then understand the importance of research on aquatic ecosystem that aims to characterize the population of aquatic organisms in order to have a good knowledge of their biological characteristics and ecological properties. We also have to look into the quality of these aquatic ecosystems, which serve as habitat to these organisms. These data could serve as guide in any environmental management policy (Lalèyè *et al.,* 2004, Wu *et al.,* 2011). There are different methods of assessing the quality of water through its faunistic composition (Benoit-chabot, 2014): macro-invertebrates, fish, bacteria, birds, and zooplankton.

Zooplankton play a key role in aquatic food chain as they are a source of food to fish and other predatory invertebrates and regulate algal populations (Bouzidi *et al.,* 2010). They are also a biological indicator of the quality state of aquatic ecosystems (Ferdou and Muktadir, 2009). The potential of zooplankton as a bioindicator is related to the fact that their development and distribution depend on a number of abiotic factors, such as temperature, salinity, stratification, pollutants and various other biotic parameters. An environment rich in rotifer taxa and abundance of *Brachionus* are frequently observed in eutrophic environments. On the other hand, the *Copepods Thermocyclops decipiens, T. minutus, T. inversus and Mesocyclops auceps* are dominant in oligo and mesotrophic environment (Perbiche-Neves *et al.,* 2013).

The Taï National Park (TNP) is the largest reserved forest of all protected primary forest in West Africa and the second largest forest in Africa after the Congo Basin forest. It offers a great diversity of flora and fauna which has been the subject of several scientific studies on flora (Adou *et al.,* 2005), Guillaumet (1994), Aké-Assi and Pfeffer (1975), Bakayoko (2005), and wildlife (Roth and Merz 1986, in Riezebos *et al.,* 1994, OIPR, 2006). However, very little is known concerning its hydrographic potential. The previous work is limited to the study of the ichthyological population of the rivers of this park (Kamelan, 2014; Kamelan *et al.*, 2014 a and b, Kamelan *et al.,* 2018; Kouamelan *et al.,* 2018). It is clear that a lot of research studies needs to be done to highlight the value of this important world heritage. Among the organisms not studied in this park, is plankton fauna. These organisms are abundant in freshwater and are very sensitive to variations in environmental conditions. The knowledge of their ecology in this natural environment would make it possible to set up important tools for assessing the quality state of the lotic ecosystems (Sladecek, 1983; Nogrady *et al.,* 1993; Moss, 1998; Zébazé Togouet, 2000).

The present study aims to characterize the spatial and temporal variation of zooplankton population in one of the main rivers of the Tai National Park (Hana River) in relation to the environmental variables.

Materials and methods

Study environment

The Taï National Park (TNP) is located in the south-west of Côte d'Ivoire, near the CI/Liberia border. With an area of approximately 5,340km², its covered area represents more than 50% of the total surface area of West African reserved forests under strict protection (OIPR, 2014).

This park is in a sub-equatorial, hot and humid climate characterized by an average annual rainfall of over 1,600 mm (OIPR, 2014), with four seasons. A long rainy season that runs from April to June, a short dry season from August to September, a short rainy season from October to November and a long dry season from December to March (Fadika, 2013).

The TNP is irrigated by many rivers, the main one is the Hana River. Three stations were located on this river along the upstream-downstream gradient. The first station (Ha1) upstream to the point of penetration of the river in the park, the second (Ha2) in the middle course and finally the third (Ha3) downstream at the exit of the park (Fig. 1).

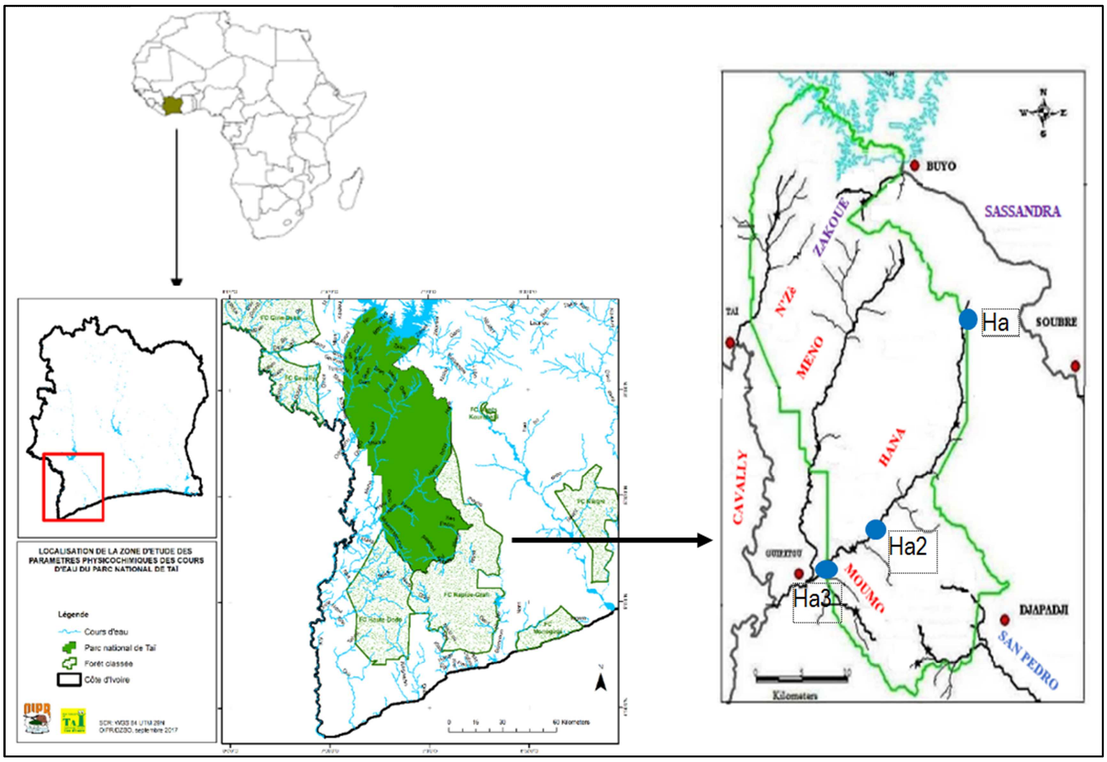

Fig. 1. Map of Tai National Park and location of sampling stations on the Hana River. Ha1: Hana Point O; Ha2: Hana Mont Nienonkoué; Ha3: Hana Ecotel.

Measurement of physicochemical parameters

In each station, water temperature, pH, conductivity, TDS, dissolved oxygen, and oxidation-reduction potential were measured *in situ* using a multi-parameter Lovibond Senso Direct 150. The determination of nutrient salts (ammonia nitrogen, nitrite, nitrate, free chlorine, total chlorine, total phosphorus and phosphate) was carried out in the field using HANNA mini-photometers performed according to the Beer Lamberts' law (Rodier *et al.,* 2009). Transparency was measured using a Secchi disk. The speed of the current was measured by timing the displacement of a plastic bottle 0.5-liter full of water along a specified distance (McMahon *et al.,* 1996) of 7m and is expressed in m/s.

Sampling and analysis of samples

Sampling of zooplankton was conducted monthly between 8 am and 10 am from May 2016 to April 2017. In each station, 150L of water was collected using a 10L bucket and filtered through a plankton net of 64µm mesh vacuum. The collected samples were reduced with the aid of a concentrator and then collected in a pillbox in which 1 to 2mg of sucrose, 2 to 3 drops of neutral red, and formaldehyde (5%) were added for their conservation.

Zooplankton organisms were identified under a microscope (ZEISS type) according to De Mannuel (2000) for Rotifers, Dussart and Defaye (2001) for Copepods and Sharma (2010), Kotov *et al.* (2012) for Cladocerans.

The counting was done using a magnifying glass of the type Leica WILD M3 c. The density of theindividuals was calculated using the following formula:

Where D is the density of the organisms (expressed asindividuals per liter:indiv / m^3), n is the number ofindividuals observed in the sample, V_1 is the total volume of the sample analyzed and V_2 is the volume of water filtered in the field.

$$D = \frac{(n \times V_1)}{V_2}$$

Data analysis

Data were analyzed for spatial and temporal variation through STATITICA 7.1 Software. The descriptive analysis was applied to physicochemical data to bring to light the central tendency and variation (respectively mean and standard deviation). Before performing the comparison test, the normality of data was checked by the Shapiro-Wilk test ($p > 0.05$ at all stations). The Kruskal-Wallis *H*-test with the multiple comparison Dunn test a posteriori, was used to verify the significant difference of spatio-temporal variations of the physicochemical parameters (Zar, 1999). A significance level of $p < 0.05$ was considered.

The organic pollution index (OPI) was calculated from these physicochemical parameters. It was obtained from the values of ammonium (NH_4^+), nitrites (NO_2^-) and phosphates (PO_4^{3-}) according to the method of Leclercq (2001).

The principle was to group the values of the three polluting elements (ammonium, nitrites and phosphates) into five classes and to determine from the values obtained in the study, the corresponding class to which belong each parameter using the average data (Table 1). The final index is the average of the pollution classes for all the parameters.

Table 1. Class limits of the Organic Pollution Index (Leclercq, 2001).

Classes	NH_4^+ (mg/L)	NO_2^- (µg/L)	PO_4^{3-} (µg/L)
5	< 0,1	< 5	< 15
4	0,1 - 0,9	6 – 10	16 – 75
3	1 - 2,4	11 – 50	78 – 250
2	2,5 – 6	51 – 150	251 – 900
1	< 6	< 150	< 900

Classe 5: zero organic pollution, Classe 4: low organic pollution, Classe 3: moderate organic pollution, Classe 2: strong organic pollution, Classe 5: very high organic pollution.

The structure and dynamics of zooplankton populations were assessed from the Shannon index, equitability, occurrence percentage, and taxonomic richness.

(1) The Shannon index (H ') is obtained using the following formula:

$$H' = -\sum_{i=1}^{n} Pi \, log2 \, Pi$$

with *Pi* = relative abundance of taxon I;

(2) the equitability of Pielou (1966) is calculated according to the formula:

$$E = H'/\log_2 S$$

where H ': the Shannon index and S: the specific richness;

(3) the percentage of occurrence (F) is determined from the following formula:

$$F = (Si / St) \times 100;$$

where Si: Number of samples where taxon is obtained and St: Total number of samples.

The classification of taxa based on their percentage of occurrence was done according to Dajoz (2000). The Kruskal-Wallis *H*-test was used to compare the zooplankton abundance between sampling sites. On the other hand, the Mann-Whitney *U*-Test made it possible to evaluate the intensity of the seasonal fluctuation of zooplankton population. The differences are said to be significant when a *p*-value is less than 0.05. Correlations between environmental variables and taxonomic richness were tested by the Spearman correlation test. In order to study relationships between environmental variables and the structure and dynamics of the zooplankton community, Canonical Correspondence Analysis (CCA) was performed based on the data matrix of zooplankton densities. CCA is an ordination method effective in directly revealing correlations between the spatial structure of communities, and environmental factors that might be responsible for that structure (Ter Braak and Smilauer, 2002). Environmental variables and zooplankton data were log10 (x+1) transformed prior to analysis. Monte Carlo permutations (500) were done so as to identify a subset of measured environmental variables, which exerted significant and independent influences on zooplankton distribution at $p < 0.05$. CCA was performed using CANOCO 4.5 (Ter Braak and Smilauer, 2002).

Results and discussion

Physicochemical parameters

The results of the physicochemical analyzes of the Hana River are shown in Table 2. The spatio-temporal analysis of the physicochemical parameters does not indicate any significant difference apart from oxygen, phosphate, total phosphorus and free chlorine, which revealed a significant spatial variation ($p < 0.05$).

Table 2. Mean values and standard deviations of physicochemical parameters of the Hana River.

Physicochemical parameters	Ha1 (a)			Ha2 (b)			Ha3 (c)		
	RS	DS	Average	RS	DS	Average	RS	DS	Average
Temperature (°C)	26,565	28,33	27,74±3,11	25,935	26	26,20±1,07	26,01	26,695	26,59±1,24
pH	7,26	7,15	7,22±0,54	6,81	7,13	7,07±0,46	6,93	7,195	7,14±0,57
Oxygen (mg/L)	4,49	3,525	3,89±1,33 bc	6,85	6,71	6,80±0,73 a	6,595	6,155	6,42±1,02 a
Conductivity (µS/cm)	55,54	56,505	61,19±26,01	44,555	50,13	48,94±8,73	41,46	49,08	46,71±8,38
TDS (mg/L)	39,02	40,355	43,27±18,75	31,515	35,805	34,75±6,44	29,36	35,055	33,20±6,11
Redox (mV)	68,67	66,51	64,23±29,88	86,625	93,71	80,06±39,92	102,815	73,545	80,96±52,5
Nitrites (mg/L)	0,0110	0,0125	0,014±0,009	0,0109	0,0107	0,008±0,005	0,0053	0,0055	0,006±0,005
Nitrates (mg/L)	5,875	3,7	4,30±2,74	1,479	3,175	2,50±1,49	2,36	1,65	2,01±1,36
Phosphates (mg/L)	0,157	0,137	0,168±0,072 b	0,2545	0,724	0,619±0,484 ac	0,133	0,2075	0,227±0,131 b
Phosphorus total (mg/L)	0,15	0,12	0,12±0,052 c	0,1995	0,299	0,214±0,142 c	2,175	1,65	2,54±1,58 ab
Ammonium (mg/L)	4,744	1,825	3,577±2,63	2,411	3,167	2,713±1,527	1,910	3,365	2,492±1,241
Chlorine total (mg/L)	0,1235	0,0875	0,107±0,051	0,102	0,0535	0,079±0,035	0,1135	0,081	0,08±0,044
Free Chlorine (mg/L)	0,2915	0,154	0,201±0,152 b	0,018	0,032	0,025±0,012 ac	0,0775	0,190	0,121±0,081 b
Velocity (m/s)	0,555	0,2775	0,2775	0,451	0,4445	0,4445	0,293	0,203	0,203
Transparence (cm)	37,5	33,5	33,5	41,15	52,45	52,45	38,55	59,3	59,3

TDS: Dissolved Solids, a: Significant statistical difference to a ; b: Significant statistical difference to a ; c: Significant statistical difference to c ; ab: Significant statistical difference to ab ; ac: Significant statistical difference to ac ; bc: Significant statistical difference to bc ; RS: Rain Season; DS: Dry Season.

In general, dissolved oxygen levels ranged from 3.53mg/L in the dry season to 6.85mg/L in the rainy season. The Ha2 station is the most oxygenated in the two seasons (6.85mg/L in the rainy season and 6.71mg/L in the dry season) while in the Ha1 station the oxygen level is the lowest (4.49mg/L in the rainy season and 3.53mg/L in the dry season). Concerning Phosphorus compounds a high concentration of phosphates was observed during the dry season compared to the rainy season (0.724mg/L and 0.133mg/L respectively). During the rainy season, the maximum value of 0.254mg/L was obtained in the station Ha2 and the minimum of 0.133mg/L was obtained in Ha3. On the other hand, in the dry season, the highest value was 0.724mg/L obtained in Ha2 station while at Ha1 station the concentration was 0.137mg/L the lowest. Total phosphorus levels was highest during the rainy season (2.175mg/L) and lowest in the dry season (0.12mg/L). In the rainy season, this value increased from upstream to downstream (Ha1: 0.12mg/L, Ha2: 0.20mg/L and Ha3: 2.18mg/L). The lowest value obtained in the dry season was 0.12mg/L at Ha1 and the highest was 0.299mg/L at Ha2 in the same season.

The free chlorine level was highest in the rainy season (0.291mg/L) and lowest in the dry season (0.018mg/L). During the first period, the highest level was measured at Ha1 station (0.291mg/L) and Ha2 has the lowest (0.018mg/L). In the second period, the maximum value was obtained at Ha3 (0.190mg/L) and the minimum at Ha2 (0.032mg/L) (Table 3). The average value of the Organic Pollution Index (OPI) in all the stations indicates a strong organic pollution in the Hana River. It oscillates between 2.67 (Ha1 and Ha2) and 3 at the Ha3 station.

Zooplankton population

Qualitative analysis

A total of 36 zooplankton taxa were identified in the Hana River of Taï National Park, including 28 Rotifers (77.78%), 4 Cladocerans (11.11%), 2 Copepods (5.56%) (Table 4), and organisms such as copepod Nauplii and insect larvae (5.55%).

Table 3. Average values of nitrites (NO_2^-), ammonium (NH_4^{+}) and phosphates inmg/L and the corresponding OIP (Organic Pollution Index).

	Ha1		Ha2		Ha3	
	Average	OPI	Average	OPI	Average	OPI
NO_2^-	0,014	3	0,008	4	0,006	4
NH_4^+	3,577	2	2,713	2	2,492	2
PO_4^{3-}	0,168	3	0,619	2	0,227	3
OPI Total	$OPI_1 = 2{,}67$		$OPI_2 = 2{,}67$		$OPI_3 = 3$	

The 36 taxa are divided into 13 families with Lecanidae as the most diversified family (07 species), followed by Trichocercidae with 06 species. Taxonomic richness varied significantly ($p < 0.05$) from one station to another, with the highest value recorded in the Ha3 station (24 taxa) against 14 taxa obtained in the Ha2 station.

Table 4. Species richness of the zooplankton population in the Hana River and their percentage of occurrences.

Groups	Family	Taxa	Abbreviations	Ha1	Ha2	Ha3	Occurrences (%)
Rotifers	Brachionidae	*Anuraeopsis navicula*	*A. nav*		+		33,33
		Brachionus angularis	*B. ang*	+		+	66,67
		Keratella cochlearis	*K. coc*	+	+		66,67
		Keratella lenzis	*K. len*	+			33,33
	Lecanidae	*Lecane bulla*	*L. bul*		+	+	66,67
		Lecane closterocerca	*L. clo*			+	33,33
		Lecane elachis	*L. ela*			+	33,33
		Lecane leontina	*L. leo*	+			33,33
		Lecane lunaris	*L. Lun*			+	33,33
		Lecane obtusa	*L. obt*			+	33,33
		Lecane ungulata	*L. ung*			+	33,33
	Colurellidae	*Colurella uncinata*	*C. unc*	+			33,33
		Lepadella sp.	*L.* sp	+	+	+	100
		Lepadella patella	*L. pat*	+		+	66,67
	Testudinellidae	*Testudinella mucronata*	*T. muc*	+		+	66,67
		Testudinella neboisi	*T. neb*		+		33,33
		Testidunella parva	*T. par*		+		33,33
		Testudinella patina	*T. pat*	+			33,33
	Trichocercidae	*Trichocerca chattoni*	*T. cha*		+		33,33
		Trichocerca elongata	*T. Elo*			+	33,33
		Trichocerca macera	*T. Mac*	+	+	+	100
		Trichocerca sp.	*T.* sp		+	+	66,67
		Trichocerca rousseleti	*T. Rou*	+	+		66,67
		Trichocerca ruttneri	*T. Rut*			+	33,33
	Filinidae	*Filinia longiseta*	*F. lon*			+	33,33
		Filinia terminalis	*F. Ter*		+	+	66,67
	Euchlanidae	*Dipleuchlanis propatula*	*D. pro*			+	33,33
	Mytilinidae	*Mytilina crassipes*	*M. cra*			+	33,33
	Moinidae	*Moina sp.*	*M. sp.*			+	33,33
		Moina micrura	*M. mic*			+	33,33
	Macrothricidae	*Macrothrix rosea*	*M. ros*			+	33,33
	Chydoridae	*Alona sp.*	*A. sp*	+			33,33
	Cyclopidae	Undetermined	Cyclo	+		+	66,67
	Nauplius	Undetermined	Naup	+	+	+	100
	Harpaticoidae	Undetermined	Harpa	+	+		66,67
	Insects	Undetermined	Inse	+	+	+	100
	TOTAL	36		16	14	24	-
Taxonomic richness		Rain season		9	7	12	
		Dry season		10	11	15	
Shannon index		Rain season		2,02	1,72	2,4	
		Dry season		1,88	1,94	1,93	-
Equitability		Rain season		0,92	0,89	0,97	
		Dry season		0,82	0,81	0,71	

In the Ha1 station, the zooplankton population (16 taxa) consisted of 68.75% rotifers, 6.25% cladocerans, 12.5% copepods and 12.5% other organisms. The most represented families at this station are Brachionidae and Colurellidae with 18.75% each of the specific diversity. The population was dominated by the genus *Keratella* and *Lepadella* with 2 taxa per genus. Among the taxa identified at Ha1, 11 are constant and 4 accessories (*Keratella lenzis*, *Lecane leontina*, *Colurella uncinata* and *Testudinella patina*.

In the Ha2 station, 14 taxa were found (78.57% Rotifers, 7.14% copepods and 14.26% other organisms). Trichocercidae and Brachionidae are the most diversified families at this station (28.57% and 14.29% respectively). In the Ha2, 10 taxa are constant and 4 accessories (*Anuraeopsis navicula, Testudinella neboisi, T. parva and Trichocerca chattoni*). Finally, in the Ha3 station, the zooplankton population consisted of 24 taxa composed of rotifers 75%, cladocerans 16.67%, copepods 4.17% and other organisms 8.33% were identified. Specific diversity is dominated by the family *Lecanidae* (25% of species) and *Trichocercidae* (16.67% of species), the genus *Lecane* is the most abundant with 30% of species. Of these, 11 are constant and 13 accessories. Thus, *Lepadella* sp., *Trichocerca macera*, insects and nauplius are the only constant organisms that appeared in all the three stations of the Hana River.

Relating to time, the species population are higher during the rainy season in all stations compared to dry season. This same seasonal evolution is observed in equitability in the different stations. Inversely, the Shannon index are lowest in the dry season except for the Ha2 station. In this study we observed that some taxa are specific to particular stations, so at station Ha1 the taxa *Keratella lenzis, Lecane leontina, Colurella uncinata, Testudinella patina* and *Alona sp.,* Ha2 station are characterized by the taxa *Anuraeopsis navicula, Testudinella neboisi, T. parva* and *Trichocerca chattoni* and at Ha3 we find *Lecane closterocerca, Lecane elachis, Lecane lunaris, Lecane obtusa, Lecane ungulata, Trichocerca elongata, Trichocerca ruttneri, Filinia longiseta, Dipleuchlanis propatula, Mytilina crassipes, Moina* sp., *Moina micrura* and *Macrothrix rosea.* On the other hand, other taxa are found in the three stations *Lepadella sp., Trichocerca macera,* copepods nauplius and insects.

Quantitative analysis

Structure and spatio-temporal variation in the population abundance

The rotifers are the most abundant zooplankton group found in the Hana River (47.70%), followed by Copepoda (34.56%) and insects (15.46%). Cladocerans are the least abundant of all zooplankton group (2.27%). Rotifers are dominated by *Lepadella* sp. (20.02%), *Trichocerca* sp. (13.35%), *Mytilina crassipes* (9.53%), *Lepadella patella* (7.63%), *Trichocerca macera* (6.67%), and *Keratella cochlearis* (5.05%) which together account for 62.25% of the total population abundance. The other taxa (22) together constitute 37.75% of the total rotifer abundance. In Cladocerans*, Macrothrix rosea* constitutes 40% of the total abundance of Cladocerans, followed by *Moina micrura, Moina* sp. and *Alona* sp. each representing 20% of the abundance of Cladocerans. Cyclopoidae are the major copepod taxa with 69.74% followed by copepod nauplius unidentified (27.63%) and Harparthicoidae (2.63%).

The spatio-seasonal variation in the total abundance of the zooplankton population is illustrated in Fig. 2. The seasonal variation in population abundance is marked by the values obtained in the dry season (2000indiv/m^3 to 6600indiv/m^3) significantly higher ($p < 0.05$) than the value obtained during the rainy season (933indiv/m^3 and 1466indiv/m^3). During the rainy season (Fig. 3), the population abundance structure is dominated by rotifers in all stations representing 67.31% of the total abundance. This group is followed by Copepods (21.15%) and Insects (9.62%) found in Ha1 and Ha2 stations.

Cladocerans represent only 1.92% of the total abundance and they are only found in Ha1 station. This same distribution of total abundance of the zooplankton population is observed in the dry season (Fig. 4) with little variation in the abundance between the stations. Rotifers (41.63%), Copepods (38.71%)

and Insects (17.27%) are present in all stations. Cladocerans are present in Ha3 and represent only 2.38% of the total abundance.

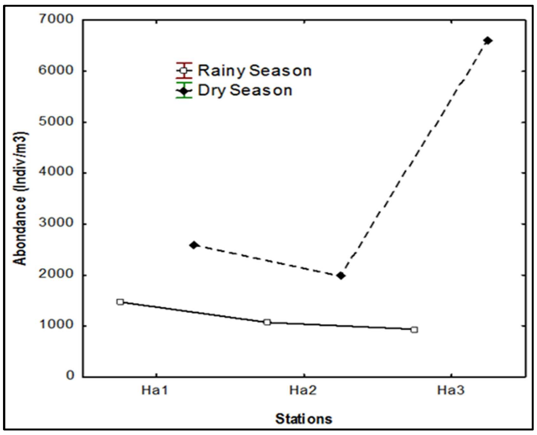

Fig. 2. Spatio-temporal variations in zooplankton population abundance sampled in the Hana River from May 2016 to April 2017.

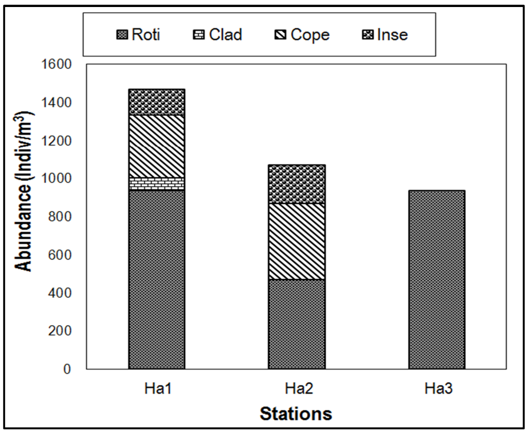

Fig. 3. Spatial variation in abundance and structure of the zooplankton stand sampled in the Hana River during rain season.

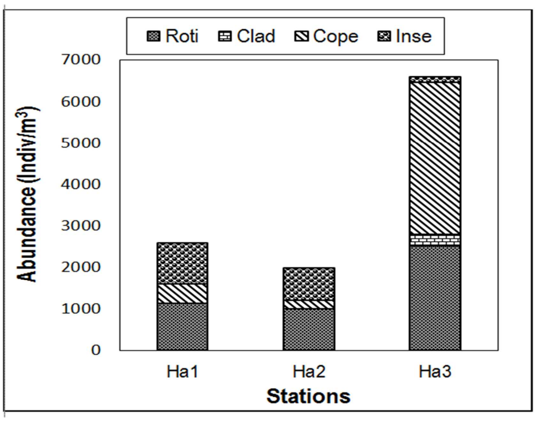

Fig. 4. Spatial variation in abundance and structure of the zooplankton stand sampled in the Hana River during dry season.

The abundance of Rotifer is similar to total zooplankton population variation. It is higher in the dry season (66indiv/m^3 to 1200indiv/m^3) (Fig. 5) and lower in the rainy season (66indiv/m^3 to 466indiv/m^3) (Fig. 6). In the dry season, the abundance of rotifer population is dominated by *Lepadella* sp (25%, 66 - 800 indi/m^3), *Mytilina crassipes* (14.3%, 0-666indiv/m^3), *Trichocerca* sp (10%; 133 - 333indiv/m^3) and *Keratella cochlearis* (6.15%, 0 - 286indiv/m^3). *Lepadella* sp. is the dominant taxon at station Ha1 (333indiv/m^3), *Trichocerca* sp. swarm at station Ha2 (333indiv/m^3). *Mytilina crassipes* is the most dominant species at Ha3 station (666indiv/m^3). On the other hand, during the rainy season, this group is dominated by *Trichocerca* sp. *(20%, 66 - 333indiv/m^3), Lepadella patella (17.14%, 66 - 333indiv/m^3), Lepadella* sp. and *Testudinella mucronata (8.57%, 66 - 133indiv/m^3 each)* and *Trichocerca macera (8.57%, 0 - 200indiv/m^3).*

This season is marked by an abundance of *Lepadella patella* and *Trichocerca* sp. at station Ha1 (333indiv/m^3), *Filinia terminalis* and *Lepadella* sp. at station Ha2 (133indiv/m^3) and *Trichocerca macera* at station Ha3 (200indiv/m^3). During the dry season the total abundance of Copepods (Fig. 7) increases from the interior of the park (66 to 133indiv/m^3) towards the periphery (66 to 300indiv/m^3). In the rainy season (Fig. 8), the Nauplius are the most dominant organisms in this group (81.82%, 600indiv/m^3 of the total abundance). As for the Cladocerans, they are only found in the dry season at the Ha3 station with 66 to 133indiv/m^3 dominated by *Macrothrix rosea*.

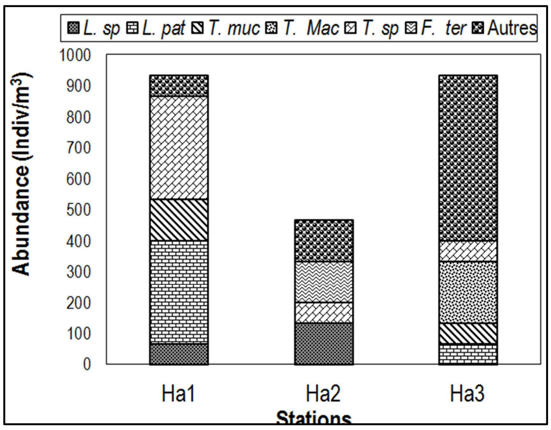

Fig. 5. Spatial variation in abundance and structure of Rotifers sampled in the Hana river during rain season.

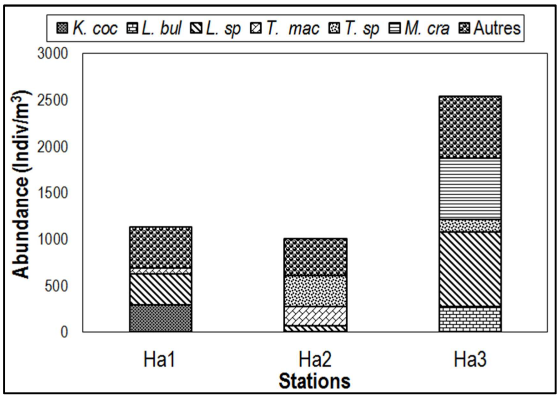

Fig.6. Spatial variation in abundance and in the Hana structure of Rotifers sampled river during dry season.

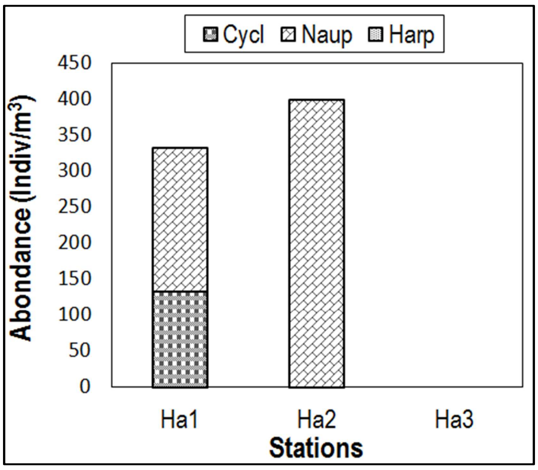

Fig. 7. Spatial variation in abundance and structure of copepods sampled in the Hana River during rain season.

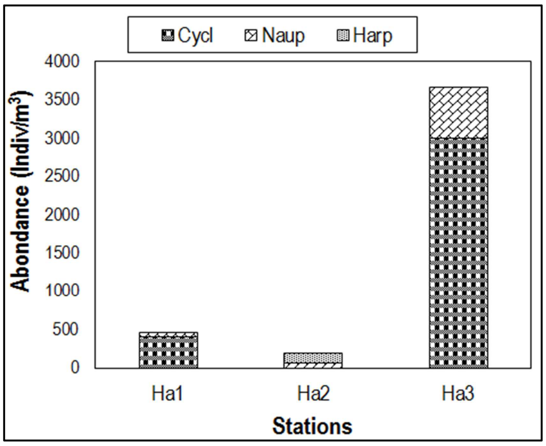

Fig.8. Spatial variation in abundance and structure of copepods sampled in the Hana River during dry season.

Correlations between abundance of zooplankton organisms and environmental variables

The correlation between environmental variables and the distribution of zooplankton taxa in the Hana River during the rainy season and the dry season can be seen in the Figs. 9 (I and II). The first graph shows that in the rainy season, the axis I ($\lambda 1 = 0.78$) expressing 65.9% of the data variance, separates the stations into two groups (Fig. 9.I).

The AB group composed of the Ha1 and Ha2 stations negatively correlated to the axis I and opposite to the group C of the Ha3 station. As for the axis II ($\lambda 2 = 0.40$) which expresses at 34.1% of the data segregates the stations in subgroup B (Ha2) negatively correlated on the axis II and the subgroup A (Ha1) positively to this same axis.

The Ha1 station is characterized by a high level of ammonium and nitrite with a conductivity, TDS and a fairly strong current. Station Ha2 is negatively correlated to axis I with phosphate. As for the Ha3 station, it is characterized by an oxidation-reduction potential (redox) and a high total phosphorus level. Taxa *Alona* sp., *Testudinella patina* and copepods cyclopoids were found in Ha1 station. The Ha2 station is characterized by the presence of *Keratella cochlearis* taxa, *Lecane bulla, Filinia terminalis, Lepadella* sp., *Copepod* nauplii and insects. At station Ha3 we found the *Trichocerca ruttneri, T. elongata, T. macera, Euchlanus dilatata, Lecane lunaris, L. ungulata, L. elachis, L. obtusa* and *Brachionus angularis taxa*. This same structure was observed during the dry season (Fig. 9.II).

Indeed, the axis II separates the stations Ha1 and Ha3 in its negative part from the station Ha2 in its positive part. Stations Ha1 and Ha3 are associated with the following parameters: total phosphorus, pH, free chlorine and total chlorine. While the Ha2 station is linked to Nitrate, Speed, Phosphates and Oxidation-Reduction Potential. The taxa *Keratella cochlearis, K. lenzis, Lecane leontina* and *Colurella uncinata* are found in the Ha1 station. *Trichocerca rousseleti, T. chattoni, Testidunella neboisi, T. parva, Anuraeopsis navicula* and Harparthicoides copepods are found in the Ha2 station. Finally, at station Ha3 we found the taxa *Lecane bulla, L. closterocerca, Lepadella patella, Moina* sp., *M. micrura, Macrothrix rosea, Filinia longiseta, Filinia, terminalis, Mytilina crassipes* and Nauplius.

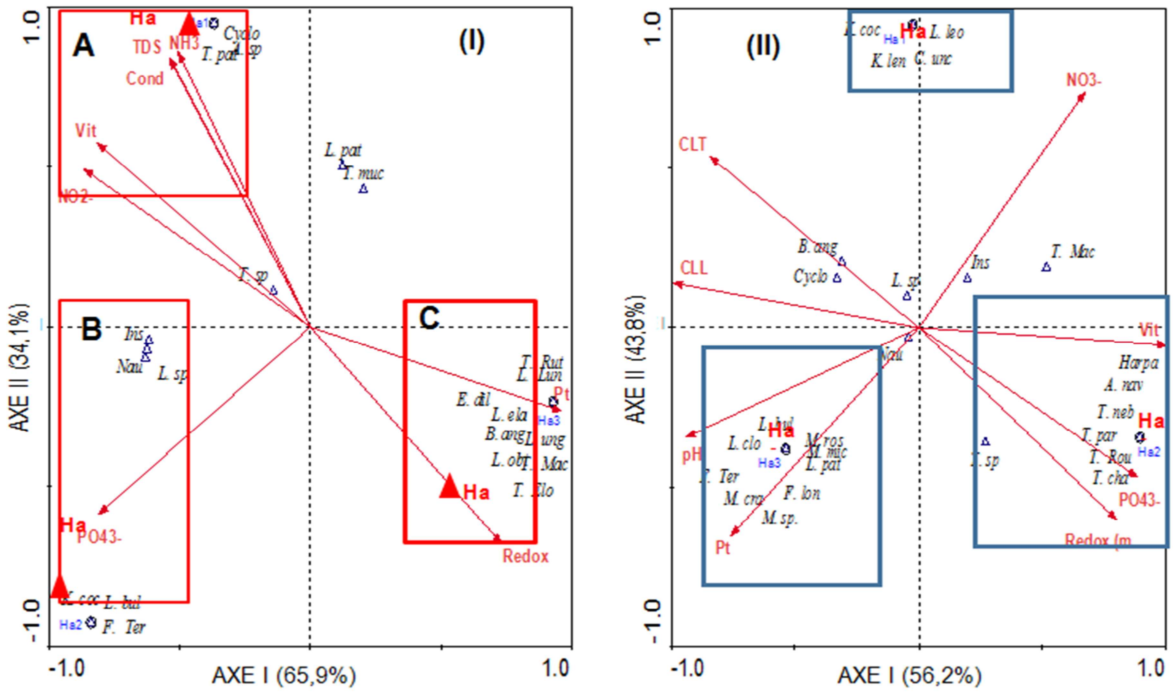

Fig. 9. CCA of physicochemical parameters data and zooplankton species collected in the river Hana of PNT in rain season (I) and in dry season (II). Pt: Total phosphorus, NO_2^-: Nitrite, Vit: Velocity, PO_4^{3-}: Phosphates, Redox: Oxidation reduction potential, TDS: Dissolved Solids Rate, Cond: Conductivity et NH_4^+: Ammonium.

Discussion

The values of the various abiotic factors observed showed that the watercourses considered have almost the same physicochemical characteristics, despite some significant differences ($p < 0.05$) observed for certain parameters in one station to another. This similarity in the values of physicochemical parameters may be related to the characteristics of the watershed quite similar in this region. Indeed, these rivers source their waters from the geological substrates that have very close physicochemical properties (the dominant soils are ferralitic strongly desaturated (OIPR, 2014). In contrast, a significant difference in oxygen level is observed in Ha1 and the stations Ha2 and Ha3. The Ha1 station is located in a rural area and is subjected to anthropogenic pollution from peripheral areas. Indeed, this position makes the Ha1 station a real receptacle of runoff that drains the top soil mixed with fertilizer. This will cause a natural cleaning reaction by the river, thus involving aerobic bacteria. All this would contribute to a decrease in the level of dissolved oxygen (CCME, 1999). The high concentrations of free chlorine in the peripheral stations originate from the household activities carried out at these stations by the local population. The present study has collected 36 zooplankton taxa (Table 4) from the Hana River of the TNP dominated by the rotifers (28 taxa). Such taxonomic richness with rotifer dominance has already been reported in other tropical lotic ecosystems (Egborge & Tawari, 1987 in the Warri River in Nigeria; Onwudinjo & Egborge, 1994 in the rivers of Benin; Foto Menbohan *et al.*, 2006 in the tropical hydrosystems of Cameroon; Arimoro and Oganah, 2010 in the Niger Delta; Ouattara *et al.*, 2007 in Bia and N'Da *et al.*, 2015 in Bagoué, Côte d'Ivoire). The results obtained indicate a large spatial variability in the richness and abundances of the zooplankton species that populate the different study stations. The highest species richness and highest abundances are observed in the station Ha3. While the lowest abundances and the lowest in terms of the specific richness are obtained in the Ha1 and Ha2 stations. This shows that this part of the Hana River offers better conditions for the development of the zooplankton population.

It is characterized by low mineralization (conductivity, TDS, ammonium and nitrite) and a relatively high oxygen level. These observations are in agreement with those of Vannote *et al.* (1980), Lecerf (2005) who showed the efficiency of the fluvial system to produce living matter in downstream areas of rivers following the formation of retention zones of organic matter (dead arm, lentil facies). The maximum in the abundance of the zooplankton population observed in the Ha3 station would also be due to the passive drift of the organisms towards the points situated downstream of the rivers (Bournaud and Thibault, 1973) also of the natural self-purification potential of the forest mass favoring proliferation conditions for these organisms. However, the low abundance of the zooplankton population in the Ha1 and Ha2 stations could be explained by the relatively advanced state of degradation of these stations. In actual fact, the Ha1 station is situated at the point of entry to the Hana River in the park, but this part of the peripheral area of the TNP is a major agricultural zone for cash crops farming (cocoa, coffee and rubber). This position makes the Ha1 station a real receptacle for runoff that drains the topsoil mixed with fertilizer. This will cause a natural cleaning reaction by the river, thus involving aerobic bacteria. All this would contribute to a decrease in the level of dissolved oxygen (CCME, 1999). It is therefore an important source of diffuse pollution that negatively impacts the ecological quality of the hydrosystems of this important aquatic ecosystem. According to Fagrouch *et al.* (2011), the taxonomic richness decreases with the increase in the degradation of the water quality. Similarly, Fromentin and Planque (1996), Beaugrand *et al.* (2003) and Omondi *et al.* (2011) found that taxonomic richness is sensitive to the impact of human activities on aquatic ecosystems, particularly zooplankton, which is often a good indicator of the environmental conditions of the freshwater. Low values in taxonomic richness and low zooplankton abundance in the most polluted parts of an aquatic ecosystem have already been observed by Foto Menbohan *et al.* (2012). These results are corroborated by the different Organic Pollution Index (OPI) calculated in these stations. The index revealed a high organic pollution (OPI = 2.67) in the Ha1 and Ha2 stations while the latter is moderate upstream of the river (in Ha3, OPI = 3). Seasonal variability in the richness and abundance of zooplankton in the Hana River stations was very marked by a statistically significant difference ($p < 0.05$) between the rainy season and the dry season. A similar result was obtained by N'da *et al.*, 2015 in Bagoé in Ivory Coast, Imoobe and Adeyinka (2009) in the tropical rivers of Nigeria, Onana *et al.,* 2014 in the rivers of Nigeria, Wouri in Cameroon and Kuczynski (1996) in Argentina. The high values of species richness and abundance in the dry season in all stations are justified by the fact that during the dry season, the waters are relatively calm and have many facies favorable to the proliferation of these organisms; which is not the case in the period of heavy rain when strong currents and flows are unfavorable to the installation of planktonic organisms. The distribution of the zooplankton population is determined significantly by several environmental variables total phosphorus, nitrite, ammonium, phosphates, oxidation-reduction potential, current velocity, TDS and Conductivity. Regarding to the last four parameters, our result agrees with those of N'Da *et al.,* 2015 and Ouattara *et al.,* 2001.

The CCA (Fig. 9) clearly separates the Ha3 station from the Ha1 and Ha2 stations on its axis I (expresses more than 50% of the data) in both seasons. These last two stations are characterized by a strong mineralization (conductivity, TDS, ammonium and nitrite) and a high current velocity during the rainy season. A high abundance of the species *Testudinella patina* observed in the station Ha1 would indicate an eutrophication state more or less advanced. Indeed according to Sladecek (1983), this species is a beta-mesosaprobie with a degree of saprobia of 7 corresponding to a bioindicator of eutrophic environments. In actual fact, the region of soubre is known to be one of the biggest coffee and cocoa producing region in Côte d'Ivoire. This good yield is as a result of a considerable utilization of agricultural inputs allowing a better fertilization of the soil.

Therefore, during the rainy season, Ha1 serve as a receptacle for runoffs from peripheral areas where agricultural activities are being practiced.

On the other hand, the presence of the species *Keratella cochlearis* (oligosaprobite, 5), *Lecane bulla* and *Filinia terminalis* (oligosaprobite and beta-mesosaprobite, 3-5 and 6-4 respectively) in the station Ha2 and the species *Trichocerca ruttneri, T. elongata, T. macera* (oligosaprobite, 8, 8 and 10 respectively), *Euchlanus dilatata, Lecane lunaris, L. ungulata,* (oligosprobite and beta-mesosaprobite, 3-5, 3-4 and 5-5, respectively) and *Brachionus angularis* (beta-mesosaprobite and alpha-mesosaprobite; 5-5) in the station Ha3 shows the oligotrophic character of the environment (Sladecek, 1983) showing a progressive self-purification from upstream to downstream of this river.

Conclusion

This study gave the taxonomic composition of the zooplankton population of the Hana River for the first time. It shows that population abundance and diversity vary according to seasons and location. It is dominated by Rotifers qualitatively and quantitatively. The Rotifer species found in the stations consist essentially of the species indicators of oligotrophic and eutrophic environments proliferating abundantly in this stream. The distribution of these species is mainly associated with 8 parameters, they are: total phosphorus, nitrite and velocity, which best express this distribution. Therefore, the Hana River is of good ecological quality in terms of zooplankton composition, however a drastic measure must be taken against the growing agricultural activities in the surrounding areas for better preservation of the Taï National Park.

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