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Spatio-temporal distribution of Naididae tubificids species and bio-evaluation of the quality of some surface water bodies of Yaoundé, Cameroon

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Despite their great interest for the integrated management of water resources, information on the ecology of aquatic oligochaetes is still sketchy in Cameroon. The present study aims at contributing to the knowledge on the distribution, microhabitat and life history of Naididae tubificids taxa in some eight water bodies of the city of Yaoundé. A total of 132 samples were analysed and the morphospecies *Branchiura* spp. and *Limnodrilus* spp. were identified. The most abundant species were *Branchiura* spp. with 2035 individuals versus 880 *Limnodrilus* spp. Both of them demonstrate low seasonal variations. It appeared that, these annelids are more abundant on clay-rich soils than on sand and the herbarium. Assessment of the organic pollution index indicates an organic pollution of the sampled waters ranging from moderate to high (3.67-2). The redundancy canonical analysis shows that *Branchiura* spp. are more present in saline waters revealing high organic pollution factors variables. During the study period, some 10 individuals of *Limnodrilus* spp. presented a shrunken tail. That reveals a strong environmental pressure due to the action of predators or the presence of heavy metals in the aquatic system evaluated. All these characteristics indicate a high pollution and predation pressure in the milieu.

Key words: Annelids oligochaete, ecology, bottom nature, polluted water.

INTRODUCTION

In the city of Yaoundé, which is the political capital of Cameroon, surface water is used for the production of drinking water, irrigation of crops in urban agriculture, fish farming activities (aquaculture), recreation, and the list is very extensive. Nevertheless, due to uncontrolled urbanization, these waters are subject to very high pollution (Kemka et al., 2004; Zébazé et al., 2006; Ebang et al., 2012; Ajeegah et al., 2014; Kapso et al.,

2018; Ngong et al., 2019). In fact, since the population grows faster than the basic public services, a drastic lack of sanitary infrastructures is noticed. Consequently, almost 82.8% of the untreated wastewater is directly discharged into the environment (Ngambi, 2015) and this alters the quality of the natural resource.

For a good monitoring of the surface water bodies, aquatic oligochaetes can be an important ecological

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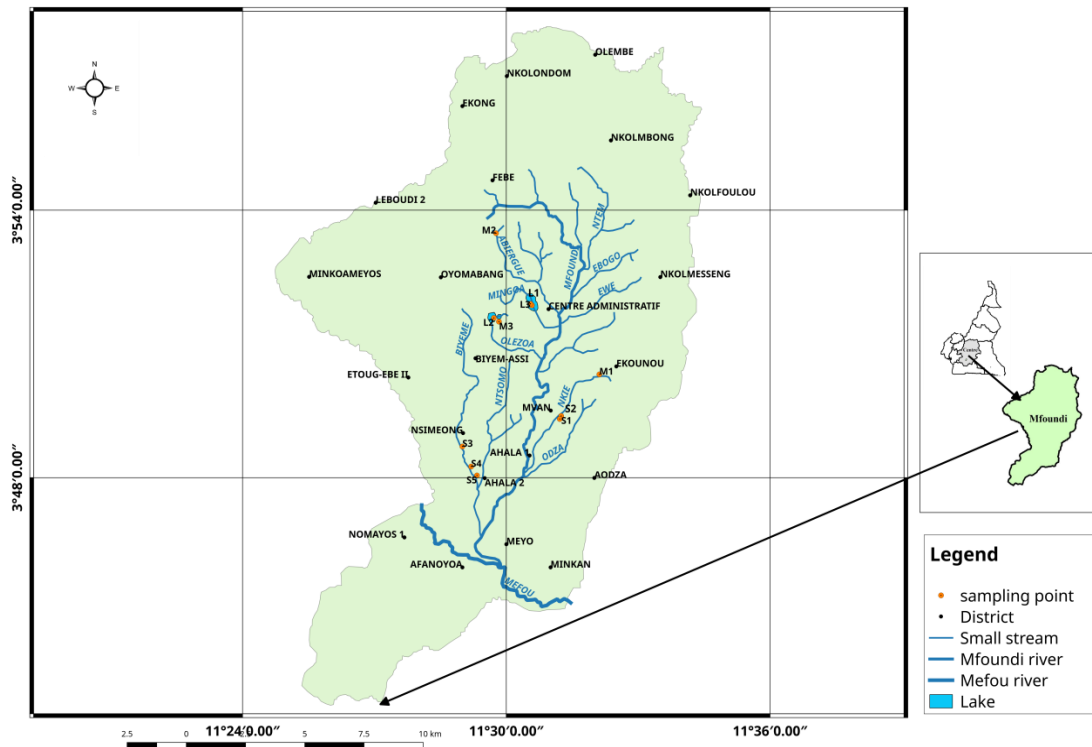


Figure 1. Map showing sites in the aquatic system in Yaoundé (Cameroon).

tool. The application of Naididae, especially those belonging to the group of tubificids as bioindicators of water quality, is quite common in ecological studies (Vivien et al., 2011; Rodriguez and Renoldson, 2011; Vivien et al 2020). Naididae tubificids constitute a well-diversified group. It includes 6 subfamilies namely Limnodriloidinae, Phalodrilinae, Rhyacodrilinae, Rhyacodriloidinae, Telmatodrilinae and Tubificinae (Martin et al., 2008). All of them are endobenthic worms (Martin and Ait, 2012).

Due to their high resistance to organic pollution and their bioaccumulative capacity, most of them adapt to harsh environmental conditions (Schenkova and Helešic, 2006). Besides being excellent indicators of water quality, Naididae tubificids are also highly involved in the flux and the availability of organic matter and pollutants in the water body. For example, they play both a direct role in the elimination of heavy metals via their own metabolism (biodegradation, bioaccumulation, detoxification), and an indirect role (as the result of their bioturbation activities) through the modification of the physico-chemical conditions and the stimulation of sulfo-reducing and metallo-reducing bacteria (Lagauzère, 2008). However, despite their great interest for the integrated management of water resources, information on their ecology is still sketchy in Cameroon. Although several studies have been carried out on the group of macroinvertebrates (Foto, 2012; Ajeegah et al., 2013; Tchakonté, 2016; Ajeegah et al., 2018; Foto et al., 2019, 2021), the only recorded article dealing with the fauna of freshwater oligochaetes in Cameroon is that of Dahl (1957) on the banks of the Nyong in the localities of Mpoume, Makak and

Nenyanga. So this study aims at examining the spatio-temporal distribution of these organisms and evaluating the environmental parameters of the sampling sites in order to assess the quality of water.

METHODOLOGY

Sites and period of study

This study was conducted in the city of Yaoundé, that is located in the forest region of the southern plateau of Cameroon, between longitudes 11°20' and 11°40', latitudes 3°30' and 3°58'. This town is subject to an equatorial climate that is characterized by four seasons: the short rainy season (SRS) from March to June, the short dry season (SDS) from July to August the long rainy season (LRS) from September to November, and the long dry season (LDS) from late December to February (Sighomnou, 2004). This climate combined with the relief characterized by hills, valleys, the high density of the human population (Ngambi, 2015) and the extensive hydrographic network, favours urban agriculture in the city of Yaoundé.

This research was carried out from March 2016 to February 2017. The environmental parameters were measured following a monthly sampling frequency. Since metals are non-biodegradable and persist in the environment for a long time (Briffa et al., 2020), the heavy metals (Cd, Pb, Hg, Zn, Cr, Fe) were measured only once. Physico-chemical and biological data collected were assessed on seasonal basis (SRS, SDS, LRS, LDS). The sampling sites chosen (Figure 1) were taken into account on the different types of hydrosystems that can be found in the city. Five sampling sites were chosen on two streams (S1 and S2 on the Nkie stream, S3, S4 and S5 on the Biyeme stream). Three sampling points were chosen on three lakes (L1 on the Municipal lake, L2 on the Obili lake and L3 on the small Municipal lake). Three other sampling points were chosen on three different marshy areas (M1 at Tsinga, M2 at Ekounou and M3 at Ngoa Ekelle). Some characteristics of these points are given in Table 1.

Table 1. Characteristics of sampling sites.

Hydrosystem name	Sites	Anthropization	Used of the sampling point	Nature of substratum	Geographic coordinates		
					Latitude	Longitude	Altitude (m)
Nkie	S1	Separated two dwellings	Nothing	Sandy-clay	3° 49' 22.7"	11° 31' 15.4"	694
Nkie	S2	Isolated	Nothing	Sandy	3° 49' 18.9"	11° 31' 12.9"	703
Biyeme	S3	Located downstream of a field	Nothing	Muddy	3° 48' 42.3"	11° 29'	675
Biyeme	S4	Located near a car garage and a bar	Car and motor wash	Muddy	3° 48' 15.1"	11° 29' 12.3"	675
Biyeme	S5	located near a road under construction	Pump for irrigation of crops	Sand-muddy	3° 48' 03. 4"	11° 29' 19.6"	678
Municipal Lake	L1	Located in the centre of the city	Fishing	Herbarium	3°51' 52. 3"	11° 30' 34.7"	728
Obili Lake	L2	Bordered by fish ponds	Fishing	Herbarium	3° 51' 35"	11°29' 43"	720
Small Municipal Lake	L3	Located in the centre of the city	Fishing	Herbarium	3° 51' 53.9"	11° 30' 32.7"	727
Swamp at Tsinga	M1	Downstream a market and a car garage	Watering of livestock	Muddy	3° 50' 18.7"	11° 32' 07.2"	675
Swamp at Ekounou	M2	Near a big market garden	Irrigation of crops	Sandy-clay	3° 53' 28. 5"	11° 29' 45. 8"	752
Swamp at Ngoa Ekelle	M3	Behind a student housing estate	Irrigation of crops	Muddy	3° 51' 30"	11° 29' 50"	729

Physico-chemical analysis

The water temperature, potential of Hydrogen (pH), colour, suspended solids (SS), turbidity, alkalinity, salinity, electric conductivity, heavy metals, dissolved carbon dioxide (CO₂), dissolved oxygen (O₂), nitrogen compounds (NH₄⁺, NO₂⁻, NO₃⁻) and orthophosphate (PO₄³⁻) were measured according to the protocol of Rodier et al. (2009) and APHA (1990). The organic pollution index (Leclercq, 2001) was calculated in order to give a synthetic account of the degree of pollution of the water sampled by using the three basic parameters required in organic pollution evaluation, namely: ammoniacal nitrogen (NH₄⁺), nitrite (NO₂⁻) and orthophosphate ions (PO₄³⁻). This index allows to define 5 ecological quality classes of water that are: Zero pollution (4.6 ≤ IPO ≤ 5), low pollution (4.0 ≤ IPO ≤ 4.5), moderate pollution (3.0 ≤ IPO ≤ 3.9), high pollution (2.0 ≤ IPO ≤ 2.9), very high pollution (1 ≤ IPO ≤ 1.9) (Leclercq, 2001).

Biological analysis

The sampling of annelids was carried out by means of a net which is 30 cm × 30 cm dimension that is fixed to a handle and equipped with a conical thread of 100 µm Ø opening of mesh and 50 cm deep (Martin and Ait, 2012). The multihabitat

approach proposed by Stark et al. (2001) and adapted from Barbour et al. (1999), which consists of a total of 20 shots, equivalent to an approximate surface area of 3 m² in a station of 100 m long was applied. After sampling, organisms were fixed in 10% formalin for a maximum of 24 h; they were then rinsed and stored in 70% alcohol-contained in pill bottles (Morgan and Morgan, 1990; Martin and Ait, 2012). In the laboratory, each oligochaete specimen was placed in a drop of glycerine which allows, because of its lightening power, to observe the external and internal structures of the organism under an optical microscope equipped with a camera. The identification was carried out using the keys proposed by Brinkhurst (1985) and Martin and Ait (2012). Mature individuals were distinguished from immature by their larger size and the presence of a clitellum. The species richness (S) of each community and the abundance of each population were sought.

Statistical analysis

The software Microsoft Office Excel 2007, SPSS 20. 0 and XLSTAT 11.0 made it possible to: (i) establish the descriptive statistics of individuals and sites (summaries tables, redundancy canonical analysis); (ii) measure the robustness of the spatio-temporal distribution of biological variables using the

Kruskal-Wallis test associated with the Mann-Whitney "U" test. (iii) calculate the Spearman "r" coefficient between the abundance of organisms and the characteristics of the biotope. The differences observed are significant at 1 and 5% safety thresholds.

RESULTS

Spatio-temporal variations of physico-chemical parameters of water

The physico-chemical results of our sampling points are presented in Table 2 (central values of physico-chemical parameters), Table 3 (seasonal values of physico-chemical parameters) and Table 4 (values of heavy metals in each site). As lakes and swamps are stagnant waters, the velocity of water flow has only been assessed in the streams. The highest flow was recorded at S5 and the lowest at S2 (p < 0.05). The highest temperature values were recorded in lakes and the lowest in streams. However, within each type

of ecosystem the temperature variations were not significant ($p > 0.05$). There was no significant difference for suspended solids, colour turbidity, pH and carbon dioxide contain within or between ecosystems. However swamps more often had relatively higher values. Sampled water, with values ranging from 7.14 ± 0.83 to 7.83 ± 0.48 were slightly basic while relatively higher values of CO_2 were recorded in swampy areas. Electrical conductivity, total dissolved solid, and alkalinity followed almost the same spatial and temporal variations. Mean values of these parameters were significantly lower in lakes than in swamps and stream sites ($p < 0.05$). In stream sites, the lower values were obtained at stations S1 and S2. In lakes, values obtained at L3 were significantly lower than those obtained at L2 and L1 ($p < 0.05$). In swamps the lower values of that parameters were recorded at M2 ($p < 0.05$).

Values of salinity were more important in streams and marshes than in lakes ($p < 0.05$). Within the stream ecosystem, the salinity of water at S3 was significantly higher than at S1 and S2. In the other types of ecosystems, the salinity of water did not vary significantly between the different sampling sites. Values of orthophosphates, nitrites, nitrates and ammonia nitrogen did not significantly differ from one station to another within each ecosystem. However, nitrates were significantly higher in swamps than in streams and lakes. The mean values of dissolved oxygen did not vary significantly within and between ecosystems, nor the organic pollution index (OPI) values which indicated an organic pollution of the sampled waters essentially ranging from moderate (3.06 ± 0.75 at S2 and 3.00 ± 0.86 at S1) to high (from 2.86 ± 0.73 to 2.42 ± 0.38 in the rest of sampling sites). Values of the physico-chemical parameters, except for OPI, were comparable between the seasons ($p > 0.05$). In streams and lakes, the highest values of OPI were obtained during the SRS and the lowest values during the LDS ($p < 0.05$). In swampy areas, the highest values of OPI were obtained during the SDS. These were significantly higher than those obtained during the LRS and LDS (Table 3).

The highest values of heavy metals were registered in swamps (Cd: 9.51 ± 8.35 $\mu\text{g/L}$, Pb: 1.02 ± 1.63 $\mu\text{g/L}$, Hg: 7.35 ± 12.60 $\mu\text{g/L}$, Zn: 1.77 ± 2.98 $\mu\text{g/L}$, Cr: 0.37 ± 0.57 $\mu\text{g/L}$, Fe: 124.85 ± 171.75 $\mu\text{g/L}$). Streams were the least rich in Cd (0.43 ± 0.64 $\mu\text{g/L}$), Pb (0.09 ± 0.08 $\mu\text{g/L}$), and Hg (0.06 ± 0.08 $\mu\text{g/L}$), while the lakes were the least rich in Zn (0.82 ± 0.20 $\mu\text{g/L}$), Cr (0.05 ± 0.04) and Fe (14.88 ± 16.08 $\mu\text{g/L}$) (Table 4).

Spatial distribution of Naididae

A total of 2035 *Branchiura* spp. individuals (1789 adult and 246 immature) and 880 *Limnodrilus* spp. (678 mature and 202 immature) were identified (Table 5). About 10 individuals of *Limnodrilus* spp. presented shrunken tail. *Branchiura* spp. as well as *Limnodrilus* spp. abundance varied significantly from one ecosystem to another following the profile: swampy areas (30 ± 20

Branchiura spp., 14 ± 21 *Limnodrilus* spp.) > streams (15 ± 11 *Branchiura* spp., 6 ± 9 *Limnodrilus* spp.) > lakes (2 ± 2 *Branchiura* spp., 2 ± 2 *Limnodrilus* spp.). No organism was collected at L3. Concerning the distribution of *Branchiura* spp. in streams, with a mean abundance of 31 ± 7 individuals, S3 was the most populated site ($p < 0.05$). *Limnodrilus* spp were not collected at S2. At the other stream stations, their abundance was lower in S5 (1 ± 1 individual).

In lake systems, no significant difference was revealed in spatial distribution of taxa ($p > 0.05$). In swampy areas, the abundance of *Branchiura* spp. was significantly higher at M2 (45 ± 15 individuals) and that of *Limnodrilus* spp. at M3 (26 ± 31 individuals). *Branchiura* spp. were overall more abundant than *Limnodrilus* spp. in streams and marshes ($p < 0.05$) and not different in lakes ($p > 0.05$). In streams and marshes, *Branchiura* spp. were always the more abundant taxa in all sites except at S1 and M3 where the both taxa were equally abundant.

Seasonal distribution of Naididae

Table 6 shows no significant seasonal variation of the abundance of *Branchiura* spp. and *Limnodrilus* spp. within each ecosystem ($p > 0.05$). More than 87% of *Branchiura* spp. specimens and 75% of *Limnodrilus* spp. specimens were mature during all seasons.

Density of the populations

With a median density of 8 individuals/ m^2 (Figure 2a), *Branchiura* spp. were significantly more abundant in the mud and sand/clay substrates than in the other ones (herbal, sandy and sand/mud), where the density of these oligochaetes fluctuated between 1 to 3 individuals/ m^2 . Similarly, the density of *Limnodrilus* spp. (Figure 2b) was significantly higher in the mud ($0-39$ individuals/ m^2) as well as in the sand/clay substrates ($0-19$ individual/ m^2). This taxa was not found in the sand while in the sand-mud substrate, it could reach 1 individual/ m^2 . In herbarium, the density of this taxa fluctuated between 0 to 4 individuals/ m^2 .

Influence of environmental parameters on the dynamics of organisms

The water temperature and the organic pollution index were negatively and often significantly correlated with the abundance of all the maturity stages of both taxa. All the other parameters (electrical conductivity, alkalinity, total dissolved solids, salinity, orthophosphate and water velocity) were positively and often significantly correlated to the abundance of the mature stages of these oligochaetes. Nitrate was positively and only significantly correlated to mature *Branchiura* spp. and negatively but not significantly correlated to mature stage of *Limnodrilus* spp. (Table 7).

Table 2. Central values of physico-chemical parameters at each station.

Ecosystems	Stations	Velocity (m/s)	Temperature (°C)	Turbidity (FTU)	Colour (Pt-Co)	SS (mg/L)	pH (UC)	CO ₂ (mg/L)	Alkalinity (mg/L)	TDS (mg/L)
Streams	S1	0.43±0.14 ^b	25.3±1.52 ^a	26.1±38.1 ^a	122.8±133.6 ^a	17.2±19.6 ^a	7.29±0.36 ^a	16.96±8.15 ^a	28.2±11.7 ^b	121.3±16.4 ^b
	S2	0.09±0.03 ^c	25.38±0.85 ^a	37.0±30.9 ^a	141.8±131.1 ^a	26.7±18.0 ^a	7.14±0.83 ^a	15.65±9.69 ^a	27.1±7.4 ^b	134.2±9.1 ^b
	S3	0.34±0.1 ^b	25.18±0.65 ^a	22.6±19.8 ^a	140.9±95.5 ^a	14.9±8.4 ^a	7.59±0.37 ^a	17.77±4.21 ^a	55.01±13.0 ^a	231.6±9.8 ^a
	S4	0.71±0.15 ^b	25.48±0.82 ^a	24.7±19.7 ^a	115.5±48.3 ^a	14.2±10.6 ^a	7.80±0.34 ^a	17.57±9.17 ^a	55.3±14.0 ^a	221.5±26.3 ^a
	S5	1.00±0.26 ^a	25.67±0.75 ^a	27.7±27.1 ^a	109.0±53.9 ^a	16.3±11.0 ^a	7.72±0.28 ^a	17.95±6.20 ^a	50.8±8.1 ^a	199.0±35.7 ^a
Average values of Rivers		0.51±0.35	25.44±0.95^c	27.6±27.4^a	126.0±96.9^a	17.8±14.5^a	7.51±0.53^a	17.18±7.53^a	43.3±16.9^a	181.5±50.4^a
Lakes	L1	/	28.57±0.83 ^a	26.3±25.5 ^a	91.5±40.2 ^a	19.5±11.1 ^a	7.83±0.48 ^a	17.18±11.80 ^a	29.7±12.5 ^a	133.4±38.9 ^a
	L2	/	29.18±1.11 ^a	30.0±25.9 ^a	146.4±95.4 ^a	19.8±11.7 ^a	7.56±0.49 ^a	17.01±8.20 ^a	31.9±12.5 ^a	134.2±15.5 ^a
	L3	/	28.71±0.92 ^a	28.3±36.5 ^a	106.1±78.9 ^a	16.8±15.0 ^a	7.42±0.45 ^a	16.11±7.97 ^a	14.3±4.6 ^b	68.5±47.8 ^b
	Average values of Lakes		/	28.82±0.97^a	28.22±28.95^a	114.7±76.7^a	18.7±12.4^a	7.60±0.49^a	16.77±9.22^a	25.28±12.99^c
Marshes	M1	/	26.35±1.31 ^a	26.4±27.6 ^a	99.3±55.5 ^a	21.4±21.3 ^a	7.55±0.28 ^a	21.50±14.02 ^a	43.3±10.0 ^a	219.9±64.2 ^a
	M2	/	26.48±1.62 ^a	47.5±57.9 ^a	156.3±178.6 ^a	53.8±71.0 ^a	7.49±0.42 ^a	24.22±25.92 ^a	24.5±13.4 ^b	111.8±29.6 ^c
	M3	/	26.74±1.00 ^a	26.4±30.7 ^a	160.1±87.0 ^a	20.9±15.9 ^a	7.48±0.37 ^a	21.47±16.91 ^a	31.8±10.8 ^a	158.4±34.8 ^b
	Average values of Marshes		/	26.52±1.31^b	33.4±41.1^a	138.5±119.0^a	32.0±45.2^a	7.51±0.35^a	22.40±19.09^a	33.2±13.6^b
		Electric conductivity (µS/cm)	Salinity (‰)	PO₄³⁻ (mg/L)	NO₂⁻ (mg/L)	NO₃⁻ (mg/L)	NH₄⁺ (mg/L)	O₂(%)	OPI	
Streams	S1	243.2±32.8 ^b	0.11±0.01 ^b	1.20±1.38 ^a	1.95±3.30 ^a	1.41±0.86 ^a	0.47±0.89 ^a	47.53±24.40 ^a	3.00±0.86 ^a	
	S2	271.8±18.6 ^b	0.13±0.01 ^b	3.65±4.48 ^a	1.30±3.17 ^a	2.21±1.20 ^a	0.49±0.65 ^a	47.32±22.19 ^a	2.81±0.67 ^a	
	S3	459.5±22.2 ^a	0.29±0.20 ^a	2.40±2.75 ^a	1.52±3.01 ^a	2.59±1.92 ^a	0.93±2.11 ^a	47.78±20.43 ^a	2.64±0.78 ^a	
	S4	438.1±55.9 ^a	0.22±0.03 ^{ab}	2.06±2.73 ^a	1.76±3.27 ^a	1.96±1.40 ^a	0.26±0.32 ^a	46.14±20.73 ^a	2.75±0.67 ^a	
	S5	436.3±38.6 ^a	0.21±0.02 ^{ab}	1.09±1.58 ^a	3.30±6.27 ^a	2.40±1.49 ^a	0.18±0.10 ^a	47.74±19.55 ^a	3.06±0.75 ^a	
Average values of Rivers		369.7±99.5^a	0.19±0.11^a	2.08±2.87^a	1.97±3.92^a	2.11±1.42^b	0.46±1.07^a	47.30±20.80^a	2.85±0.74^a	
Lakes	L1	295.0±62.1 ^a	0.14±0.03 ^a	0.90±1.35 ^a	2.43±4.83 ^a	3.33±4.14 ^a	0.43±0.90 ^a	47.22±22.74 ^a	2.83±0.69 ^a	
	L2	261.0±55.9 ^a	0.11±0.03 ^a	1.69±2.48 ^a	1.48±1.54 ^a	2.83±1.48 ^a	0.19±0.13 ^a	51.80±20.78 ^a	2.78±0.73 ^a	
	L3	129.3±47.7 ^b	0.07±0.03 ^a	2.02±2.49 ^a	1.48±1.57 ^a	1.47±0.98 ^a	0.15±0.12 ^a	49.77±20.21 ^a	2.86±0.73 ^a	
	Average values of Lakes		228.4±90.3^c	0.10±0.04^b	1.53±2.16^a	1.80±3.01^a	2.54±2.65^b	0.25±0.53^a	49.59±20.74^a	2.82±0.70^a
Marshes	M1	444.4±112.3 ^a	0.22±0.05 ^a	1.70±2.16 ^a	1.65±2.04 ^a	4.12±2.87 ^a	0.13±0.07 ^a	55.19±18.04 ^a	2.42±0.38 ^a	
	M2	215.3±54.7 ^c	0.18±0.23 ^a	2.40±2.41 ^a	1.97±2.34 ^a	5.30±4.88 ^a	0.47±0.77 ^a	59.37±14.02 ^a	2.53±0.73 ^a	
	M3	300.5±39.1 ^c	0.14±0.02 ^a	2.57±3.83 ^a	1.07±1.41 ^a	3.53±3.18 ^a	0.22±0.19 ^a	52.94±17.59 ^a	2.61±0.45 ^a	
	Average values of Marshes		320.1±120.7^b	0.18±0.14^a	2.22±2.84^a	1.56±1.95^a	4.32±3.72^a	0.27±0.47^a	55.83±16.39^a	2.52±0.53^a

Values in bold = ecosystem averages. Values in simple character = station means. On each column, Means values within each ecosystem with same letter = no significant difference, while those with different letters = significant difference. Between ecosystem types, means values with same letter = no significant difference, while those with different letters = significant difference.

Table 3. Seasonal values of physico-chemical parameters.

Ecosystems	Seasons	Velocity (m/s)	Temperature (°C)	Turbidity (FTU)	Colour (Pt-Co)	SS (mg/L)	pH (UC)	CO ₂ (mg/L)	Alkalinity (mg/L)	TDS (mg/L)
Streams	SRS	0.63±0.37 ^a	25.47±1.28 ^a	23.6±25.2 ^a	151±135.6 ^a	16.3±12.8 ^a	7.53±0.42 ^a	19.48±13.14 ^a	45.2±16.8 ^a	180.9±54.1 ^a
	SDS	0.45±0.30 ^a	24.67±0.61 ^a	49.5±29.9 ^a	168.3±147.9 ^a	26.9±16.9 ^a	7.38±0.18 ^a	16.54±5.61 ^a	38.5±14.3 ^a	189.2±50.0 ^a
	LRS	0.63±0.42 ^a	25.41±0.82 ^a	14.5±10.7 ^a	84.2±31.1 ^a	11.2±7.3 ^a	7.38±0.39 ^a	17.76±3.53 ^a	45.7±17.4 ^a	179.3±51.5 ^a
	LDS	0.38±0.26 ^a	25.85±0.67 ^a	29.6±30.9 ^a	117.5±104.5 ^a	19.5±16.5 ^a	7.65±0.76 ^a	15.35±4.08 ^a	42.4±18.3 ^a	179.8±50.6 ^a
Lakes	SRS	/	29.01±1.44 ^a	22.1±25.2 ^a	108.9±113.1 ^a	13.9±10.8 ^a	7.51±0.40 ^a	20.34±15.94 ^a	26.0±11.0 ^a	114.4±47.5 ^a
	SDS	/	28.30±0.40 ^a	55.2±36.4 ^a	176.0±85.7 ^a	26.8±11.8 ^a	7.32±0.15 ^a	15.54±5.41 ^a	23.8±8.0 ^a	106.8±41.8 ^a
	LRS	/	28.83±0.94 ^a	16.9±13.1 ^a	100.1±41.3 ^a	13.7±9.0 ^a	7.46±0.46 ^a	17.80±3.10 ^a	21.3±10.2 ^a	112.0±54.3 ^a
	LDS	/	28.93±0.77 ^a	27.8±30.8 ^a	99.4±48.3 ^a	22.1±14.0 ^a	7.93±0.55 ^a	13.93±6.69 ^a	28.4±17.9 ^a	112.8±50.4 ^a
Marshes	SRS	/	27.41±1.51 ^a	20.7±19.5 ^a	128.1±93.3 ^a	13.3±10.1 ^a	7.74±0.21 ^a	34.61±26.03 ^a	25.9±10.8 ^a	173.2±49.6 ^a
	SDS	/	26.15±1.33 ^a	55.6±42.2 ^a	172.3±105.2 ^a	52.8±43.8 ^a	7.31±0.19 ^a	23.80±5.67 ^a	35.8±14.4 ^a	162.3±48.1 ^a
	LRS	/	26.19±0.79 ^a	52.7±66.6 ^a	185.5±185.1 ^a	51.4±76.8 ^a	7.25±0.33 ^a	17.80±3.46 ^a	32.0±17.9 ^a	146.9±59.4 ^a
	LDS	/	26.30±1.28 ^a	17.43±9.5 ^a	94.2±64.2 ^a	21.1±18.0 ^a	7.63±0.36 ^a	15.99±2.65 ^a	38.3±10.1 ^a	168.8±82.9 ^a
		Electric conductivity (µS/cm)	Salinity (‰)	PO₄³⁻ (mg/L)	NO₂⁻ (mg/L)	NO₃⁻ (mg/L)	NH₄⁺ (mg/L)	O₂(%)	OPI	
Streams	SRS	359.9±107.1 ^a	0.22±0.20 ^a	2.22±4.72 ^a	5.86±6.15 ^a	2.60±1.55 ^a	0.19±0.15 ^a	36.83±25.74 ^a	3.33±0.77 ^a	
	SDS	378.2±99.5 ^a	0.19±0.07 ^a	1.53±1.41 ^a	0.07±0.13 ^a	2.67±0.99 ^a	0.55±0.44 ^a	54.36±13.52 ^a	2.77±0.50 ^b	
	LRS	365.8±102.7 ^a	0.18±0.05 ^a	2.51±2.50 ^a	0.17±0.33 ^a	1.85±1.07 ^a	0.11±0.10 ^a	40.35±23.89 ^a	2.91±0.60 ^{ab}	
	LDS	376.0±98.5 ^a	0.18±0.05 ^a	1.93±1.82 ^a	1.34±1.73 ^a	1.66±1.63 ^a	0.89±1.76 ^a	56.84±10.06 ^a	2.48±0.75 ^c	
Lakes	SRS	230.9±95.3 ^a	0.11±0.05 ^a	0.64±1.28 ^a	3.63±4.94 ^a	3.58±4.86 ^a	0.08±0.09 ^a	37.09±28.05 ^a	3.44±0.69 ^a	
	SDS	213.6±83.6 ^a	0.01±0.03 ^a	0.72±0.83 ^a	0.04±0.04 ^a	3.05±1.72 ^a	0.32±0.22 ^a	55.38±15.36 ^a	3.17±0.51 ^b	
	LRS	209.1±81.0 ^a	0.10±0.04 ^a	1.99±2.30 ^a	0.94±0.99 ^a	2.02±0.96 ^a	0.10±0.04 ^a	48.28±19.55 ^a	2.63±0.42 ^c	
	LDS	248.5±102.6 ^a	0.11±0.05 ^a	2.27±2.79 ^a	1.94±2.31 ^a	1.89±1.19 ^a	0.47±0.87 ^a	57.07±14.24 ^a	2.33±0.53 ^d	
Marshes	SRS	317.7±90.8 ^a	0.24±0.25 ^a	3.81±4.42 ^a	3.27±2.99 ^a	3.33±3.41 ^a	0.14±0.20 ^a	62.09±17.57 ^a	2.56±0.60 ^{ab}	
	SDS	312±89.9 ^a	0.17±0.06 ^a	1.37±1.09 ^a	0.13±0.21 ^a	3.85±1.03 ^a	0.23±0.14 ^a	61.47±7.88 ^a	2.78±0.69 ^a	
	LRS	297.1±104.7 ^a	0.15±0.08 ^a	2.61±2.64 ^a	0.86±0.94 ^a	6.63±5.46 ^a	0.59±0.85 ^a	49.03±18.83 ^a	2.37±0.56 ^b	
	LDS	343.1±166.4 ^a	0.17±0.08 ^a	1.16±1.39 ^a	1.53±1.00 ^a	3.55±2.73 ^a	0.15±0.12 ^a	53.42±5.83 ^a	2.47±0.36 ^b	

On each column, values with same letter = no significant difference, values with different letters = significant difference.

Table 4. Values of heavy metals in each station.

Types ecosystems/stations	Heavy metals ($\mu\text{g/L}$)						
	Cd	Pb	Hg	Zn	Cr	Fe	
Standards for crops irrigation (FAO, 2003)	10	5000	1	2000	100	5000	
Streams	S1	0.00	0.00	0.00	0.10	21.60	
	S2	0.01	0.13	0.00	2.90	0.18	212.74
	S3	0.26	0.03	0.20	1.20	0.01	125.00
	S4	0.36	0.21	0.05	0.32	0.23	109.20
	S5	1.54	0.08	0.04	0.14	0.05	112.00
	Mean	0.43 \pm 0.64	0.09 \pm 0.08	0.06 \pm 0.08	0.93 \pm 1.19	0.09 \pm 0.10	116.11 \pm 67.85
Lakes	L1	2.74	0.00	0.00	0.87	0.10	11.47
	L2	1.41	0.00	0.45	0.98	0.05	32.40
	L3	2.04	0.47	0.01	0.60	0.01	0.78
	Mean	2.06 \pm 0.67	0.16 \pm 0.27	0.15 \pm 0.26	0.82 \pm 0.20	0.06 \pm 0.05	14.88 \pm 16.08
Marshes	M1	0.23	0.12	0.00	0.00	0.03	321.80
	M2	11.9	2.9	0.16	5.21	1.02	46.5
	M3	16.4	0.04	21.9	0.1	0.04	6.25
	Mean	9.51 \pm 8.35	1.02 \pm 1.63	7.35 \pm 12.60	1.77 \pm 2.98	0.37 \pm 0.57	124.85 \pm 171.75

The canonical redundancy analysis (Figure 3) presents the environmental variables that described the distribution of Naididae tubificids in our sampling sites. This canonical redundancy analysis explains 58.5% of species-environment correlation with a variance of 70.2%. The distribution of species along axis 1 are explained by the electrical conductivity, the total dissolved solids, the salinity, the dissolved carbon dioxide, the alkalinity, the nitrates, the temperature and the Organic Pollution Index. Axis 2 is significantly correlated to suspended solids, orthophosphates, nitrates, salinity, dissolved carbon dioxide and the organic pollution index. Thus, conditions of high electrical conductivity, salinity, total dissolved solids content, alkalinity, nitrates and low

temperature values appeared favourable to the development *Branchiura* spp. while *Limnodrilus* spp. preferred environments that were rich in dissolved carbon dioxide and fairly poor in suspended solids, orthophosphates, nitrates and ammonium ions.

DISCUSSION

Oligochetes belonging to the genera of *Branchiura* (Beddard, 1892) and that of *Limnodrilus* (Claparède, 1862) were collected in the different sampling sites during the study period. Among these genera only the first one has already been identified in the surface water in Cameroon, precisely in urban streams of

Douala (Tchakonte, 2016). None of these has been identified in poor anthropized streams of the center and the west regions of Cameroon (Nyamsi, 2018; Kengne, 2018). Naididae tubificids are for the most characteristic of well mineralized and hypoxic milieu (Martin and Ait, 2012; Schenková and Helešic, 2006). Species belonging to the genus *Branchiura* have developed gills to cope with these harsh conditions (Martin and Ait, 2012). *Limnodrilus hoffmeisteri* also possesses a hemolymph that is rich in erythrocrucorine which can address easily low oxygen conditions (Martin and Ait, 2012). Therefore the high abundance of *Branchiura* spp. and *Limnodrilus* spp. in our milieu indicates the low oxygenation of these environments. This is justified by the non satisfied values of dissolved

Table 5. Relative abundance (%) of the various species of Oligochaetes collected at each station.

Station	Taxa (n _i ; \bar{X} ; %)		Total (n _i)
	<i>Branchiura</i> spp.	<i>Limnodrilus</i> spp.	
S1	138; 12±4 ^b ; 47.39±19.09 ^a	180; 15±14 ^a ; 52.61±19.09 ^a	318
S2	47; 4±2 ^b ; 100	/	47
S3	376; 31±7 ^a ; 83.38±6.22 ^a	77; 6±3 ^a ; 16.62±6.22 ^b	453
S4	207; 17±7 ^b ; 81.85±22.31 ^a	71; 6±8 ^a ; 18.15±22.31 ^b	278
S5	104; 9±6 ^b ; 91.37±7.59 ^a	9; 1±1 ^b ; 8.63±7.59 ^b	113
S_T	872; 15±11^b; 80.78±28.62^a	337; 6±9^b; 19.20±28.62^b	1209
L1	43; 4±2 ^a ; 58.91±37.30 ^a	31; 3±4 ^a ; 42.76±33.97 ^a	74
L2	34; 3±2 ^a ; 59.19±28.69 ^a	23; 2±1 ^a ; 40.81±20.69 ^a	57
L_T	77; 2±2^c; 59.05±32.54^a	54; 2±2^c; 40.95±31.02^a	131
M1	299; 25±16 ^b ; 70.20±24.60 ^a	130; 11±11 ^b ; 29.80±24.60 ^b	429
M2	542; 45±15 ^a ; 91.68±6.95 ^a	48; 4±4 ^b ; 8.32±6.95 ^b	590
M3	245; 20±21 ^b ; 43.16±25.77 ^a	311; 26±31 ^a ; 56.84±25.77 ^a	556
M_T	1087; 30±20^a; 68.35±22.47^a	489; 14±21^a; 31.65±22.47^b	1576

S_T = Total streams. L_T = Total lakes. M_T = Total marshes. Mean abundances within each ecosystem with same letter = no significant difference, while those with different letters = significant differences. Relative abundance (per station) of both taxa with same letter = no significant difference, while those with different letters = significant differences.

Table 6. Seasonal values of mean abundances of *Branchiura* spp. and *Limnodrilus* spp. in different ecosystems.

Ecosystems	Seasons	Taxa (n _i ; \bar{X})		Total (n _i)
		<i>Branchiura</i> spp.	<i>Limnodrilus</i> spp.	
Streams	SRS	253; 17±13 ^a	89; 6±15 ^a	342
	SDS	140; 14±10 ^a	39; 4±5 ^a	179
	LRS	187; 12±9 ^a	108; 7±6 ^a	295
	LDS	292; 15±11 ^a	101; 5±6 ^a	393
Lakes	SRS	28; 3±3 ^a	22; 2±4 ^a	50
	SDS	13; 2±2 ^a	4; 1±1 ^a	17
	LRS	15; 2±2 ^a	9; 1±1 ^a	24
	LDS	21; 2±3 ^a	19; 2±3 ^a	40
Marshes	SRS	457; 51±17 ^a	204; 23±38 ^a	661
	SDS	154; 26±11 ^a	59; 10±9 ^a	213
	LRS	175; 19±17 ^a	100; 11±14 ^a	275
	LDS	300; 25±19 ^a	126; 11±8 ^a	426

On each column, means values with same letter = no significant difference, those with different letters = significant difference.

oxygen in our samples (< 75%, Table 2).

The distribution of tubificids in our study sites is governed by many factors. The significant correlations between the indicators of water organic pollution (electrical conductivity, TDS, Salinity, Nitrates) and oligochaetes abundance (Table 7) indicate that these organisms prefer polluted water. Schenková and Helešic (2006) obtained similar results in a small stream in the Czech Republic, where the abundance of the oligochaetes community was significantly and positively correlated with the electrical conductivity and nitrate. Water temperature was negatively and significantly correlated with the abundance of *Branchiura* spp. and *Limnodrilus* spp. This physical parameter varies between 21.9 and 31°C in this tropical

area (Table 2). As the Naididae originate from temperate zones (Timm, 1980), we suggest that the above species are sensitive to some degree of heat. In fact, Timm (2020) demonstrates that the reproductive capacity of Oligochaetes decreases at elevated temperatures (25° to 35°C). In the literature, we also notice that the reproduction rate of *Branchiura sowerbyi*, for example, declines when the water temperature exceeds 25°C (Aston and Miler, 1982; Bonacina et al., 1994).

No specimen of *Limnodrilus* spp. was collected at S2. The lower pH values obtained at this station (sometimes 5UC) could justify this result. Roff and Kwiatkowski (1977) also observed the absence of *L. hoffmeisteri* in lakes with a pH below 6.6. As with

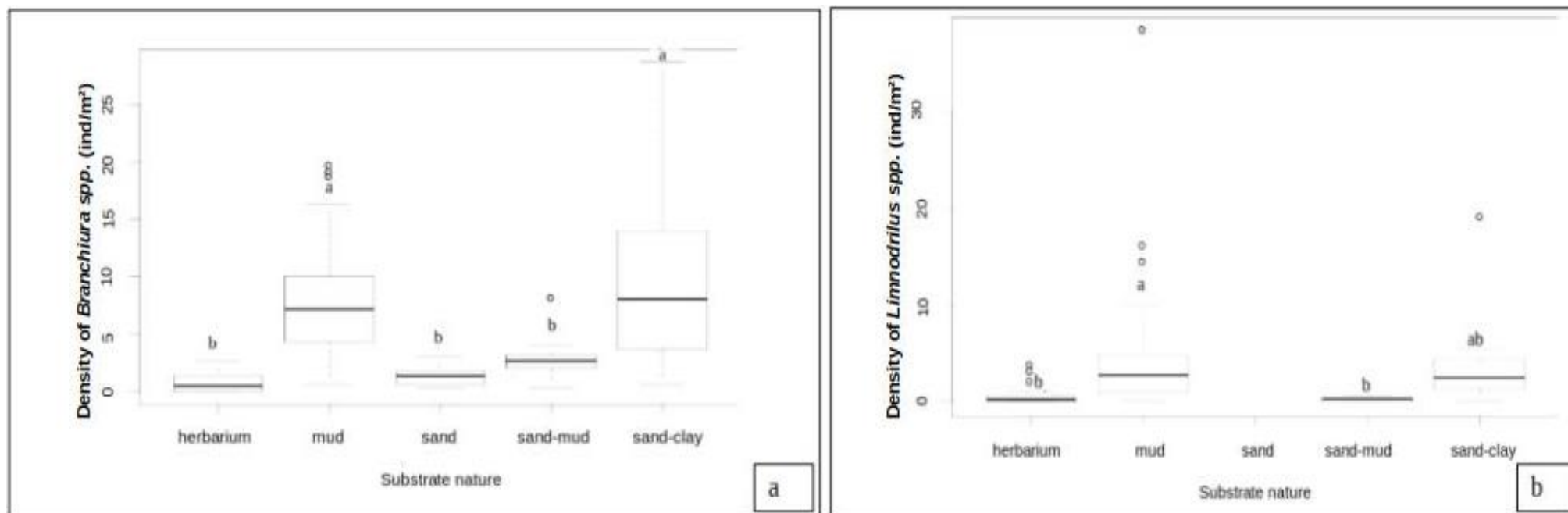


Figure 2. Densities of (a) *Branchiura* spp. and (b) *Limnodrilus* spp as a function of substrat.

Table 7. Correlations between physico-chemical parameters and the abundance of Naididae Tubificids.

Species mature stages	Variables								
	Velocity	Temperature	Conductivity	Alkalinity	TDS	PO ₄ ³⁻	NO ₃ ⁻	salinity	IPO
<i>Branchiura</i> spp. mature	0.176*	-0.320**	0.387**	0.309**	0.411**	0.112	0.190*	0.434**	-0.151
<i>Branchiura</i> spp. immature	0.179*	-0.442**	0.365**	0.335**	0.355**	0.175*	0.120	0.446**	-0.200*
<i>Limnodrilus</i> spp. mature	0.019	-0.212*	0.186*	0.225**	0.160	0.111	-0.026	0.185*	-0.174*
<i>Limnodrilus</i> spp. immature	-0.087	-0.078	0.228**	0.152	0.270**	0.011	0.087	0.206*	-0.080

* = significant correlation at 5%, ** = significant correlation at 1%.

Ragonha et al. (2013), the substrate composition played an important role in the oligochaetes

community structure and distribution in this study. In the current study, tubificids preferentially

colonised muddy and sand-clay substrates (Figure 2). This result does not agree with those of Ragonha et

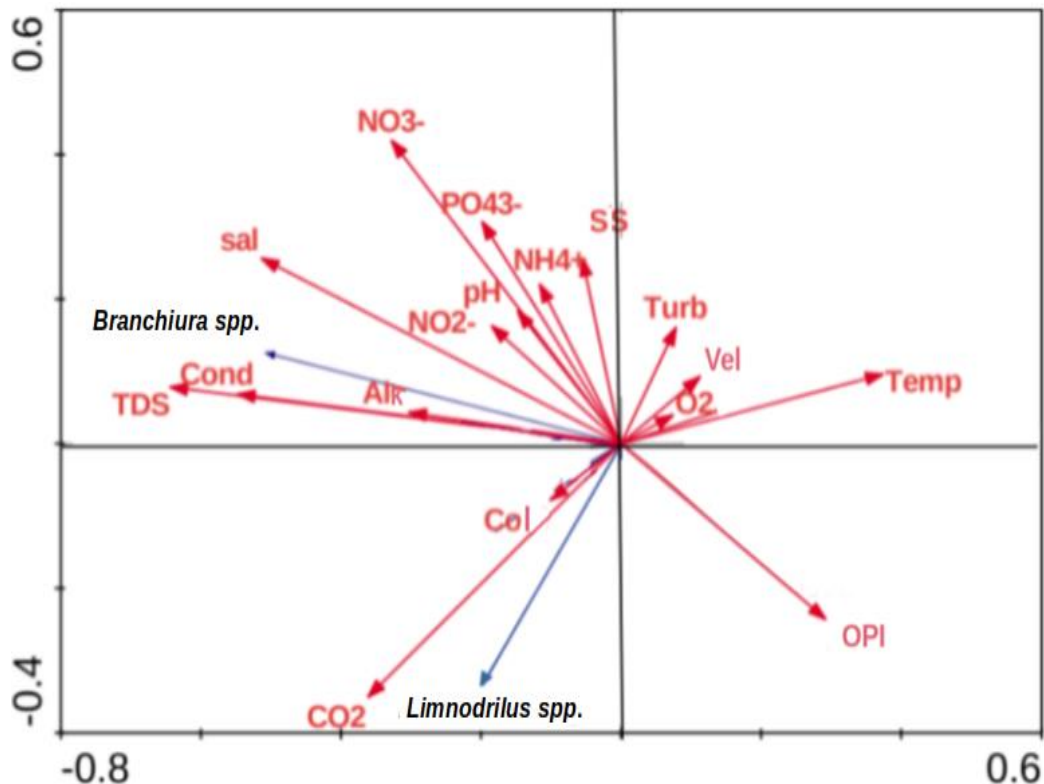


Figure 3. Result of the canonical redundancy analysis performed on the biotic variables measured in the different sampling stations.

al. (2013) who reported the dominance of tubificids in sand rich organic matter. Schenková et al. (2001) also found more tubificids in fine sand that is rich in organic matter than in other substrates.

There was no significant difference between seasonal distribution of Naididae tubificids identified in the present study (Table 6). Conversely, Nijboer et al. (2004) argued that the seasons mostly influence the hydrographic regime of a given site, with consequences on the development of the vegetation, and the grazing groups of oligochaeta such as Naididae-Naidinae, Pristininae. Schenková and Helešić (2006) also associated the seasonal variation of oligochaetes to the development of the vegetation which favours the installation of Naididae-Naidinae. It is worth to also make clear that *Branchiura* spp. and *Limnodrilus* spp. weakly colonised herbarium (Figure 2) Mature individuals of *Branchiura* spp. as well as of *Limnodrilus* spp. were collected throughout the year (Table 6). A year-round maturity period had already been reported for *Tubifex tubifex* and *L. hoffmeisteri* in rivers in Spain (Martinez-Ansemi, 1990). Contrary to the results obtained by Tchakonte (2016) in the polluted waters of the city of Douala, *T. tubifex* was not collected in our study stations. According to Zeybek et al. (2018), this specie is very abundant in polluted environments where it often co-occurs with *Limnodrilus hoffmeisteri*, although *T. tubifex* is a poor competitor in the environment (Nijboer et al., 2004). It only thrives in extreme environmental conditions that limit the

development of other benthic macroinvertebrates (Nijboer et al., 2004). Competitive or predatory pressure is a limiting factor for its presence in aquatic environments (Milbrink, 1983; Zeybek et al., 2018). In our study stations, the observation of a shrunken tail in some oligochaetes, which is a sign of regeneration, could precisely reflect a certain predatory pressure in our environment. In this respect, Kaliszewicz (2003) demonstrated the regeneration of the anterior, the posterior and even both parts of the body in some Naididae such as *Stylaria lacustris* following their sectioning by insect larvae. The predation pressure could also explain the low densities of oligochaetes in our study area (Figure 2) where some stations even contained fish. The shrunken tail could also be a result of a decontamination strategy developed by these aquatic worms. Bouché et al. (2000) observed the amputation of the tail of *T. tubifex* following the exposure to concentration of 0.01 to 0.05 mg/l of cadmium. After having accumulated the metal in its tail, this annelid gets rid of it. Since the cadmium concentrations obtained at some stations are at least equal to those reported by Bouché et al. (2000), *Limnodrilus* spp. collected might have had the same response to this stress. The values of cadmium and mercury found in swampy stations (M2 and M3) are above the water quality standards for crops irrigation and may be harmful to human.

The dominance of the abundance of *Branchiura* spp. over that of *Limnodrilus* spp. (Table 5) can on one hand

be explained by their better adaptation to pollution. The Canonical Redundancy Analysis (Figure 3) showed a higher link between *Branchiura* spp. and the indicators of organic pollution. It could also be explained by their possible better (a) adaptation to the predation pressure and (b) annual productivity rate. In fact, studies on *Branchiura sowerbyi* showed that it possesses sensorineural specializations that maximize the detection of vibrations in the substrate, water movement and contact which make it more successful in escaping predators (Drewes and Zoran, 1989). Raburu et al. (2002) also demonstrated that *B. sowerbyi* reproduced and developed faster than *L. hoffmeisteri*.

Conclusion

This study enabled us to isolate and identify, to the genus level, the Naididae tubificids present in 8 water bodies of the city of Yaoundé. These are *Branchiura* spp. and *Limnodrilus* spp. The distribution of these organisms in the study sites was governed by the oxygenation of the milieu, its mineralization, the nature of the substrate and the temperature. *Branchiura* spp. and *Limnodrilus* spp. are two pollution-resistant species. Their presence in those water bodies, in addition to showing the high pollution level of the water, also shows the high predation pressure in the milieu studied.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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