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Rotifers in the Niger River, Niger: diversity and abundance in relation to environmental parameters

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A first study of the rotifers of the Niger River in Niger is reported here. Two surveys took place under contrasting hydrological conditions: low-water level (16 April to 8 May 2018) and high-water level (1 to 15 February 2019). Zooplankton and physico-chemical parameters were sampled at eight stations spread over 520 km from Ayorou to Gaya. In total, 32 taxa were identified, including 26 at species level. During the low-water sampling, *Polyarthra* sp. (31%), *Brachionus caudatus* (23%), *Synchaeta longipes* (11%), *Keratella tropica* (7%) and *Filinia longiseta* (5%) were the most abundant, whereas *Brachionus quadridentatu s* (26%), *Lecane hastata* (25%), *Keratella cochlearis* (9%), *Keratella lunaris* (5%), *Hexarthra* sp. (3%) were dominant during the high-water sampling. The mean abundance of rotifers ranged between 14 × 10^3 ind. m^{-3} during the high-water sampling and 244 × 10^3 ind. m^{-3} during the low-water sampling. The highest diversity was observed in the three stations located upstream from the city of Niamey. The results reflect the difference in environmental parameters between the downstream and upstream Niamey stations. RDA analyses showed that the main environmental factors explaining the distribution of rotifers were dissolved oxygen, orthophosphate and nitrate concentrations.

Keywords: Ayorou, abundance, diversity, chemical composition, Gaya, zooplankton

Introduction

There is growing interest in large river ecosystems, but knowledge of river zooplankton remains fragmented with little being known about the factors that structure zooplanktonic communities in lotic rather than in lentic systems (Jack and Thorp 2002). Relatively few studies have been done on phytoplankton and zooplankton, compared with macroinvertebrates and fish (Thorp et al. 1994; Welker and Walz 1998; Jack and Thorp 2002). This lack of knowledge could be the result of the perception that rivers are not appropriate environments for zooplankton, because of the short residence times in a given stretch (Vannote et al. 1980; Picapedra et al. 2018). This has resulted in an underestimation of the essential role of zooplankton in the trophic dynamics of rivers (Lair 2006). Nevertheless, considerable zooplankton populations have been reported from both temperate and tropical lotic systems (Basu and Pick 1997; Casanova and Henry 2004). Factors that can regulate zooplankton biomass in rivers can be physical, chemical, biotic and hydrological (Basu and Pick 1996; Viroux 2002; Thorp and Casper 2003).

Dumont (1981) firstly reported the zooplankton populations in the Niger River in Mali. De Ridder (1992) published a list of 92 rotifer species found in different lakes and rivers in Mali; Pagano et al. (2010) reported 23 rotifer species on the Sélingué reservoir, a tributary of the Niger in the upper Niger, Mali. These studies mainly focused on the biological description of crustaceans and rotifers in the Upper Niger and the Inner Delta. Other studies performed downstream from Niger in Nigeria focused on the composition of the zooplankton fauna (crustaceans and rotifers), the spatio-temporal distribution and abundance as a function of environmental parameters (Jeje and Fernando 1992; Egborge 1994; Arimoro et al. 2010; Ikhuriah et al. 2015). Research on West African waters, specifically the Niger River in Niger, remains scant with much of the available literature covering the upstream and downstream reaches of teh Niger River. Moreover, literature available on the Niger River in Niamey has focussed primarily on macroinvertebrates and algae (Alhou 2007; Djima 2013). Therefore, studies on zooplankton in the Niger watershed are pertinent. No zooplankton studies on the Niger part of the Niger River exist to our knowledge.

Given the absence of literature on zooplankton in the Niger River in Niger, the aims of this study were to: (1) provide a first inventory of zooplankton communities (focussing on rotifers) in the middle Niger catchment area of Niger; (2) identify the environmental factors that contribute to the spatial and temporal distribution of the rotifer communities; and, (3) compare the community in the Middle Niger (arid tropical zone) with the one found upstream and downstream of the territory of Niger (humid tropical zones).

Materials and methods

Study area

The Niger River is the third longest river in Africa (4 200 km), after the Nile and the Congo, and is the most important river in West Africa in terms of length. Its basin covers an area of nearly 2.2 million km², including approximately 1.5 million km² of active watershed and 0.7 million km² of fossil watershed, dry all year round. The climate of the Niger Basin is governed by the seasonal movement of two air masses split by an intertropical front or convergence zone (FIT) (Harmattan in the north, monsoon in the south). The Niger Basin is thus generally characterised by two distinct seasons in the year: a rainy season, centred on four months (June to August), with prolonged high runoff, because of water arrival from the drainage basin and a dry season the rest of the year. The zones crossed by the Niger in Niger are the semiarid tropical zone (northern Sudan), receiving average rainfall between 750 and 1 000 mm y^{-1}, and the semiarid zone (Sahelian) with rainfall between 400 and 750 mm y^{-1}. The highest temperatures observed in summer from April to June can exceed 40 °C in the shade (L'hôte and Mahé 1996).

This study was done on the middle Niger of the Niger River, from Ayorou (14°44′3.44″ N; 0°54′50.65″ E) to Gaya (11°52′38.28″ N; 3°25′17.36″ E; Figure 1). This area of 520 km long is located in the south-west of Niger and is bordered in the North with the Mali, in the east with the Burkina Faso and in the South with the Benin and Nigeria.

Sampling stations and periods

Eight (8) stations (Figure 1) were sampled along the climatic gradient: seven (S1, S2, S3, S4, S5, S6 and

Table 1: Geographical location of the sampling stations

Code	Locality	Coordinates
S1	Ayorou	14°44′03.44″ N, 0°54′50.65″ E
S2	Tillabéri	14°12′24.41″ N, 1°26′40.52″ E
S3	Tondibiat	13°33′43.85″ N, 2°00′31.21″ E
S4	Saga	13°28′12.97″ N, 2°07′50.70″ E
S5	Kollo	13°19′17.15″ N, 2°17′34.37″ E
S6	Say	13°06′06.66″ N, 2°22′18.01″ E
S7	Kirtachi	12°46′33.20″ N, 2°28′19.70″ E
S8	Gaya	11°52′38.28″ N, 3°25′17.36″ E

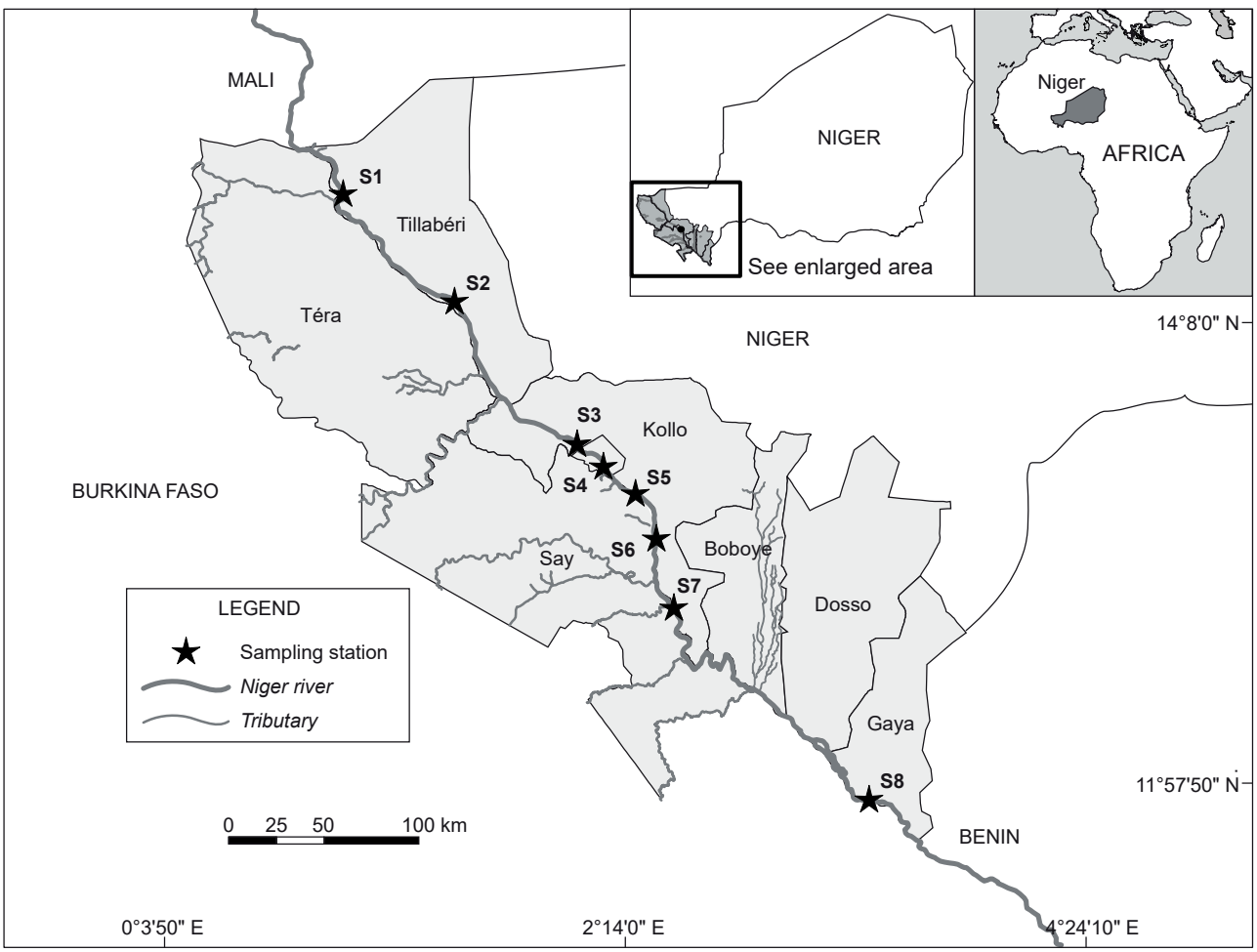

Figure 1: Map of Niger within the African continent (top right), the Niger River within Niger territory (mid-top right) and the sampling stations along the Niger River (black stars)

S7) stations in the Sahelian zone and one (S8) station in the semiarid northern Sudanese zone. As the sampling took several days, stations were sampled in upstream direction (from S8 until S1) to avoid resampling the same water. Anthropogenic activities in the basin may affect the functioning of Niger River waters (Alhou et al. 2009). The station at Saga (S4) was therefore chosen just downstream from Niamey city (1 203 766 residents, Capital of Niger, INS 2017). Many food factories are located in Niamey and these discharge solid waste, industrial and domestic residues (Alhou et al. 2009, 2014). The third factor structuring this typology was the agricultural activity, with a coverage area that is important from upstream to downstream. Stations S2, S4, S5 and S6 were situated in areas with high agricultural activity. The human impact is very noticeable in these areas of the river (high population density near the river, lack of sanitation).

Sampling periods were from 16 April to 08 May 2018, which corresponds to the low-water period, during which approximately 2/3 of the river's water dried up, and between 1 to 15 February 2019, corresponding with the period of high water (Figure 2).

Zooplankton sampling

For zooplankton sampling, 200 l of subsurface water were collected with a bucket and filtered through a 50-µm mesh plankton net. The retained zooplankton was stored in polyethylene bottles. Carbonated water was added to the sample to narcotise the zooplankton before fixing it with formaldehyde (4% final concentration). Three samples were collected from each site in the middle of the river.

Sampling for environmental variables

At each station, samples for the measurement of environmental variables were taken at the centre of the river: temperature, dissolved oxygen, conductivity, water transparency and pH were done *in situ* using a multi parameter probe *HANNA* 9829. In addition, 500 ml of water were taken into polyethylene bottles and stored in a cooler at temperature of 4 °C for subsequent nutrient analysis in the laboratory.

For suspended particulate matter (SPM) analysis, water was collected with a bucket and a volume of 150 ml to 1 l (according to the turbidity of the water) was filtered on a preweighed Whatman GF/C filter using a manual vacuum pump. The filters were stored in a cooling box for transport to the laboratory of the Department of Life and Earth Sciences (ENS) of Abdou Moumouni University in Niamey.

For chlorophyll *a* analysis, a volume of 150 ml to 1 l of water was filtered on a Whatman GF/C filter using a manual vacuum pump. After each filtration, the filter was immediately packed in an aluminium foil and stored in a cooler (4 °C) until laboratory analysis.

Zooplankton identification

In the laboratory, one to two drops of erythrosine solution prepared at 0.8 g 100 ml^{-1} of water was added to each vial to stain and then facilitate the search of organisms and their identification.

Subsamples were taken from each vial after homogenisation and placed in a counting wheel to identify and count organisms under a binocular magnifier (OLYMPUS SZX10, magnification 40× and 90×). Some identifications required analysis under a microscope (400×) (LEICA DM IRB, NIKON Optiphot 2). The minimum number of individuals counted was 150 to 200 per sample.

Rotifers were identified using the keys of Koste (1978), Pontin (1978), Segers (1995), Nogrady and Pourriot (1995), De Smet (1996), Alonso (1996), Nogrady and Segers (2002). Organisms were identified at the most accurate taxonomic level possible and densities were expressed in ind. m^{-3}.

Environmental variable analyses

Concentrations of ammonium (NH_4^+), nitrates (NO_3^-), nitrites (NO_2^-), phosphates (PO_4^{2-}), and silica (SiO_2) were determined by high-performance HPIC (High Pressure Ion Chromatography) and? Dionex (ionic liquid chromatography, equipped with an analysis column and an AS40 automated sampler).

Suspended particulate matter (SPM) quantification

For SPM quantification, the preweighed filters were dried

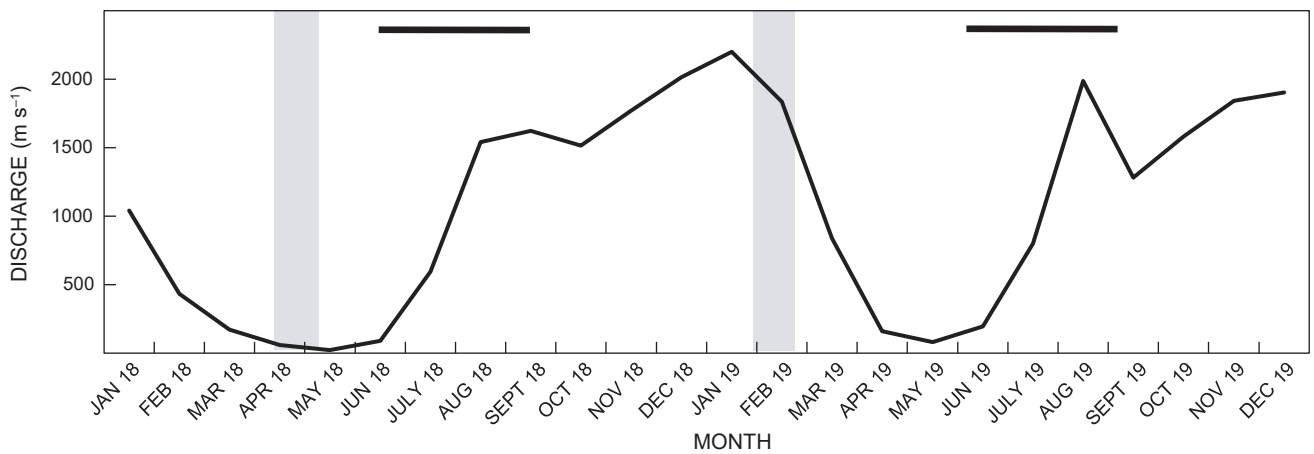

Figure 2: Average monthly discharge at Niamey between January 2018 to December 2019 (Niger Basin Authority 2020). The grey areas indicate the sampling periods. The black bars indicate the rainy season

(24 h at 60 °C) before being weighted again. The difference between the measured weights was the SPM dry weight:

$$SPM\ (mg\ l^{-1}) = (P_1 - P_0)/\text{filtered water volume}$$

where, P_0 = dry filter weight before filtration (mg); P_1 = dry filter weight after filtration (mg).

$$H' = -\sum (Pi) \times (\log_2 Pi)$$

Chlorophyll a concentration determination

The concentration of chlorophyll *a* was measured by spectrophotometry using the following formula:

$$Chl\ a\ (\mu g\ l^{-1}) = (OD_b - OD_a) \times 28.92 \times v/(V \times l)$$

where, OD_b: the optical density of the extract at 665 nm before acidification; OD_a: the optical density of the extract at 665 nm after acidification; v: volume of solvent used for extraction in ml; V: volume of water filtered in litre; l: length of the light path in cm.

Data analysis

Analysis of the data focuses on the structure of zooplankton communities, including taxonomic richness, diversity and equitability within the sampled stations. Diversity was determined using the Shannon–Weaver diversity index (*H′*) of Shannon and Weaver (1949):

$$E = H'/H'_{max}$$

where, *H′* = Shannon–Weaver diversity index *H′;* S = number of taxa at a given station; Pi = proportion of total sample abundance represented by species i. E = Evenness, $H'_{max} = \log_2(S)$ = maximum diversity possible

The significance of differences between stations was tested using a non-parametric ANOVA (Kruskal–Wallis) and multiple comparison tests (Mann–Whitney *U*-test). Subsequently, multivariate analyses were done to analyse the relationship between the distribution of the zooplankton community and environmental factors for each sampling campaign separately and for all data considered together.

Abundances were transformed to log(*x* + 1) to obtain a normal distribution. A Detrended Correspondence Analysis (DCA) was first done on the zooplankton data using CANOCO software, version 4.5 (ter Braak et al. 1987; ter Braak 1994), to determine the method of ordination to be used. Because the total inertia was less than 2.6, the species were considered to be represented by a linear model and a redundancy analyses (RDA) was done. Abundance data of the identified taxa were centred and standardised. A Monte Carlo test (999 permutations) was applied to test statistical significance of the environmental variables in explaining the zooplankton distribution using a significance limit of $p < 0.05$.

Results

Physico-chemical parameters

Tendencies of parameters over the sampling transect were only reported when significant, which implies no significant tendencies over the transect when only differences between the two sampling periods are mentioned. A significant drop in temperature was observed between the two sampling periods ($p < 0.05$, Figure 3a). Conductivity was variable according to the river regime, with a much greater variation during the low-water period. During both samplings, conductivity values were significantly higher upstream (S1, S2, S3, S4 and S5) than downstream (S6, S7 and S8) where they stabilise. Conductivity was significantly higher between station 1 and 5 during low-water than during high-water sampling ($p < 0.05$, Figure 3b).

Regardless of the sampling period, pH values do not change and remained at neutral to alkaline values of approximately 7–7.5 at all stations ($p > 0.05$, Figure 3c). NO_3 and NO_2 concentrations were generally very low, but higher during the low-water than during the high-water period ($p < 0.05$, Figures 3d and 3e). Ammonium was very low at all stations and at each period, except at stations S2 and S4, the latter located downstream of the city of Niamey. In addition, the concentration was higher during low-water sampling than during high-water sampling ($p < 0.05$, Figure 3f). The silica concentration was significantly higher during the high-water period than during the low-water period ($p < 0.05$, Figure 3g).

Total-P concentrations showed the highest values during high-water sampling ($p < 0.05$) with a maximum of 160 mg l^{-1} at station S6 (Figure 3h). The lowest concentrations were recorded during low-water sampling with a minimum of 10 mg l^{-1} at station S1. PO_4-P concentrations were higher during the high-water sampling ($p < 0.05$, Figure 3i). Dissolved oxygen and SPM concentrations do not vary significantly between low and high water ($p > 0.05$ for both, Figures 3j and 3k) Chl *a* concentration was generally higher during the low than during the high-water period ($p < 0.05$, Figure 3l).

Rotifer taxonomic composition and abundance

In total, 32 rotifer taxa were identified at the eight stations and during the two sampling periods (low water and high water), including 26 taxa determined at the species level. All these species belong to Monogononta (1). The Brachionidae were dominant (14 taxa), followed by Lecanidae (five taxa), Filinidae (two taxa), Asplanchnidae (one taxon), Mytilinidae (one taxon), Lepadellidae (one taxon), Synchaetidae (one taxon) and Trichoceridae (one taxon) and Trichotriidae (one taxon).

The total abundance of rotifers was higher during the low-water period than during the high-water period ($p < 0.05$). Values were less than 20×10^3 ind. m^{-3} at most stations except at station S5 (81×10^3 ind. m^{-3}) and S8 (115.6×10^3 ind. m^{-3}) during low-water periods. Total abundance was notably low in S1 and S2, and ranged from (80 ind. m^{-3} in S2) to (3 700 ind. m^{-3}) in S4 (Figures 4a and 4b).

Ten rotifer taxa were dominant with more than 50% of abundance in both surveys: *Brachionus caudatus, Filinia longiseta, Keratella tropica, Polyarthra sp., Synchaeta longipes, Brachionus quadridentatus, Hexarthra* sp., *Keratella cochlearis, Lecane lunaris, Lecane hastata*) (Figures 4a and 4d). The total number of taxa observed during the low-water sampling was 24, and during the

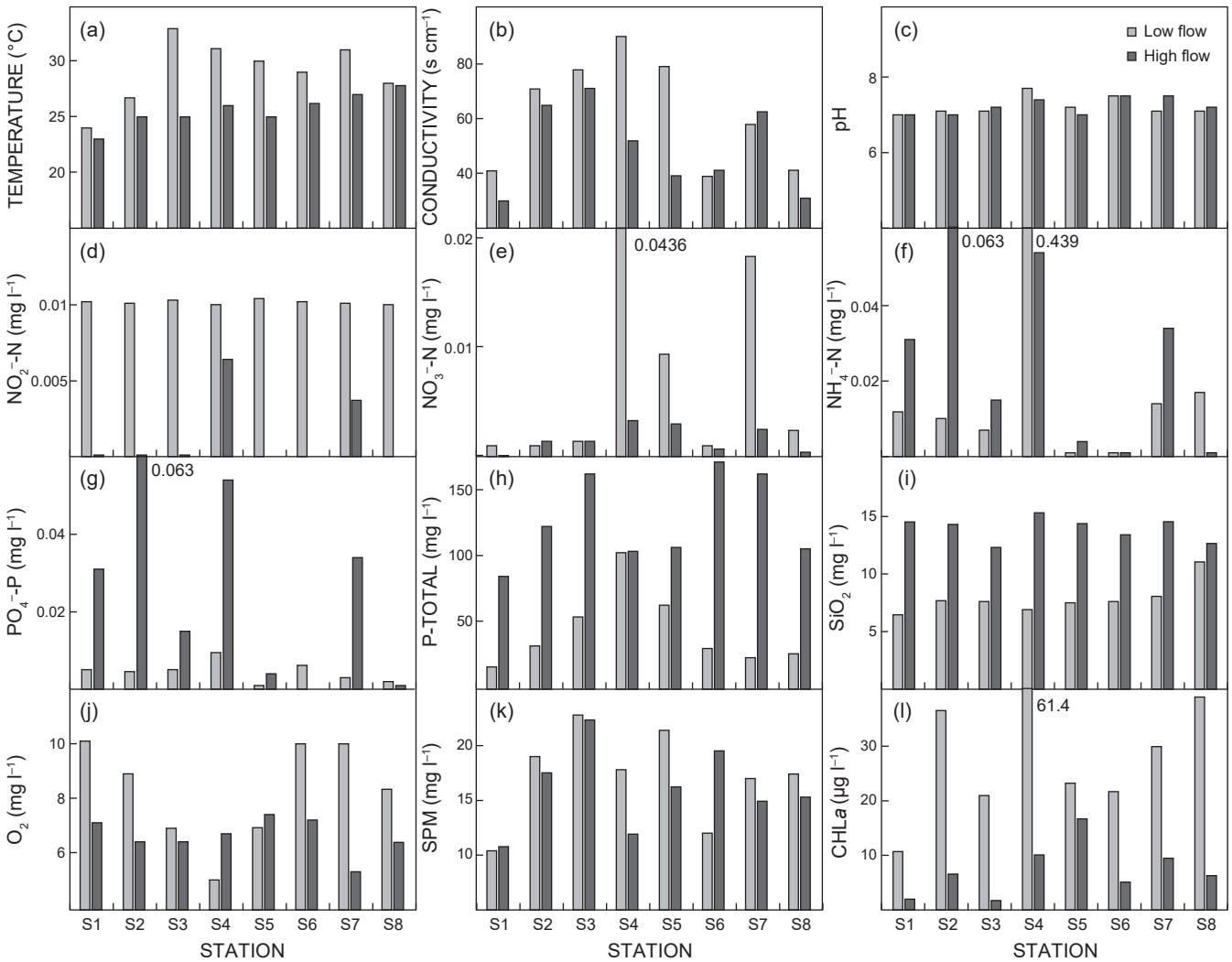

Figure 3: Environmental parameters: Temperature (a), Conductivity (b), pH (c), NO_2 (d), NO_3 (e), NH_4 (f), SiO_2 (g), Mg^{2+}, P-total (h), PO_4 (i), O_2 (j), SPM (k), and Chl *a* (l)

high-water sampling was 28. Altogether 20 rotifer taxa were common to both surveys. Four species were only found during high-water sampling (*Brachionus calyciflorus*, *Brachionus patulus*, *Macrochaetus sericus* and *Keratella lenzi*. Rotifers were mainly represented by *Polyarthra* sp. (31%) and *Brachionus caudatus* (23%) during the low-water sampling and *Brachionus quadridentatus* (25%) and *Lecane hastata* (24%) during the high-water sampling.

Two taxa showed high abundance during the low-water period: *Polyarthra* sp. at station S5 and *Brachionus caudatus* at S8 (77 × 10^3 and 57 × 10^3 ind. m^{-3}), respectively (Figure 4a). *Keratella tropica* and *Synchaeta longipes* were relatively abundant at S8 (17.4 × 10^3 and 27.2 × 10^3 ind. m^{-3}, respectively). The less abundant species during low-water sampling were mainly Brachionidae, with different species present at practically all stations (Figure 4b). Only *Brachionus bidentatus* at S4 and *Brachionus falcatus* at S8 have abundances >1 200 ind. m^{-3}. The rare taxa (<20 ind. m^{-3}) *Lecane lenzi* and *Mytilina ventralis*, who were found in considerable abundance only at S3 and S6 during low water, were counted within the group 'others' in Figure 4b.

During the high-water period (Figure 4d), *Brachionus quadridentatus* was present at all stations except S2; with highest abundance at S8 (26 × 10^3 ind. m^{-3}). *Lecane hastata* was present at all stations except at S1 and S2 with an abundance of 800 ind. m^{-3} at station S4. *Lecane lunaris* was present in rather low abundance (maximum 756.16 ind. m^{-3}), except at S1 and S8. It showed the highest abundance at stations S8 and S4. *Keratella cochlearis* was observed only at the stations downstream of the city of Niamey (S5, S6 and S8).

Five (5) taxa were present in relatively low abundance during the high-water sampling (Figure 4e). The most abundant, *Polyarthra* sp., *Mytilina ventralis*, *Lecane lenzi* make out 80% of abundance at S4. Apart from *Platyias quadricornis* at S5, all remaining taxa reached <400 ind. m^{-3}. With the exception of S2, all stations showed 30 to 50% of rare taxa, grouped as 'others'.

During both samplings, the number of taxa vary between 11 and 14 for all stations, except at station S5 (seven taxa)

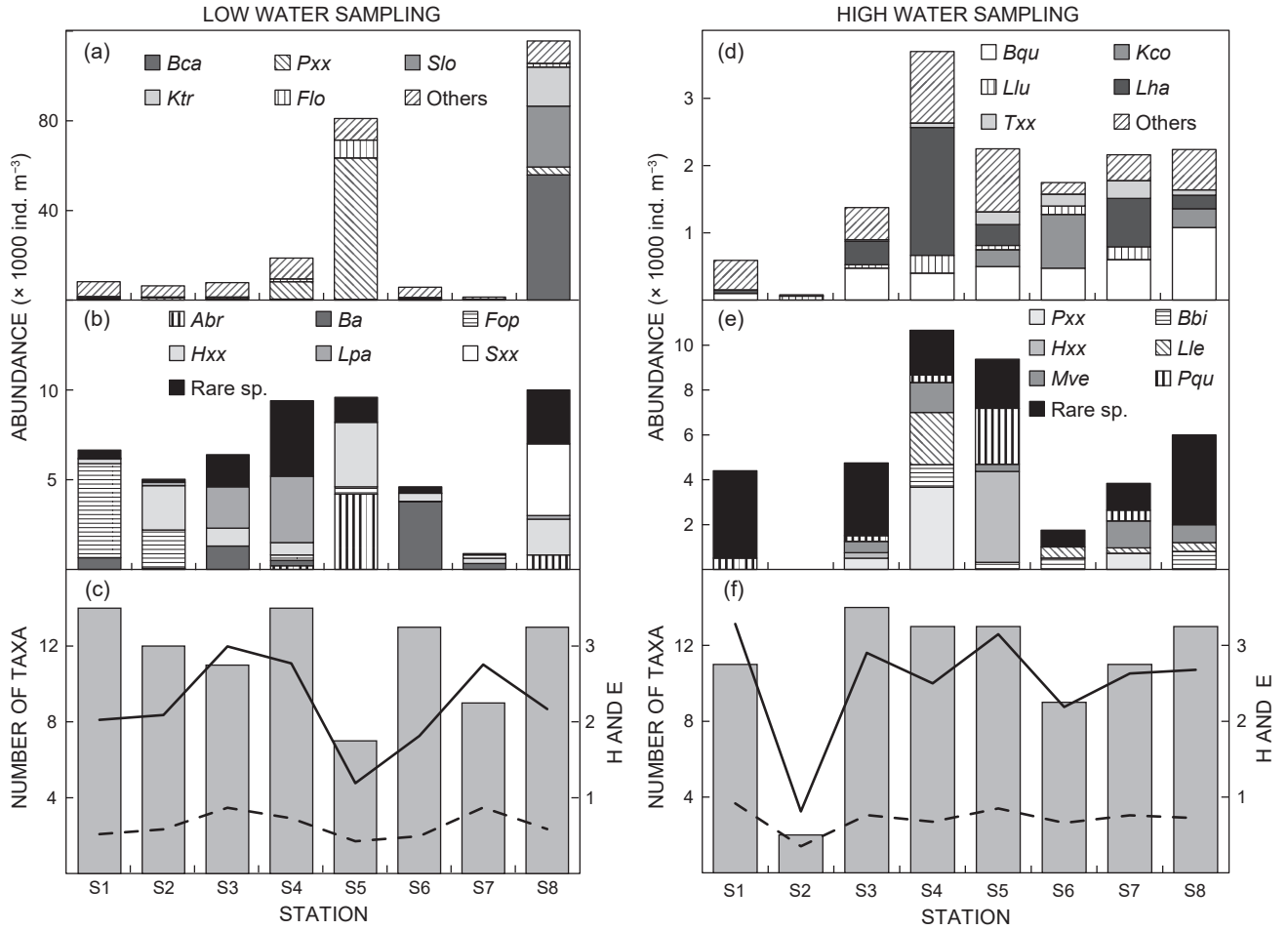

Figure 4: Low-water sampling (a) total abundance and most abundant taxa, (b) detail of others, (c) number of taxa (bars); Shannon–Weaver diversity index (*H'*, full line), evenness (E, broken line), high-water sampling: (d) total abundance and most abundant taxa, (e) detail of others d), (f) number of taxa (bars); Shannon–Weaver diversity index (*H'*, full line), evenness (E, broken line) Abr: *Asplanchna brightwellii*, Bca: *Brachionus caudatus*, Flo: *Filinia longiseta*, Bqu: *Brachionus quadridentatus*, Ktr: *Keratella tropica*, Kco: *Keratella cochlearis*, Llu: *Lecane lunaris,* Lha: *Lecane hastata*, Slo: *Synchaeta longipes*, Pxx: *Polyarthra* sp., Hxx: *Hexarthra* sp., Bfa: *Brachionus falcatus*, Bbi: *Brachionus bidentatus,* Bdi: *Brachionus diversicornus,* Bqc: *Brachionus quadricornus*, Lept: Lepadella patella, Lxx: *Lecane* sp., Lle: *Lecane lenzi*, Mve: *Mytilina ventralis*, Pqu: *Platyias quadricornis*, Others: Other taxa than those indicated in each graph

and station S7 (nine taxa) during low water, and station S2 (two taxa) and S6 (nine taxa) during high-water sampling. Brachionidae and Lecanidae showed the highest number of taxa during both samplings: eight and five, respectively, during low water, 10 and six during high water. Rotifer diversity, according to Shannon–Weaver diversity index (*H'*) ranged from 1.2 at station S5 to 3.0 at station S3 (mean: 2.227) during the low-water sampling and from 0.8 at station S2 to 3.3 at station S1 (mean: 2.518) during the high-water sampling (Figures 4a and 4c). Although not visually clear on Figures 4d and 4e, because of numerous low abundant taxa at station S1 during the high-water sampling, there was a drop from 11 to two_taxa between station S1 and S2, which could_reflect a low tolerance of some taxa to water characteristics of more upstream stations. Exactly which factor was responsible was not clear, as there were no obvious changes in environmental conditions between station S1 and S2. Except for the ditch at stations S5 and S2 during low and high-water sampling, respectively, there were no clear trends in *H'* along the stations. Evenness was minimum at station S5 (0.4) and maximum at station S7 (0.9) during low-water sampling, and minimum at station S4 (0.7) and maximum at station S1 (1.0) during high-water sampling. It generally follows the same trend as *H'* (one-tailed *t*-test, $p = 0.0264$) (Figures 4a and 4c). Considering all stations, the mean number of taxa (*n*) and *H'* values were not significantly different between the two sampling periods, whereas E was slightly significantly lower during low-water than during high-water sampling (mean 0.6 and 0.8, respectively, one-tailed *t*-test, $p = 0.0264$).

Correlation between environmental variables and the abundance of zooplankton communities

To test the correlation between the environmental variables and the distribution of rotifers, all environmental variables were taken into account in a first RDA analysis and then the significant variables after the Monte Carlo test ($p < 0.05$)

were retained. Figures 5a and 5b show the distribution of rotifer taxa and stations according to significant factors during the low-water period. Because of the large number of species in relation to the number of samples, the rotifers were grouped according to families and both sampling surveys were analysed together. A DCA run on the data at family level revealed a total inertia <4. Therefore RDA analyses were done on 11 families of rotifers (Table 2). The sum of all eigenvalues for the analysis was 53.9%. Axis 1 and 2 of the RDA analysis have eigenvalues of 40.2 and 9.2%, respectively.

The main factor constructing the vertical axis was dissolved oxygen. PO_4 and NO_2 were correlated to the horizontal axis in opposite direction. The factors that characterise the low-water period were nitrate and dissolved oxygen. The high-water sampling was characterised by a high concentration of orthophosphate.

The first axis shows a discrimination of stations per sampling period (Figure 5b). The first group, situated in the right side of the ordination, characterised by high PO_4 concentrations, includes all high-water samplings (Figure 5b). Zooplankton families found at these stations were Mytilinidae, Trichotridae, Notommatidae, and Lecanidae.

The second group, located on the left side of the ordination, characterised by high NO_2 and O_2 concentrations, include all low-water stations in a gradient from low to high O_2 concentrations: S4, S3, S5, S8, S2, S6, S7 and S1.

The rotifer families found in these samples were Asplanchnidae, Brachionidae, Filinidae, Hexarthridae, Lepadellidae, Synchaetidae and Trichoceridae.

Discussion

In total, 32 rotifer taxa, belonging to 11 families, were identified in the Niger River during this study. The Brachionidae were numerically dominant (14 taxa), followed by Lecanidae (six taxa), Filinidae (two taxa), Asplanchnidae (one taxon), Mytilinidae (one taxon), Lepadellidae (one taxon), Synchaetidae (three taxa), Trichoceridae (one taxon) and Trichotriidae (one taxon), Hexarthridae (one taxon), Notommatidae (one taxon). A slightly higher number of taxa was observed during the high-water sampling (*n* = 28 taxa) than during the low-water sampling (*n* = 24 taxa). Brachionidae and Lecanidae showed the highest taxa richness during both samplings.

The rotifer diversity obtained in the current study (*n* = 32 taxa) in the Niger River in Niger was lower than the diversity of rotifers mentioned by De Ridder (1992) from different lakes (Tanda, Kabaro, Niafounké) and Niger tributaries in Mali (*n* = 92 taxa). It was also lower than those reported by Jeje and Fernando, (1992) in Middle Niger (Sokoto Basin) in Nigeria (*n* = 38 taxa), In contrast, this richness was higher than that recorded in the Sankarani tributary in Mali (Pagano et al.2011) (*n* = 23 taxa). It was comparable to that reported by (Etilé et al. 2019) in the Kankelaba River in Côte d'Ivoire (Niger tributary) (*n* = 31 taxa).

The rotifer community inventoried in this study was common to the taxa reported downstream of the Niger River (humid tropical zone) by (Arazu and Ogbeibu 2017). These authors observed 23 taxa within the genus *Brachionus*, *Lecane*, *Mytilina*, *Lepadella*, *Keratella*, *Filinia* and *Synchaeta* in the Niger River at Onisha in Nigeria.

The difference between the diversity of zooplankton

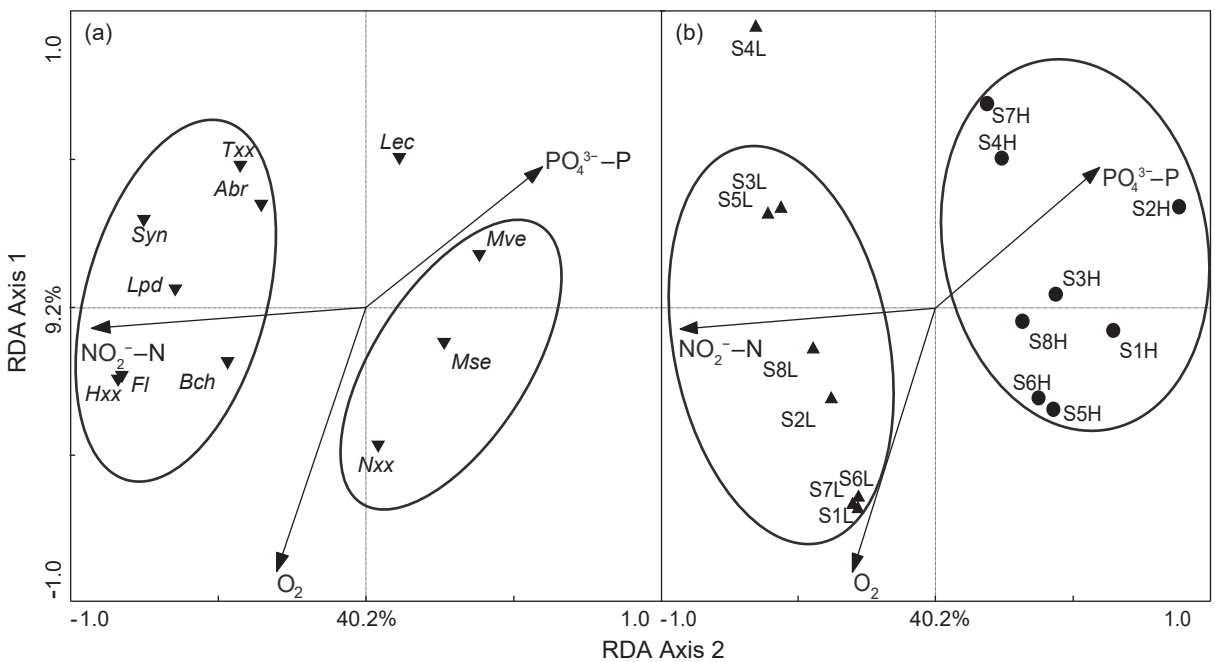

Figure 5: RDA Axis 1 and 2 biplots showing the distribution of rotifer families according to environmental variables during high-water (H) and low-water (L) sampling: (a) Environmental variables and taxa. (b) Environmental variables and stations. Abr = Asplanchnidae; Bch = Brachionidae; Nxx = Notommatidae; Fl = Filinidae; Hxx = Hexarthridae; Lec = Lecanidae; Lpd = Lepadellidae; Mve = Mytilinidae; Mse = Trichotriidae; Syn = Synchaetidae; Txx = Trichoceridae

Table 2: List of rotifer taxa observed in the Niger River in Niger (the symbols corresponds to the families of taxa)

Family	Genus	Species	Symbol
Asplanchnidae	*Asplanchna*	*Asplanchna brightwellii* Gosse, 1850	Abr
Brachionidae	*Brachionus*	*Brachionus caudatus* Barrois & Daday, 1894	Bch
–	–	*Brachionus angularis* Gosse, 1851	–
–	–	*Brachionus falcatus* Zacharias, 1898	–
–	–	*Brachionus diversicornis* (Daday, 1883)	–
–	–	*Brachionus leydigi* Cohn, 1862	–
–	–	*Brachionus quadridentatus* Hermann, 1783	–
–	–	*Brachionus bidentatus* Kertesz, 1894	–
–	–	*Brachionus patulus* OF Muller, 1776	–
–	–	*Brachionus quadricornis* (Schrank, 1803)	–
–	–	*Brachionus plicatilis* OF Muller, 1786	–
–	*Keratella*	*Keratella cochlearis* (Gosse, 1851)	–
–	–	*Keratella quadrata* (OF Muller, 1786)	–
–	–	*Keratella tropica* (Ehrenberg, 1887)	–
–	*Platyias*	*Platyias quadricornis* (Ehrenberg, 1832)	–
Filinidae	*Filinia*	*Filinia opoliensis* (Turner, 1892)	Fl
–	–	*Filinia longiseta* (Eckstein, 1833)	–
Hexarthridae	*Hexarthra*	*Hexarthra* sp.	Hxx
Lepadellidae	*Lepadella*	*Lepadella patella* (Müller, 1773)	Lpd
Lecanidae	*Lecane*	*Lecane papuana* (Murray, 1813)	Lec
–	–	*Lecane lunaris* (Ehrenberg, 1832)	–
–	–	*Lecane hastata* (Murray, 1913)	–
–	–	*Lecane leontina* (Turner, 1892)	–
–	–	*Lecane ludwigii* (Eckstein, 1833)	–
–	–	*Lecane* sp.	–
Mytilinidae	*Mytilina*	*Mytilina ventralis* (Ehrenberg, 1830)	Mve
Notomatidae	*Cephalodella*	*Cephalodella* sp. (Murray, 1913)	Nxx
Synchaetidae	*Synchaeta*	*Synchaeta longipes* Goss, 1887	Syn
–	–	*Synchaeta* sp.	–
–	*Polyarthra*	*Polyarthra* sp.	–
Trichoceridae	*Trichocerca*	*Trichocerca* sp.	TXX
Trichotriidae	*Macrochaetus*	*Macrochaetus sericus* (Thorp, 1893)	Mse

Abr = Asplanchnidae; Bch = Brachionidae; Nxx = Notomatidae; Fl = Filinidae; Hxx = Hexarthridae; Lec = Lecanidae; Lpd = Lepadellidae; Mve = Mytilinidae; Mse = Trichotriidae; Syn = Synchaetidae; Txx = Trichoceridae

in this study and the other studies cited below may be because of the natural condition of the water masses and the sampling periods. Indeed, Ezekiel et al. (2011), Yao et al. (2015) and Etilé et al. (2019) reported that the distribution of zooplankton varies from place to place and year to year, because of the dynamic nature of aquatic systems. In addition, the difference in diversity in these aquatic ecosystems can be attributed to their difference in length and depth. Graça et al. (1998) reported that, depending on the length and depth of the water, they may or may not offer a wide variety of microhabitats capable of supporting a substantial diversity of species. Other factors, such as the speed of the current, the watershed of the aquatic ecosystem, the activities done on the watershed, can also explain the difference in richness observed between these studies (Aka et al. 2000; N'da et al. 2015; Yao et al. 2015).

The rotifer community found in this study was common for tropical and subtropical freshwater systems (Okogwu 2009). A qualitative dominance of the family Brachionidae and genus *Brachionus* (10 taxa) in the zooplankton community was also reported in several other tropical freshwater ecosystems, such as the Pearl River in China (Yang et al. 2009) (*n* = 15 taxa), the Bagoé River (Niger tributary in Côte d'Ivoire) (N'da et al. 2015) (*n* = 4). According to Borges and Pedrozo (2009), these genera were generally dominant in large floodplain rivers. In our study, in the Niger River, *Brachionus* were the most diversified, whereas the *Keratella* were less represented in terms of species. Similar observations on the prevalence of the genera *Brachionus* and *Lecane* have been reported in the subtropical zone (Segers and Dumont 1995; Sarma and Elias-Gutierrez 1998; Arora and Mehra 2003; Segers 2007; Wang et al. 2009). *Brachionus quadridentatus* inhabits alkaline water, especially small ponds. This cosmopolitan species has been found in all stations during the high-water season. Brachionidae and Trochosphaeridae species generally have planktonic habits, whereas Lecanidae species were related to benthic and coastal areas, among macrophytes, but can be found in lower abundance drifting with the plankton (Almeida et al. 2009; Lansac-Tôha et al. 2009; Picapedra et al. 2017; Picapedra et al. 2018).

The abundance of rotifers was higher during the low-water sampling than during the high-water sampling. This difference could be explained by hydrological conditions. Indeed, hydrology, through residence times, was one of the important factors influencing the development of zooplankton directly (Viroux 1997; Basu et al. 2000).

Basu and Pick (1996) observed that, in Canadian rivers, zooplankton biomass was positively related to residence time of the water. Residence times <three days (Rzoska 1978, Walz and Welker 1998), corresponding with the generation time of rotifers, can be critical for zooplankton development. The Niger River has a gentle slope, averaging 10 cm km^{-1} in the middle Niger. The average current velocity was 0.029 and 0.058 m s^{-1} during low and high water, respectively. This means residence time was roughly divided by two between low and high water, favouring zooplankton development during low water.

Residence time was a main factor controlling the abundance of rotifers in large rivers. Etilé et al. (2019), also observe highest zooplankton abundance during low-water periods in the Kankelaba River (Ivory Coast). Neverteless, Aoyogui and Benecker (2004) found the opposite results in a floodplain river of Upper Parana in Brazil.

The difference in current velocity (and residence time) between both sampling periods also coincides with seasonal changes and impacts on the physico-chemical composition of the river water, as evident from the data in Figures 3 and 5. This creates different living circumstances for zooplankters.

Considering all samples taken during both the low and high-water periods, the RDA showed a significant discrimination of the different stations on the basis of the abundance of taxa (considered at family level). Two groups of sampling stations can be distinguished (Figure 5b), corresponding to the high-water samples characterised by the highest O_2 and NO_2 concentrations, and the high-water samples, characterised by high PO_4 concentrations.

During the low-water sampling in May, the water temperature exceeded 27 °C at all stations, except S1 and S2. This could also have favoured rotifer development on comparison to the lower temperature range (23–27 °C) during high water. Water temperature was recognised as an important abiotic factor structuring zooplankton communities (Galkovskaja 1987; Berzins and Pejler 1989; Holst et al. 1998; Tackx et al. 2004). However, the seasonal dynamics of zooplankton communities in the tropics have been attributed to a number of other factors, such as water characteristics, predation, edible algal quality and quantity and competition (Hellawell 1986; Ovie and Adeniji 1994).

The high concentration of oxygen during low-water sampling was likely because of the important development of phytoplankton during this period, as shown by the high Chl *a* concentrations. Downstream of Niamey relatively low Chl *a* values were observed. Phytoplankton development was also favoured by longer residence times and higher temperatures (Ndjouondo and Dibong 2014). Although all nutrient concentrations observed in this study were low, NH_4 concentrations were higher during high-water sampling, whereas NO_2 and NO_3 were higher during low water, probably because of conversion of NH_4 by the higher oxygen concentrations during low water; with NO_3 and NO_2, as such, providing readily available nutrients for phytoplankton growth during the low-water period. Because of higher current velocities, one would expect sediment resuspension and consequently SPM to be higher during high-water sampling than during low water (Wahl et al. 2008). The fact that SPM concentrations were on the contrary higher at most stations during low than during high-water sampling indicates the importance of phytoplankton contribution to SPM.

Rotifers have the ability to feed on a wide range of foods, from filamentous algae to bacteria (Allan 1976), but phytoplankton is known as a good quality food for rotifers (Walz 1945; Pourriot 1977; Devetter 1998; Lair et al. 1998). The high phytoplankton abundance during low-water sampling has probably contributed to the high rotifer abundance.

The high concentrations of oxygen may also have favoured some rotifer taxa during low-water conditions. Indeed, for some species of the genus *Brachionus, Keratella* and *Cephalodella* that were situated at the left, low-water side of the RDA plot or next to the dissolved oxygen vector, oxygen concentration seems to be a limiting factor (Mikschi 1989). The fact that genera like *Filina, Hexarthra,* and *Synchaeta* were associated with the NO_2 vector corresponds to their known tendency for nitrogen rich, but also phosphorus rich environments (Devetter 1998).

During seasonal flooding, tributaries exchange nutrients and organisms with the main river (Shiel et al. 1982; Rossaro 1988; Bayley 1995; Grosholz and Gallo 2006). This can explain the higher concentrations of NH_4, PO_4, SiO_2 and P-total observed during high water, compared with low-water sampling. In the RDA plot, the high-water sampling period was specifically marked by concentrations of phosphorus, which could be explained by the import of fertilizers, probably related to agriculture practiced during the previous year in the Niger catchment.

Another effect of the flooding was the inundation of the riparian habitats of the Niger River, which results in an increase in the size of the littoral zone and a connexion between previously isolated aquatic habitats (Bonecker et al. 2005).

Imports from tributaries and exchange with riparian zones can also be important in determining the abundance and the taxonomic composition of zooplankton (Pace et al. 1992; Romare et al. 2005). Zooplankton from tributaries can be carried away by water during flood periods (Rossaro 1988; Thorp et al. 1994), which was a source of organisms in the main river channels. Although 28 of the 35 rotifer taxa observed in this study were common to both samplings, seven taxa occurred only at during high-water sampling. *Macrochaetus sericus, Lecane ludwigi, Keratella quadrata Brachionus patulus*, *Brachionus quadridentatus, Brachionus leydigi and Mytilina ventralis.* The presence of these species during the high-water period could be explained by the presence of macrophytes, which provides a more favourable habitat for zooplankton than open water for reasons of habitat diversity, richness of food quality and quantity, refuge from predators and pelagic competitors, and water movement (Basu et al. 2000; Špoljar et al. 2012).

The aspect of exchange between the main river, the riverbanks and the tributaries will be subject to another paper.

The fact that these taxa were not found during low-water sampling, when rotifer abundance was highest, can be interpreted as washing away of tributary sources as the flood waters recede (Saunders and Lewis 1988a; Pace et al. 1992). Taxa specifically found only during low-water sampling were *Brachionus falcatus, Brachionus diversicornis* and *Mytilina ventralis.* Indeed, those species

were fond of eutrophic and warm waters. Phytoplankton are an important source of food for these rotifer species (Lair et al. 1998) and the high concentration of chlorophyll *a* during low-water periods was not surprising.

Although the majority of taxa occurred during both samplings, some, like *Brachionus caudatus*, *Filina longiseta*, *Polyarthra* sp., *Synchaeta longiseta* and *Keratella tropica* showed the highest abundance peaks during low-water sampling. Their populations were lower during high-water sampling, when species with highest abundance were *Brachionus quadridentatus*, *Lecane hastata, Keratella cochlearis* and *Lecane lunaris*. Therefore, the environmental factors differed sufficiently between both sampling periods to lead to different composition of rotifer communities. The resulting Shannon–Weaver diversity index values (*H'*), varying between 1.2 (at station 5) and 3.0 station during low-water and 0.8 and 3.3 during high-water sampling, were on the low side of the generally range between 1.5 and 3.5 reported in most ecological studies (Kerkhoff 2010). The low value at station S5 during low-water sampling was caused by the predominance of *Polyarthra* sp. (85%) there. The high abundance of *Polyarthra* at station S5 during low and at S4 in high-water period sampling may be because of the fact that S5 was located near the springs of the city of Kollo and S4 was located downstream from the city of Niamey receiving waste of organic and industrial origin from the city (Alhou 2007). In addition, genera like *Polyarthra*, *Keratella* and *Brachionus*, which were most abundant in this study, have been reported as indicators of eutrophication and pollution (Sladecek 1983; Saksena 1987; Wang et al. 2009). Nevertheless, in the Niger River reach sampled in this study, they occur in a system characterised by very low nutrient and SPM concentrations, corresponding to oligotrophic conditions (Kuczyńska-Kippen and Basińska 2014). The presence of these taxa under different conditions could be related to the quantity and quality of the resource in the environment. According to Kerabin (1985), in mesotrophic lakes where nanoplankton dominates and where the quantity of detritus may be low, because of a low biomass of algae, nanoplankton species of the genera *Polyarthra, Brachionus, Keratella* dominate.

In conclusion, this first inventory of the rotifer community in the middle Niger River (Niger) has enabled identification of 32 taxa and showing differences in rotifer abundance and community composition between a low and a high-water sampling period. The low-water circumstances showed the highest rotifer abundance, whereas slightly more taxa and a higher evenness of the community were found during high water. Oxygen and nitrite concentrations characterised the low-water sampling conditions, whereas high water was associated with higher phosphate concentrations. This first relating of the rotifer community to environmental conditions suggests that in the low-nutrient middle Niger environment, longer residence times, combined with higher nutrient concentrations trigger a phytoplankton bloom during low-water periods, which favours rotifer development.

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References

Agostinho AA, Sidinei MT, Luiz CG. 2004. Threats for biodiversity in the floodplain of the Upper Paraná River: effects of hydrological regulation by dams. *Ecohydrology & Hydrobiology* 14: 255–268.

Aoyagui ASM, Bonecker CC. 2004. Rotifers in different environments of the Upper Paraná River floodplain (Brazil): richness, abundance and the relationship with connectivity. *Hydrobiologia* 522: 281–90. https://doi.org/10.1023/B:HYDR.0000029980.49859.40.

Arazu VN, Ogbeibu AE. 2017. The composition, abundance and distribution of zooplankton of river Niger at Onitsha stretch, Nigeria. *Animal Research International*. 14: 2629 – 2643.

Arimoro FO, Oganah AO. 2010. Zooplankton community responses in a perturbed tropical stream in the Niger Delta, Nigeria. *The Open Environmental & Biological Monitoring Journal*. 3: 1–11. https://doi.org/10.2174/1875040001003010001.

Aka M, Pagano M, Saint-Jean L, Arfi R, Bouvy M, Cecchi P, Corbin D, Thomas S. 2000 Zooplankton variability in 49 shallow tropical reservoirs of Ivory Coast (West Africa*). International Review of Hydrobiology* 85: 491–504. https://doi.org/10.1002/1522-2632(200008)85:43.0.CO;2-G.

Alhou B. 2007. Impact des rejets de la ville de Niamey (Niger) sur la qualité des eaux du fleuve Niger. PhD thesis, facultés universitaires Notre-Dame de la Paix, France.

Alhou B, Issiaka Y, Awaiss A, Micha JC. 2014. Premier inventaire des macro-invertébrés du fleuve Niger à Niamey comme bioindicateurs de la pollution urbaine et industrielle. *Hydroecologie Appliquee* 18: 139–163. https://doi.org/10.1051/hydro/2014002.

Alhou B, Goddeeris B. 2011.Contribution à l'identification des larves de Chironomidae du fleuve Niger à Niamey. *International Journal of Biological and Chemical Sciences* 4: 2068–2081.

Allan JD. Life history patterns in sooplankton. 1976. *American Naturalist* 110: 165–180. https://doi.org/10.1086/283056.

Almeida VLS, Dantes Ê, Melo-Júnior M, Bittencourt-Oliveira MC, Moura AN. 2009. Zooplanktonic community of six reservoirs in northeast Brazil. *Brazilian Journal of Biology* 69: 57–65. https://doi.org/10.1590/S1519-69842009000100007.

Arimoro FO, Oganah AO. 2010. Zooplankton community responses in a perturbed tropical stream in the Niger Delta, Nigeria. *The Open Environmental & Biological Monitoring Journal* 3: 1–11. https://doi.org/10.2174/1875040001003010001.

Arora J, Mehra NK. 2003. Seasonal dynamics of rotifers in relation to physical and chemical conditions of the River Yamuna (Delhi), India. *Hydrobiologia* 491: 101–109. https://doi.org/10.1023/A:1024490805310.

Bayley PB. 1995. Understanding large river-floodplain ecosystems. *Bioscience* 45: 153–157. https://doi.org/10.2307/1312554.

Basu BK, Kalff J, Pinel-Alloul B. 2000. The influence of macrophyte beds on plankton communities and their export from fluvial lakes in the St Lawrence River. *Freshwater Biology* 45: 373–382. https://doi.org/10.1046/j.1365-2427.2000.00635.x.

Basu BK and Pick FR. 1997. Phytoplankton and zooplankton development in a lowland, temperate river. *Journal of Plankton Research* 19: 237–253. https://doi.org/10.1093/plankt/19.2.237.

Basu BK, Pick FR. 1996. Factors regulating phytoplankton and zooplankton biomass in temperate rivers. *Limnology*

and Oceanography 41: 1572–1577. https://doi.org/10.4319/lo.1996.41.7.1572.

Bērziņš B and Pejler B. 1989. Rotifer occurrence in relation to oxygen content. *Hydrobiologia* 183: 165–172. https://doi.org/10.1007/BF00018721.

Bonecker CC, Costa CLD, Velho LFM, Lansac-Tôha FA. 2005. Diversity and abundance of the planktonic rotifers in different environments of the Upper Paraná River floodplain (Paraná State – Mato Grosso do Sul State, Brazil). *Hydrobiologia* 546: 405–414. https://doi.org/10.1007/s10750-005-4283-2.

Casanova SMC and Henry R. 2004. Longitudinal distribution of Copepoda populations in the transition zone of Paranapanema River and Jurumirim Reservoir (São Paulo, Brazil) and interchange with two lateral lakes. *Brazilian Journal of Biology* 64: 11–26. https://doi.org/10.1590/S1519-69842004000100003.

De Ridder M. 1992. Contribution to the study of African rotifers: rotifers from Mali. *Hydrobiologia* 237: 93–101. https://doi.org/10.1007/BF00016034.

Djima IT. 2013. Les algues du fleuve du Niger et des milieux humides connexes de l'ouest du Niger. PhD thesis. Laboratoire de Biologie végétale Garba Mounkaila. Faculté des Sciences, Université Abdou Moumouni Niamey, Niger.

Devetter M. 1998. Influence of environmental factors on the rotifer assemblage in an artificial lake. *Hydrobiologia* 387: 171–178. https://doi.org/10.1023/A:1017050011995.

Dumont HJ, Pensaert J, Van de Velde I. 1981. The crustacean zooplankton of Mali (West Africa): Faunal composition, community structure, and biogeography, with a note on the water chemistry of the lakes of the internal delta of the River Niger. *Hydrobiologia*. 80: 161–87. https://doi.org/10.1007/BF00008434.

Etilé RN, Kouassi AM, Aka MN, Pagano M, N'douba V, Kouassi NJ. 2009. Spatio-temporal variations of the zooplankton abundance and composition in a West African tropical coastal lagoon (Grand-Lahou, Côte d'Ivoire). *Hydrobiologia* 624: 171–89. https://doi.org/10.1007/s10750-008-9691-7.

Ezekiel EN, Ogamba EN, and Abowei JFN. 2011. The zooplankton species composition and abundance in Sombreiro River, Niger Delta, Nigeria. *Asian Journal of Agriculture Science* 3: 200–204.

Garcia APP, Lansac-Toha FA, Bonecker CC. 1998. Species composition and abundance of rotifers in different environments of the floodplain of the upper Parana river Brazil. *Revista Brasilian Zoology* 15: 327–343. https://doi.org/10.1590/S0101-81751998000200006.

Grosholz E, Gallo E. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. *Hydrobiologia* 568: 91–109. https://doi.org/10.1007/s10750-006-0029-z.

Holst H, Zimmermann-Timm H, Kausch H. 2002. Longitudinal and transverse distribution of plankton rotifers in the potamal of the River Elbe (Germany) during late summer. *International Review of Hydrobiology* 87: 267–280. *https://doi.org/10.1002/1522-2632(200205)87:2/33.0.CO;2-F.*

Ikhuoriah SO, Oronsaye CG, AdebanjoIA. 2015. Zooplankton communities of the river Ossiomo, Ologbo, Niger Delta, Nigeria. *Animal Research International* 12: 2249–2259.

Imoobe TO. 2011. Diversity and seasonal variation of zooplankton in Okhuo River, a tropical forest river in Edo State, Nigeria. *Centrepoint Journal* 17: 37–51.

Jeje CY, Fernando CH. 1992. Zooplankton associations in the Middle Niger-Sokoto Basin (Nigeria: West Africa). *Internationale Revue der Gesamten Hydrobiologie und Hydrographie* 77: 237–53. https://doi.org/10.1002/iroh.19920770206.

Kuczyńska-Kippen N and Basińska A. 2014. Habitat as the most important influencing factor for the rotifer community structure at landscape level. *International Review of Hydrobiology* 99: 1–7. https://doi.org/10.1002/iroh.201301704.

Lair N. 2006. A review of regulation mechanisms of metazoan plankton in riverine ecosystems: aquatic habitat versus biota. *River Research and Applications* 22: 567–593. https://doi.org/10.1002/rra.923.

Lansac-Tôha FA, Bonecker CC, Velho LFM, Simões NR, Dias JD, Alves GM,Takahashi EM. 2009. Biodiversity of zooplankton communities in the Upper Paraná River Floodplain: interannual variation from long-term studies. *Brazilian Journal of Biology* 69: 539–549. https://doi.org/10.1590/S1519-69842009000300009.

L'Hôte Y. and Mahé G. 1996. Afrique de l'Ouest et centrale, précipitations moyennes annuelles (période 1951–1989). Carte à l'échelle 1/6 000 000. Paris: Orstom.

Mikschi E. 1989. Rotifer distribution in relation to temperature and oxygen content. *Hydrobiologia* 186-187: 209–214. https://doi.org/10.1007/BF00048914.

N'da AS, Berté S, N'zi KG, Bamba M, Kouamélan EP, N'douba V. 2013. Caracteriazation of the ichtyofauna of Bagoé River: Tributary in Niger River (Northern of Côte D'Ivoire). *European Journal of Scientific Research* 106: 22–33.

Pace ML. 1986. An empirical analysis of zooplankton community size structure across lake trophic gradients. *Limnology and Oceanography* 31: 45–55. https://doi.org/10.4319/lo.1986.31.1.0045.

Pace ML, Findlay SEG, Lints D. 1992. Zooplankton in advective environments: the Hudson River community and a comparative analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 1060–1069. https://doi.org/10.1139/f92-117.

Pagano M, Arfi R, Defaye D. 2010. Zooplankton communities of the Sélingué reservoir (Mali, West Africa). The role of environmental factors. In: Defaye D, Suarez-Morales E, von Vaupel Klein JC (Eds), *Studies on Freshwater Copepoda: a Volume in Honour of Bernard Dussart*. pp 383–401.

Picapedra PHS, Fernandes C, Lansac-Tôha FA. 2016. Zooplankton Community in the Upper Parnaíba River (Northeastern, Brazil). *Brazilian Journal of Biology* 77: 402–412. https://doi.org/10.1590/1519-6984.20215.

Picapedra PHS, Fernandes C, Baumgartner G, Lansac-Tôha FA. 2018. Effect of slackwater areas on the establishment of plankton communities (testate amoebae and rotifers) in a large river in the semi-arid region (northeastern Brazil). *Limnetica* 37: 19–31.

Picapedra, PHS, Fernandes C, Baumgartner G. 2019. Structure and ecological aspects of zooplankton (testate amoebae, Rotifera, Cladocera and Copepoda) in highland streams in southern Brazil. *Acta Limnologica Brasiliensia* 31: e5. https://doi.org/10.1590/s2179-975x2917.

Pourriot R., Rougier C, Miquelis A. 1997. Origin and development of river zooplankton: example of the Marne. *Hydrobiologia* 345: 143–148. https://doi.org/10.1023/A:1002935807795.

Romare P, Schindler DE, Scheuerell MD, Scheuerell JM, Litt AH, Shepherd JH. 2005. Variation in spatial and temporal gradients in zooplankton spring development: the effect of climatic factors. *Freshwater Biology* 50: 1007–1021. https://doi.org/10.1111/j.1365-2427.2005.01386.x.

Rossaro B. 1988. Mid-Po River zooplankton: a seven-year study. *Hydrobiologia* 1669: 97–105. https://doi.org/10.1007/BF00015472.

Rzoska J. 1978. On the nature of rivers with case stories of Nile, Zaire and Amazon. The Hague: Junk.

Sarma SSS, Elias-Gutierrez M. 1998: Rotifer diversity in a central Mexican pond. *Hydrobiologia* 387: 47–54. https://doi.org/10.1023/A:1017008918839.

Saunders JF, Lewis WM. 1988. Zooplankton abundance and transport in a tropical white-water river. *Hydrobiologia* 162: 147–55. https://doi.org/10.1007/BF00014537.

Schiemer F, Hein T. 2008. The ecological significance of hydraulic retention zones. *Hydroecology and Ecohydrology* 21: 405–420.

Segers H. 2003. A biogeographical analysis of rotifers of the genus *Trichocerca* Lamarck, 1801 (Trichocercidae, Monogononta, Rotifera), with notes on taxonomy. *Hydrobiologia* 500: 103–114. https://doi.org/10.1023/A:1024624132386.

Segers H. 2007. Annotated checklist of the rotifers (Phylum Rotifera), with notes on nomenclature, taxonomy and distribution. *Zootaxa* 1564. https://doi.org/10.11646/zootaxa.1564.1.1.

Segers H, Dumont HJ. 1995. 102+ rotifer species (Rotifera: Monogonota) in Broa reservoir (SP., Brazil) on 26 August 1994, with description of three new species. *Hydrobiologia* 316: 183–197. https://doi.org/10.1007/BF00017436.

Sharma BK. 2009. Diversity of rotifers (Rotifera, Eurotatoria) of Loktak Lake, Manipur, north-eastern India *Tropical Ecology* 50: 277–285.

Sharma BK. 2005. Rotifer communities of floodplain lakes of the Brahmaputra Basin of Lower Assam (NE India): biodiversity, distribution and ecology. *Hydrobiologia* 533: 209–221. https://doi.org/10.1007/s10750-004-2489-3.

Shiel R, Koste W. 1992. Rotifera from Australian inland waters VIII. Trichocercidae (Monogononta). *Transactions of the Royal Society of South Australia* 116: 1–27.

Sládeček V.1983. Rotifers as indicators of water quality. *Hydrobiologia* 100: 169–201. https://doi.org/10.1007/BF00027429.

Špoljar M, Dražina T, Habdija I, Meseljević M, Grčić Z. 2011. Contrasting zooplankton assemblages in two oxbow lakes with low transparencies and narrow emergent macrophyte belts (Krapina River, Croatia). *International Review of Hydrobiology* 96: 175–90. https://doi.org/10.1002/iroh.201011257.

Sulehria AQK, Mushtaq R, Ejaz M. 2012. Abundance and composition of rotifers in a pond near balloki headworks. *Journal of Animal and Plant Sciences* 22: 1065–1069.

Tackx MLM, De Pauw N, Van Mieghem R, Azémar F, Hannouti A, Van Damme S, Fiers F, Daro N, Meire P. 2004. Zooplankton in the Schelde Estuary, Belgium and The Netherlands. Spatial and temporal patterns. *Journal of Plankton Research* 26: 133–141. https://doi.org/10.1093/plankt/fbh016.

ter Braak CJF. 1994. Canonical community ordination. Part I: Basic theory and linear methods. *Ecoscience* 1: 127–140.

ter Braak CJF, Jongman RH, van Tongeren OFR. 1987. *Data Analysis in Community and Landscape Ecology*. USA: Pudoc.

Thorp JH, Black AR, Haag KH, Wehr JD. 1994. Zooplankton assemblages in the Ohio River: seasonal, tributary, and navigation dam effects. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 1634–1643. https://doi.org/10.1139/f94-164.

Thorp JH, Mantovani S. 2005. Zooplankton of turbid and hydrologically dynamic prairie rivers. *Freshwater Biology* 50: 1474–1491. https://doi.org/10.1111/j.1365-2427.2005.01422.x.

Viroux L. 1997. Zooplankton development in two large lowland rivers, the Moselle (France) and the Meuse (Belgium). *Journal of Plankton Research* 19: 1743–1762. https://doi.org/10.1093/plankt/19.11.1743.

Viroux L. 1999. Zooplankton distribution in flowing waters and its implications for sampling: case studies in the River Meuse (Belgium) and the River Moselle (France, Luxembourg). *Journal of Plankton Research* 21: 1231–1248. https://doi.org/10.1093/plankt/21.7.1231.

Wahl DH, Goodrich J, Nannini MA, Dettmers JM, Soluk DA. 2008. Exploring riverine zooplankton in three habitats of the Illinois River ecosystem: where do they come from? *Limnology and Oceanography* 53: 2583–2593. https://doi.org/10.4319/lo.2008.53.6.2583.

Walz N. 1997. Rotifer life history strategies and evolution in freshwater plankton communities. In: Bruno Streit B, Städler T,Lively CM (Eds), *Evolutionary Ecology of Freshwater Animals*. Basel: Birkhäuser. pp 119–149. https://doi.org/10.1007/978-3-0348-8880-6.

Walz N, Welker M. 1998. Plankton development in a rapidly flushed lake in the River Spree system (Neuendorfer See, Northeast Germany). *Journal of Plankton Research* 20: 2071–2087. https://doi.org/10.1093/plankt/20.11.2071.

Wang Q, Yang Y, Chen J. 2009. Impact of environment on the spatio-temporal distribution of rotifers in the tidal Guangzhou segment of the Pearl River estuary, China. *International Review of Hydrobiology* 94: 688–705. https://doi.org/10.1002/iroh.200811122.

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