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ORIGINAL ARTICLE

Population growth potential of rotifers from a high altitude eutrophic waterbody, Madín reservoir (State of Mexico, Mexico): The importance of seasonal sampling

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ABSTRACT

To understand the population growth potential of different species of rotifers in nature, field collections through seasons are essential. We sampled zooplankton (and measured selected physicochemical variables) from the Madín reservoir, a high altitude eutrophic urban waterbody from Mexico, every month for a year. Qualitative analysis of zooplankton revealed 28 rotifer species and four cladoceran crustaceans plus one unidentified copepod. *Cephalodella catellina* (1400 ind L^{-1}), *Horaella thomassoni* (550 ind L^{-1}), *Conochilus dossuarius* (380 ind L^{-1}) and *Filinia longiseta* (25 ind L^{-1}) had higher peak density than other rotifers. Based on the concentrations of nitrates and phosphates, chlorophyll a levels or different diversity indices (*e.g.*, Carlson, Shannon-Wiener, Pantle and Buck, Ejsmont-Karabin's TSI_{Rot}), the waterbody is eutrophic to hypertrophic, depending on the season. In this waterbody we observed high densities of *Aphanothece* sp. which is a toxic picocyanobacterium. During the blooms of *Aphanothece*, we also recorded higher densities of *H. thomassoni* and *C. catellina*. Based on the gut contents we found that both these rotifer species feed on *Aphanothece* in this waterbody. This study thus suggests the potential growth of *Horaella*, *Cephalodella*, *Conochilus* and *Filinia* in this eutrophic reservoir containing blooms of *Aphanothece*.

Key words: Population dynamics; trophic state; Rotifera; species diversity; nutrients; chlorophyll-a.

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INTRODUCTION

The population growth potential of different species of rotifers is not fully explored. It is well-documented that rotifers are opportunistic species, which exploit resources and rapidly increase their abundance when conditions are favourable (Wallace *et al.*, 2006). Since Edmondson's classic works on *Keratella*, the growth potential of rotifers has been estimated based on field samples (Edmondson, 1960, 1965). Under laboratory conditions, the population growth rates of rotifers are routinely estimated using different concentrations of one or two species of algae (Nandini *et al.*, 2007; Espinosa-Rodríguez *et al.*, 2014). These usually give data on the growth rates, which are of an order of magnitude higher than those from the field conditions. For example, the rotifer *Brachionus plicatilis* can be grown to densities as high as 25,000 ind mL^{-1} (Yoshimatsu and Hossain, 2014) which certainly does not occur in nature and the highest natural densities of *B. plicatilis* is about 50 ind mL^{-1} (Sarma, 1991; Filho *et al.*, 2014). Therefore, population density of rotifers based on field collections reflect their natural growth potential while the maximal rates of population increase are reflected under test culture conditions.

Different studies on field collections of rotifers from both tropical and temperate conditions consistently show the dominance of a few species of rotifers. For example, in nature, one or more genera such as *Anuraeopsis, Keratella, Kellicottia, Brachionus, Polyarthra, Liliferotrocha, Trichocerca, Synchaeta, Cephalodella, Conochilus, Lepadella, Lecane* and *Ptygura* often become highly abundant. They reach >1 ind mL^{-1}, at least in certain seasons (Duggan *et al.*, 2002; Smith *et al.*, 2009; Nandini *et al.*, 2016; Wen *et al.*, 2017). On the other hand, certain other rotifer genera such as *Tripleuchlanis*, *Cyrtonia*, *Microcodides*, *Tetrasiphon*, *Lindia* and *Asplanchna* rarely exceed 500 ind L^{-1} (Fontaneto and Melone, 2003; Wallace *et al.*, 2006). It is generally thought that species that survive under a narrow range of environmental conditions do not show consistently high population abundances through different seasons (Moss, 2010). However, low densities of some rotifer genera mentioned earlier are not necessarily related to their narrow ranges of tolerances to environmental conditions, but other factors such as low intrinsic growth rates (Montero-Pau *et al.*, 2014). For example, both *Platyias* and *Plationus* tolerate a similar range of pH, dissolved oxygen, and temperature intervals (Sarma and Nandini, 2002). Yet, the natural densities of *Plationus* (>16 ind L^{-1}) are higher than those (<6 ind L^{-1}) of *Platyias* (Nandini *et al*., 2005; Muñoz-Colmenares *et al*., 2017). Many species of rotifers are bioindicators of water quality. For example, the saprobic index of Pantle and Buck (1955) and Sladecek´s (1983) valences for different rotifer species are widely used to classify trophic status of freshwater bodies. On the other hand, even if rotifers are not identified to species level, their total density can be still used for inferring the trophic status (*e.g*., TSI_{ROT}, Ejsmont-Karabin, 2012).

To understand the population growth potential of different species of rotifers in nature, field collections through seasons are essential from as many waterbodies as possible. Only through one full year of zooplankton sampling effort, thus including all the seasons, we can estimate the peak population densities of different species present in a given waterbody (Orcutt and Pace 1984; Ramírez-García *et al*., 2002).

Seasonal variations of rotifers have been studied in different waterbodies in Mexico. However, almost all of them are based on large (*e.g*., lake Chapala) and historically (Lake Xochimilco), culturally (*e.g*., lake Paztcuaro) or for drinking water (*e.g*., Valle de Bravo) important waterbodies (De la Lanza and García, 2002). These studies form a basis for further research, but do not necessarily become a typical representation of small but perennial waterbodies (Alcocer and Bernal-Brooks, 2010). Here, we studied the monthly variations of rotifers from the Madín Reservoir during the period 2016-2017.

METHODS

The Madín reservoir is a high altitude (2340 m above sea level) drinking water reservoir located in the State of Mexico (Mexico), in the northwest of Mexico City, at the border of the municipalities of Naucalpan de Juárez and Atizapán de Zaragoza (19°31'34''N and 99°15'39''W). It is an urban waterbody with a surface area of about 50 hectares. The maximum depth is around 50 m. The waterbody is fed mainly by a stream of the Tlalnepantla River (Inclan, 1995). Water from this reservoir is consumed by two municipalities, Naucalpan and Atizapán. Due to human activities such as emission of pollutants, generated by industries and heavy vehicles, this waterbody is contaminated and at times the pH can be acidic, up to 5 (González-González *et al*., 2014). Also, since local administration does not have the necessary equipment for proper water treatment, this waterbody receives sanitary discharges from human settlements and industrial wastewaters containing heavy metals and pharmaceuticals.

To study the seasonal density of zooplankton from the Madín reservoir, monthly plankton samples were collected from five stations for a year (Fig. 1).

Sites 1 and 5 are in the middle of two hillsides, with an approximate depth of 2 meters; unlike site 1, site 5 receives drainage from the human settlement around this area. Site 2 has an approximate depth of 10 meters and receives inflows from Tlalnepantla River; this site has some aquatic birds. Site 3 has an approximate depth of 1 m and is located on the edge of the dam; this also receives drainage from the township of Madín. Due to its shallow depth, this littoral region has terrestrial vegetation. Site 4 has the maximal depth among the sampling stations; it has a depth of 20 m in the pelagic zone of the waterbody. From each sampling station, we filtered 50 L of reservoir surface water through plankton net of 50 µm mesh size.

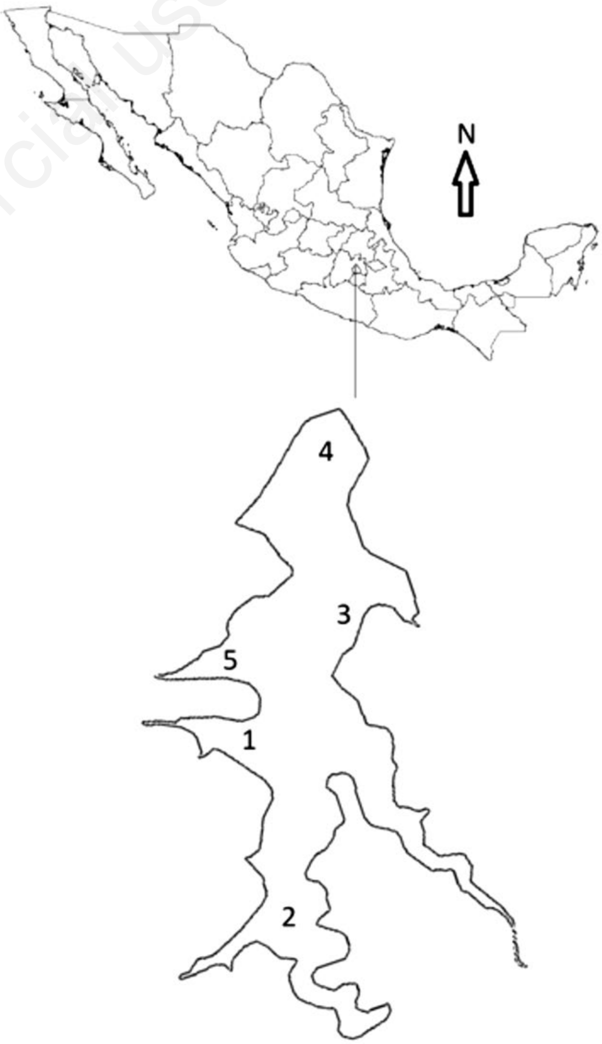

Fig. 1. Map of Madín reservoir with sampling stations 1 to 5.

The concentrated zooplankton samples were fixed in 4% formalin at the site itself. For some sampling stations, we also collected live samples for analysis in the laboratory. Also, at the time of zooplankton collection, we measured selected physicochemical variables of water (temperature, pH, dissolved oxygen, Secchi transparency, alkalinity, phaeophytin-corrected Chlorophyll *a*, conductivity, bicarbonate, carbonate, phosphates (ascorbic acid method) and nitrates) using standard methods (Clesceri *et al*., 1998).

The zooplankton samples were later analysed in the laboratory using a stereomicroscope and a compound microscope. Zooplankton taxa were identified to as far as possible to species level using standard taxonomic literature (Koste, 1978; Wallace *et al*., 2016). For identification of rotifers, trophi was isolated, when needed using commercial sodium hypochlorite. Zooplankton quantification was carried out using 3-5 aliquot samples of 1 ml from each collection using Sedgewick rafter counter and inverted microscope.

We used the following formula to derive species diversity index of Shannon-Wiener (Krebs, 1999).

$$H' = -\sum_{1}^{S} p_{i} \times \log_2 p_i$$

Where *s*=total number of species present in the sample, p_i: the proportion of individuals of the species, and *i*=total individuals.

Carlson's Trophic State Index (TSI) was derived using the data from Secchi disc transparency (TSI_{Sd}), chlorophyll *a* (TSI_{chl}), and total phosphorus concentration (TSI_{TP}) (Carlson, 1977). Total PO_4 was converted to total P using the following: Total P=Total PO_4 (mg/L) X 0.3262.

$TSI=[TSI_{TP}+TSI_{chl}+TSI_{sd}]/3$, where, TSI_{chl}=9.81 *ln* Chlorophyll *a* (µg L^{-1})+30.6; TSI_{Sd}=60-14.41 *In* Secchi depth (m); TSI_{TP}=14.42 *In* Total Phosphorous (µg L^{-1})+4.15 (Osgood, 1982).

The Saprobic index (S) was calculated using the formula proposed by Pantle and Buck (1955). Here $S=\Sigma (s.h) / \Sigma h$, where *S* is the saprobic index of Pantle and Buck (1955); *s* is the valence of each rotifer species (Sladecek, 1983); *h* is the relative frequency (1, rare; 3, common; 5; abundant). The saprobic index *S* is based on the following classification scale: 1.0-1.5, oligosaprobic; 1.6-2.5, β-mesosaprobic; 2.6-3.5, α-mesosaprobic; 3.6-4.4, polysaprobic.

When rotifers dominate aquatic systems and their density is known, then the trophic state index proposed by Ejsmont-Karabin (2012) is useful: TSI_{Rot}=5.38 *ln* (N)+19.28, where, N=total rotifer density (ind L^{-1}). When TSI_{ROT}=<45 mesotrophic; between 45-55: meso-eutrophic; between 55-65: eutrophic and >65: hypertrophic. Additionally, using the total rotifer density, trophic state was derived using the following (Ejsmont-Karabin, 1995; May and O'Hare, 2005; Ejsmont-Karabin, 2012): Total rotifer density=<500 ind L^{-1}: oligotrophic; between 500-1000 ind L^{-1}: mesotrophic; between 1000-2500 ind L^{-1}: eutrophic and between 3000-4000 ind L^{-1}: hypertrophic conditions.

To rank the dominant zooplankton species, we conducted Olmstead-Tukey analysis using species frequency and abundance data (Sokal and Rohlf, 2012). After performing Pearson correlations between the dominant rotifer species and the physicochemical variables, we conducted Canonical Correspondence Analysis (CCA) between the chosen abiotic and biotic factors to visualise the effect of different variables on rotifer taxa.

RESULTS

Data on the selected physicochemical variables showed considerable variations through seasons of dissolved oxygen (3-19 mg L^{-1}), conductivity (93-139 µS cm^{-1}) and pH (7 to 10). Temperature varied from 14 to 24°C depending on the season. Nitrates varied from 0.4 to 43.1 mg L^{-1} while phosphates from 0.17 to 3.6 mg L^{-1}.

Mean annual concentrations of bicarbonates and carbonates from all stations varied from 13 to 266 and 0 to 48 mg L^{-1}, respectively. Carlson index of trophic state showed the values ranged from 61 to 90 for the Station 5 and for the rest of the stations, the index was within this range (Tab. 1). Zooplankton was mainly composed of rotifers (28 taxa) while crustaceans were represented by four taxa and cyclopoids n.d. (Tab. 2). *Keratella tropica, Euchlanis lyra, Lecane bulla, Cephalodella catellina, Conochilus dossuarius* and *Filinia longiseta* were present for at least six months in this waterbody. The rare species *Horaella thomassoni* was present during five months.

Mean annual average density of most rotifer species were <10 ind L^{-1}. However, *H. thomassoni, C. dossuarius* and C. *catellina* were at the mean annual density of 50-70 ind L^{-1}. Fig. 2A shows the seasonal changes in the densities of *C. catellina* which had a single peak abundance of 1400 ind L^{-1} from the sampling station 4 during November and for the rest of the stations during this period, the values were 200-400 ind L^{-1}.

H. thomassoni showed population densities of up to 550 ind L^{-1} during August and November from the stations 1 and 4, respectively (Fig. 2B). *C. dossuarius* had higher densities mainly during August to October months (mean 300 ind L^{-1}) (Fig. 2C). *F. longiseta* occurred in much lower densities (up to 32 ind L^{-1}) in all the sampling stations during the study period (Fig. 2D).

The relation between species frequency and density (Olmstead-Tukey) showed that few rotifer taxa were common while rare species constituted more than 50%.

Tab. 1. Selected physico-chemical and biotic variables (range, min. and max. values) of Madín reservoir from five sites during June 2016-May 2017.

Variable	Sampling stations				
	1	2	3	4	5
DO (mg L^{-1})	3.3-10.6	2.2-13.1	3.3-16.2	3.4-15.4	4.8-19.2
Temperature (°C)	14.7-21.1	14.7-22.5	15.3-23.7	15.3-24.4	16-24
Conductivity (µS cm^{-1})	120-248	139-238	134-238	128-248	136-257
pH	6.9-9.6	7.3-9.7	7.4-10.2	7.5-10.1	7.5-10.1
Bicarbonate (mg L^{-1})	0-100	32-964	17-90	0-90	18-90
Carbonate (mg L^{-1})	0-40	0-42	0-61	0-58	0-42
NO_3^- (mg L^{-1})	0.60-16.40	0.90-8.80	0.40-25.60	0.50-32.40	1.08-43.10
PO_4^{3-} (mg L^{-1})	0.36-1.45	0.34-2.10	0.32-3.60	0.17-1.00	0.25-1.35
Chl *a* (µg L^{-1})	14.2-348.1	7.8-212.6	2.4-275.8	6.8-759.3	5.9-928.8
Hardness ($CaCO_3$ mg L^{-1})	6-120	4-140	4-132	2-112	0-116
Secchi (cm)	37-147	23-113	22-93	19-15	21-101
Carlson index	66.5-80.3	63.9-78.8	70.1-79.2	64.0-81.8	61.1-90.0
TSI_{ROT}	17-56	18-52	21-55	18-60	26-56

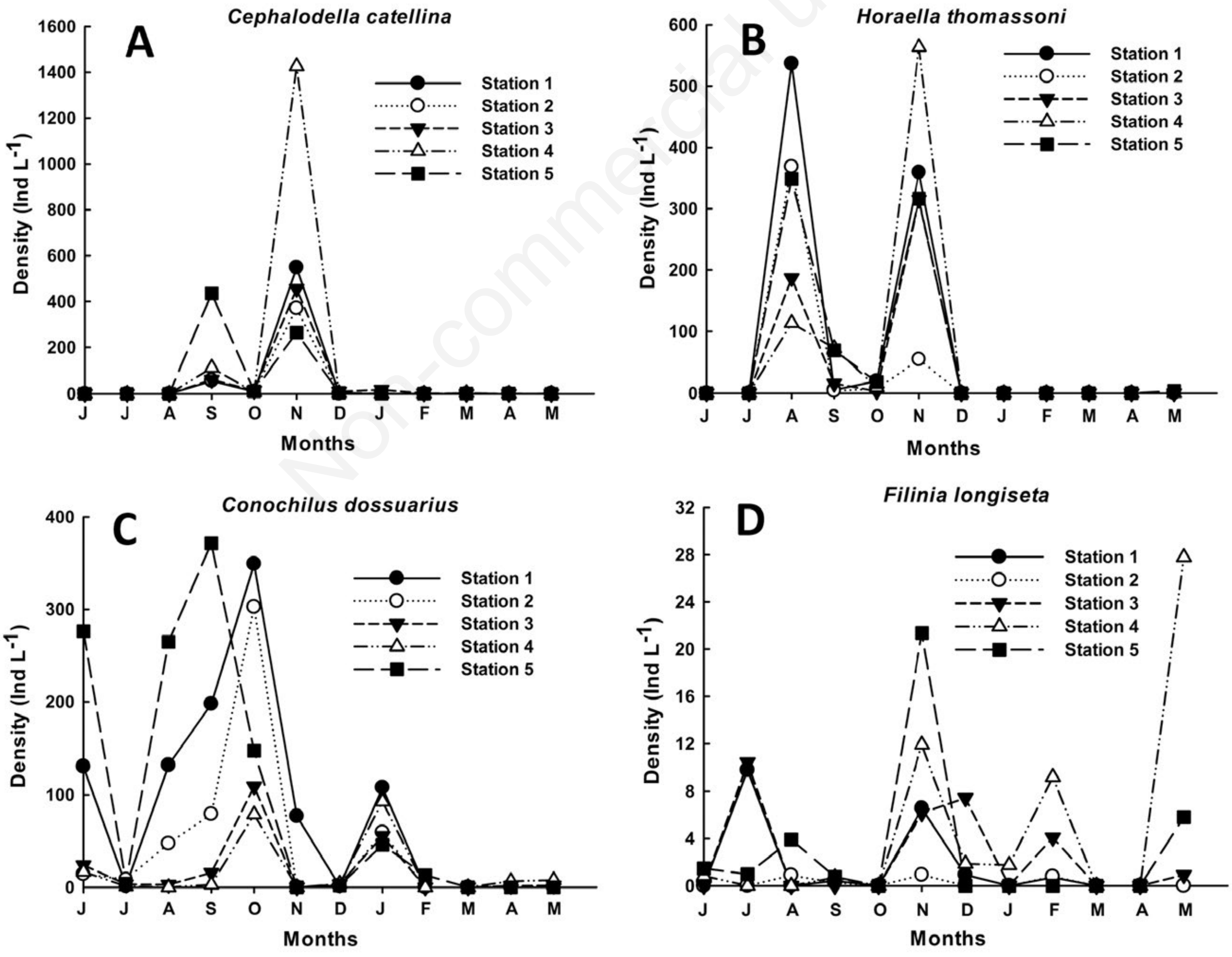

Fig. 2. Seasonal changes in the densities of *Cephalodella catellina* (A), *Horaella thomassoni* (B), *Conochilus dossuarius* (C) and *Filinia longiseta* from the Madín reservoir at different sampling stations. Note the differences on the Y-axis scale.

Tab. 2. List of zooplankton species observed from the Madín reservoir during June 2016-May 2017. Shown are the presence (X) and absence (−) of rotifer species during the sampling period.

Taxa	Months											
	J	J	A	S	O	N	D	E	F	M	A	M
Rotifera												
Family: Brachionidae												
Brachionus angularis (Gosse, 1851)	–	–	X	–	–	–	–	–	–	–	–	–
Brachionus caudatus Barrois & Daday, 1894	–	X	–	X	–	–	–	–	–	–	–	–
Brachionus havanaensis Rousselet, 1911	X	–	X	X	X	–	X	–	–	–	–	–
Brachionus quadridentatus (Hermann, 1783)	X	–	–	X	X	X	X	–	–	–	–	–
Kellicottia bostoniensis (Rousselet, 1908)	X	–	–	–	–	–	–	–	–	–	–	–
Keratella americana Carlin, 1943	–	–	–	X	–	–	–	–	–	–	–	X
Keratella cochlearis (Gosse, 1851)	X	X	–	–	–	X	X	–		X	–	X
Keratella tropica (Apstein, 1907)	–	–	–	X	–	–	X	X	X	X	–	X
Platyias quadricornis (Ehrenberg, 1832)	–	–	–	–	X	X	X	–	–	–	–	–
Family: Euchlanidae												
Euchlanis dilatata Ehrenberg, 1832	–	–	–	–	X	–	–	–	–	–	–	–
Euchlanis lyra Hudson, 1886	–	–	–	–	–	X	X	X	–	X	X	X
Family: Mytilinidae												
Lophocharis salpina (Ehrenberg, 1834)	–	–	–	–	–	–	X	–	–	–	–	–
Family: Colurellidae												
Colurella uncinata (Müller, 1773)	–	–	–	–	–	–	X	X	X	X	X	–
Family: Lepadellidae												
Lepadella acuminata (Ehrenberg, 1834)	–	–	–	–	–	–	–	X	–	–	–	–
Lepadella patella (Müller, 1773)	–	–	–	–	–	X	X	X	X	X	–	–
Family: Lecanidae												
Lecane bulla (Gosse, 1851)	–	–	–	X	–	X	X	X	X	–	X	–
Lecane closterocerca (Schmarda, 1859)	–	–	–	X	–	X	X	X	X	–	–	–
Lecane hamata (Stokes, 1896)	X	–	–	–	X	X	X	X	–	–	–	–
Lecane tenuiseta Harring, 1914	–	X	–	–	–	–	X	–	–	–	–	–
Family: Notommatidae												
Cephalodella catellina (Müller, 1786)	–	–	–	X	X	X	X	X	X	X	X	X
Cephalodella gibba (Ehrenberg, 1830)	–	–	–	–	–	X	–	X	X	–	–	–
Family: Trichocercidae												
Trichocerca sp.	–	–	–	–	X	–	–	–	X	–	–	–
Family: Asplanchnidae												
Asplanchna brightwelli (Gosse, 1850)	–	X	X	–	–	–	–	–	–	–	–	–
Family: Flosculariidae												
Sinantherina sp.	–	–	–	–	X	X	X	–	–	–	–	–
Family: Conochilidae												
Conochilus dossuarius (Hudson, 1875)	X	X	X	X	X	X	X	X	X	–	X	X
Family: Filiniidae												
Filinia longiseta (Ehrenberg, 1834)	X	X	X	X	–	X	X	X	X	–	–	X
Family: Trochosphaerldae												
Horaella thomassoni Koste, 1973	–	–	X	X	X	X	–	–	–	–	–	X
Family: Collothecidae												
Collotheca sp.	–	–	–	–	–	–	–	–	X	–	–	–
Cladocera												
Family: Daphniidae												
Daphnia ambigua Scourfield, 1947	–	–	–	–	–	–	X	X	X	–	–	–
Family: Moinidae												
Moina micrura Kurz, 1874	X	X	X	–	–	–	–	–	–	–	–	X
Family: Sididae												
Diaphanosoma birgei Korinek, 1981	X	X	X	X	X	X	–	–	–	–	–	–
Copepoda												
Family: Diaptomidae												
Mastigodiaptomus albuquerquensis (Herrick, 1895)	X	X	X	X	X	X	X	X	X	X	X	X
cyclopoids n.d. (as nauplii and adults)	X	X	X	X	X	X	X	X	–	–	–	–

From all the sampling stations, *C. catellina* and *H. thomassoni* were dominant; there were few common species. Site 3 had the highest number (10) of dominant species while Site 2 had the lowest (3). In addition, there were a few temporal species (Fig. 3).

Results from the CCA revealed that *Horaella thomassoni, Filinia longiseta, C. catellina* and *C. dossuarius* were correlated with one or more physicochemical variables (Fig. 4). For example, *C. dossuarius* negatively related to Secchi transparency, while *F. longiseta* with bicarbonates.

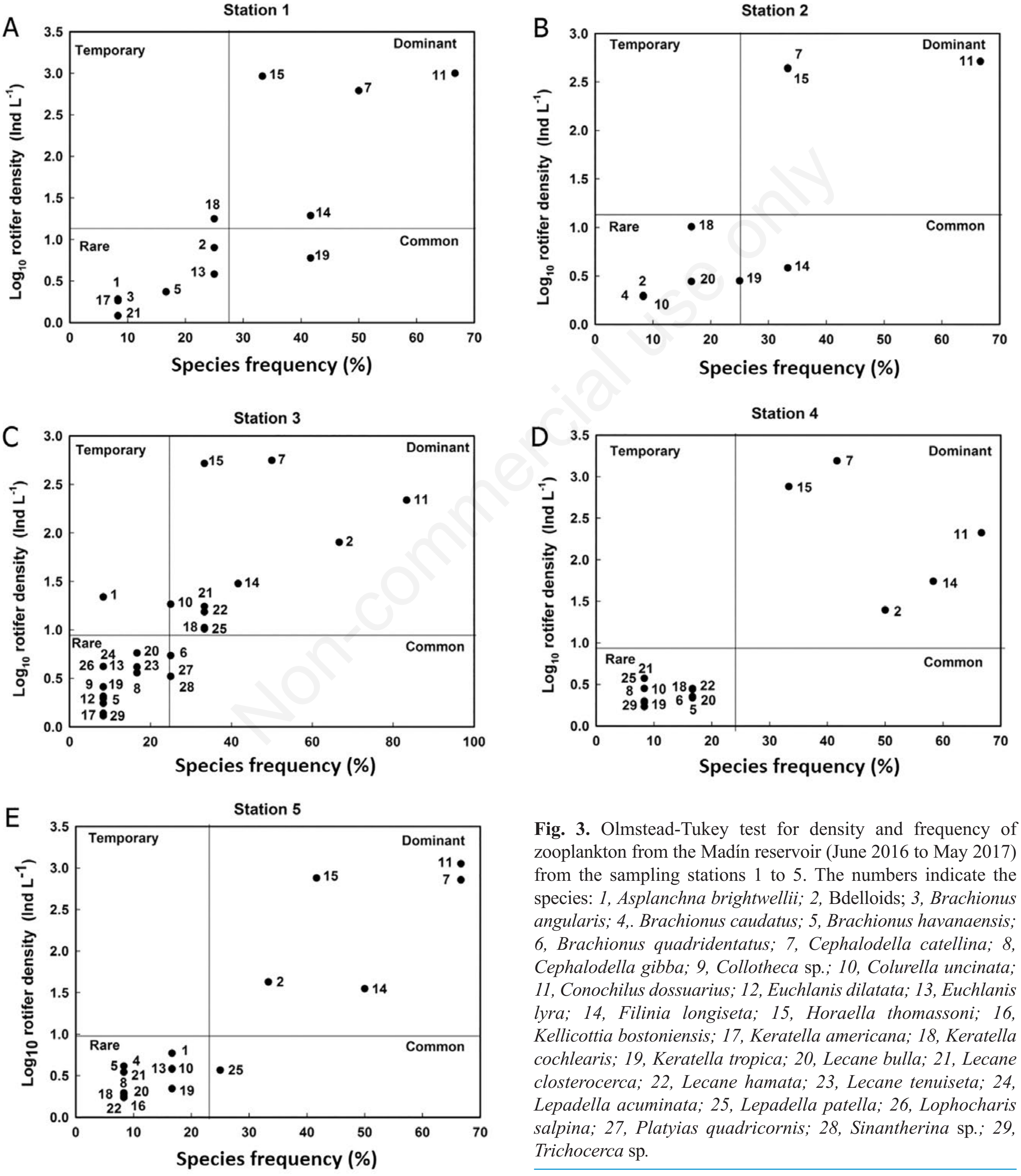

Fig. 3. Olmstead-Tukey test for density and frequency of zooplankton from the Madín reservoir (June 2016 to May 2017) from the sampling stations 1 to 5. The numbers indicate the species: *1, Asplanchna brightwellii; 2,* Bdelloids; *3, Brachionus angularis; 4,. Brachionus caudatus; 5, Brachionus havanaensis; 6, Brachionus quadridentatus; 7, Cephalodella catellina; 8, Cephalodella gibba; 9, Collotheca* sp.*; 10, Colurella uncinata; 11, Conochilus dossuarius; 12, Euchlanis dilatata; 13, Euchlanis lyra; 14, Filinia longiseta; 15, Horaella thomassoni; 16, Kellicottia bostoniensis; 17, Keratella americana; 18, Keratella cochlearis; 19, Keratella tropica; 20, Lecane bulla; 21, Lecane closterocerca; 22, Lecane hamata; 23, Lecane tenuiseta; 24, Lepadella acuminata; 25, Lepadella patella; 26, Lophocharis salpina; 27, Platyias quadricornis; 28, Sinantherina* sp.*; 29, Trichocerca* sp.

Shannon-Wiener diversity index ranged from close to zero to 2.3 bits ind^{-1} depending on the sampling station and month. In general Station 2 had the lowest species diversity in all seasons, while Station 3 had the highest. December month had the highest species diversity index for four stations (Fig. 5). Saprobic index of Pantle and Buck varied from 1.0 to 2.4 depending on the sampling station and the season. In general stations, 1 to 4 was beta mesosaprobic, while station 5 was predominantly oligosaprobic (Fig. 6).

The TSI$_{ROT}$ index in this waterbody varied from 17-60 depending on the sampling station and the month. In general for all the stations, November month had the highest TSI$_{ROT}$ index, while for February to April, these values were lowest (Tab. 1).

DISCUSSION

The range of physicochemical variables recorded in this study is known in some other waterbodies of this region (De la Lanza and García, 2002). For example, in high altitude regions of central Mexico, water temperature ranges from <10 to >24°C (Alcocer and Bernal-Brooks, 2010). In Site 1, we observed near neutral pH (6.9), but it was as high as 10 in other stations. Previous studies have shown that the pH of this waterbody was acidic (Inclan, 1995; González-González *et al*., 2014). Our study indicated that pH from all sampling stations during most part the year was on the basic range suggesting that some improvements did occur in this waterbody due to governmental intervention, including regulation of vehicular traffic.

The previously mentioned study also showed the presence of pharmaceuticals such as nonsteroidal anti-inflammatory drugs at concentrations from 0.18 to 4.51 ng L^{-1} (González-González *et al*., 2014). However, using a similar method employed in a previous study, we did not find these pharmaceuticals at detection levels. Although the disorderly urban growth around this waterbody continues to discharge the wastewater, some regulatory laws have been enforced on the local

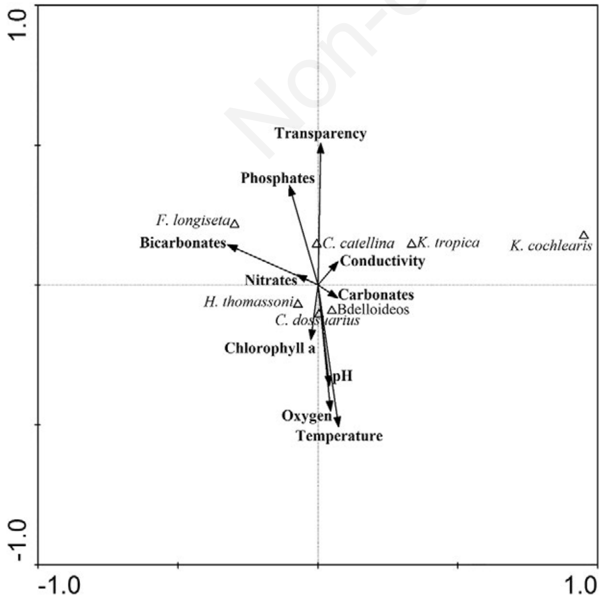

Fig. 4. Canonical correspondence analysis of rotifers from the Madín reservoir with the abiotic and biotic variables.

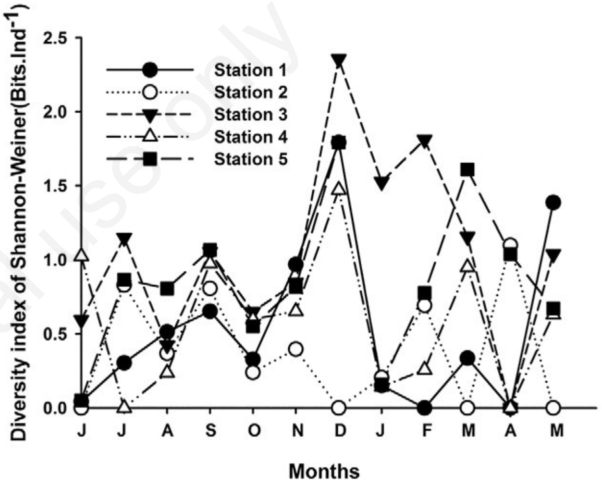

Fig. 5. Shannon-Wiener species diversity index from the Madín reservoir in relation to zooplankton collection period from different sampling stations.

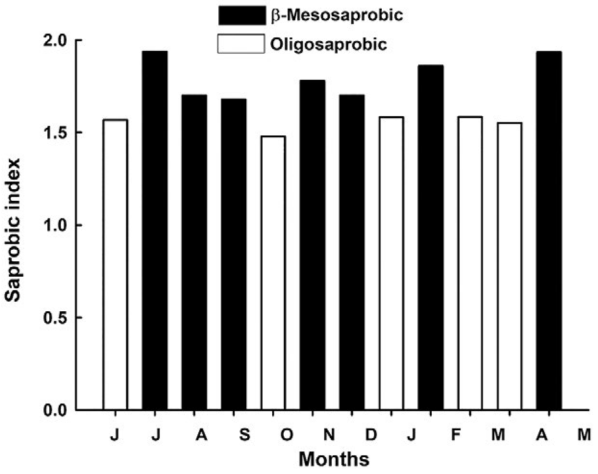

Fig. 6. Saprobic index from the Madín reservoir in relation to zooplankton collection period based on the mean values of five sampling stations.

inhabitants. This is further supported by the fact that towards the end of 2013 there was an intense effort to clean-up the reservoir by the local administration to offer drinking water from this waterbody. Similarly, in a nearby waterbody, Lake Xochimilco (Mexico City) once had high levels of triclosan, an endocrine disruptor (Duran-Alvarez *et al*., 2015) but after a few years, its concentrations were undetectable in the same waterbody (González-Pérez *et al*., 2018).

Carbonates and bicarbonates were in low or undetectable levels during certain months (June and December). The nitrate levels were not high (<2 mg L^{-1}), except in the summer months (May-June), to cause mortality to zooplankton. For example, the LC_{50} for *Daphnia magna* is about 460 mg L^{-1} (Camargo *et al*., 2005). However, phosphate levels were high (annual mean 0.64 mg L^{-1}). In Lake Xochimilco, Nandini *et al*. (2016) reported nitrate levels of <1 mg L^{-1}, while phosphates are an order of magnitude higher (2.5-7.8mg L^{-1}). On the other hand, Chl *a* levels in this work varied considerably (2 to 930 µg L^{-1}), the mean annual concentration was 110 mg L^{-1}. High Chl *a* levels were recorded in all sites during rainy months (July and August). Phosphate also showed peak values during this season, which is responsible for higher primary production in this waterbody (Moss, 2010). Based on Carlson's (1977) index of trophic state, this waterbody was eutrophic in all the stations during the entire sampling period.

Zooplankton in Madín reservoir was mainly composed of rotifers; crustaceans were represented by four taxa and cyclopoids n.d. Of the 28 rotifer taxa observed here, the family Brachionidae was dominant representing four genera and nine species. This is probably due to the high fish predation pressure (Gliwicz and Pijanowska, 1989; Hansson *et al*., 2007); this reservoir has high numbers of several fish species including carpa and tilapia. *D. ambigua* was common in winter months, while *Diaphanosoma* was in the summer months. This is supported by that fact that *Daphnia* is a temperate genus while *Diaphanosoma* is tropical (Forró *et al*., 2008). The occurrence of *Mastigodiaptomus albuquerquenseis* in this waterbody is no surprise since this genus is most common in Mexico with as many as 5 out of 10 known species are endemic to Mexican fauna (Gutíerrez-Aguirre and Cervantes-Martínez, 2016). We found four members of the genus *Brachionus* while *Trichocerca* was represented by just one species. In addition, *Trichocerca* was present in only two out of 12 months. Though we could not derive the $Q_{B/T}$ quotient for *Brachionus* to *Trichocerca* (Sládeček, 1983) (*Trichocerca* was entirely absent for certain months), the data showed that the waterbody was eutrophic.

The dynamics of rotifer abundances in this waterbody showed seasonal trends which differ from the data reported from many other high-altitude waterbodies in the Central Mexico (Nandini *et al*., 2005; Gutiérrez *et al*., 2017). For example, most works have shown the dominance of Brachionidae (*e.g.*, *Keratella*, *Anuraeopsis*) and *Polyarthra* (Jiménez-Contreras *et al*., 2009; Figueroa-Sanchez *et al*., 2014) in drinking water reservoirs, while in recreational waterbodies such as Llano Reservior, *Trichocerca* and bdelloids often dominate (Muñoz-Colmenares *et al*., 2017). On the other hand, in shallow waterbodies such as Lake Xochimilco, species of *Brachionus* (*B. calyciflorus, B. havanaensis, B. angularis* and *B. caudatus*), *Keratella* (*K. cochlearis, K. tropica*) and *Lecane* (*L. bulla*) are dominant (Nandini *et al*., 2016; Gayosso-Morales *et al*., 2017). In deep lakes such as El Sol and La Luna the dominant rotifers are *Polyarthra dolichoptera* and *Conochilus unicornis*, bdelloids, *Lecane lunaris* and *Lepadella accuminata* (Dimas-Flores *et al*., 2008). Thus, in none of these studies, dominance of uncommon rotifers such as *Horaella* has been reported. In the present work, *H. thomassoni* reached density as high as 550 ind L^{-1}. Earlier records indicate that this species occurs in much lower density (150 ind L^{-1}). In eutrophic waterbodies, cyanobacterial dominance is common. In this work, though phytoplankton analysis was not done, we observed high densities of *Aphanothece* sp. *Aphanothece* is a picocyanobacterium that produces toxins called nodularins. These nodularins are hepatotoxic cyclic peptides that are toxic to zooplankton (Ferrão-Filho and Kozlowsky-Suzuki, 2011). Interestingly during the blooms of *Aphanothece*, we also recorded higher densities of *Horaella*. It is possible that *Horaella* feeds on *Aphanothece*. Gut contents revealed freshly collected fragments of *Aphanothece* but could not be confirmed. However, based on the functional role, all species of Gnesiotrocha including *Horaella*, *Filinia* and *Conochilus*, possess malleoramate trophi, well adapted to feed on bacteria or detritus or other smaller food particles (Obertegger *et al*., 2011). Since *Aphanothece* belongs to picocyanobacteria, their cell size is within the preferred range of Gnesiotrocha. Laboratory studies indicate that several rotifers can feed well on cyanobacteria in spite of their poor nutritional quality or toxicity (Starkweather and Kellar, 1983; Alva *et al*., 2009).

The Madín reservoir has a high quantity of particulate organic matter since it receives domestic wastes containing organic substances. This is further confirmed by the Saprobic index of Pantle and Buck (1955), which ranged from 1.25 to 2.5. Thus, the waterbody is oligosaprobic to β-mesosaprobic. This is similar to Lake Xochimilco with a saprobic index ranging from1.5 to 2.0 (Nandini *et al*., 2016). The total rotifer density was however much lower: the mean annual density was 180 ind L^{-1} and when data of all the five stations were combined, 11 months had mean density of < 500 ind L^{-1}

(oligotrophic condition) while only one month (November) had close to 1000 ind L^{-1} (mesotrophic). Therefore, the use of total rotifer density as a parameter to determine the trophic state was not applicable to this reservoir, most probably due to the presence of inedible and possibly toxic picocyanobacteria (*Aphanothece*) and cyanobacteria (*e.g.*, *Microcystis*). This is also possibly responsible for low species diversity (<1 bits ind^{-1} mean Shannon diversity), which is much lower than most waterbodies in this region (*e.g.*, 1.2-3.4 bits ind^{-1}: Xochimilco (Gayosso-Morales *et al*., 2017); 1.0-4.3 bits ind^{-1}: Iturbide Reservoir (Sarma *et al*., 2011); 1.0-4.2 bits ind^{-1}: Llano reservoir (Muñoz-Colmenares *et al*., 2017)). The mean annual TSI$_{ROT}$ index for Madín reservoir was 38 indicating a mesotrophic condition of the waterbody (Ejsmont-Karabin, 2012). In a nearby high-altitude waterbody in Mexico City, Gutiérrez *et al*. (2017) reported that the mean annual TSI$_{ROT}$ index was <40, which is close to the value observed in the present study.

This study highlights the growth potential of *Horaella thomassoni, Conochilus dossuarius* and *Cephalodella catellina*. All these three species were able to reach up to 500 ind L^{-1} during winter. *C. dossuarius* was earlier reported at densities of up to 20 ind L^{-1} from the Lake Catemaco, a tropical waterbody from the State of Veracruz (Mexico) (Torres-Orozco and Zanatta, 1998). The growth potential of *C. catellina* is interesting. It is a small notommatid member (body length <100 µm) and reached up to 1400 ind L^{-1} from site 4 during November. The genus *Cephalodella* is the most diverse of all rotifer genera with nearly 10% of all species (about 2000 taxa of global diversity). Though the reproductive biology of *C. catellina* is reported (Alvarado-Flores *et al*., 2017: Trophi of Fig. 3E shown in there does not belong to this species, possibly that of *Notommata glyphura*), its natural densities are generally low (Muñoz-Colmenares *et al*., 2017). Being very small, this species is also microphagous with an affinity to feed on small phytoplankton, bacteria and detritus abundant in the Madín Reservoir. Its high population density during blooms of *Aphanothece* suggests that it may be able to feed on this picocyanobacterium.

CONCLUSIONS

The growth potential of rotifers can be known based on field collections since culturing most of them under laboratory conditions is not possible due to unavailability of data on their and feeding habits. Our study showed that the seasonal study of Madín reservoir was helpful to understand the potential for high population densities of rotifers such as *Horaella thomassoni*, *Conochilus dossuarius* and *Cephalodella catellina*. For example, it was observed that *Cephalodella catellina* could reach peak density of up to 1400 ind L^{-1}, while the rare species *Horaella thomassoni* was capable of attaining peak population densities of more than 550 ind L^{-1}. Our study further indicated that picocyanobacteria could be a potential source of food for Gnesiotrocha and smaller *Cephalodella* species. However, laboratory tests are still needed to confirm this and also the toxic nature of *Aphanothece* to rotifers.

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