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Effect of organic and inorganic turbidity on the zooplankton community structure of a shallow waterbody in Central Mexico (Lake Xochimilco, Mexico)

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Abstract

Aim: Lake Xochimilco is shallow (< 2m) water-body in Mexico City consisting of several interconnected canals. It is now eutrophic, with high levels of turbidity as a result of suspended sediment and phytoplankton blooms. We selected two sites, the Rowing channel with organic turbidity due to cyanobacterial blooms and the Main channel with inorganic turbidity from re-suspended clay. The aim of this work was to present data on zooplankton dynamics in two channels of the lake over one year (June, 2013 to May, 2014).

Methodology: We collected zooplankton by filtering 80L of water from two sites in each of the canals, as well as measuring temperature, pH, conductivity, dissolved oxygen, nitrate-N and phosphate-Ps, Chlorophyll-a, and Secchi disk transparency at each of the sites.

Results: The zooplankton community was dominated by rotifers; cladocerans and copepods were few. The common rotifer genera in the lake were *Keratella*, *Brachionus*, *Polyarthra*, *Trichocerca*, *Filinia*, *Asplanchna* chydorid cladocerans like *Chydorus sphaericus*, *Pleuroxus varidentatus*, *Alona* sp. and copepods *Acanthocyclops americanus* and *Microcyclops rubellus*. The canonical correspondence analysis (CCA) in the Rowing channel station, showed that the first two ordination axes explained 46% of the variance of the species data in CCA. The first and second axes were well correlated with the environmental data. The Monte Carlo permutation test was significant on the first axis.

Interpretation: Our study showed that the presence of organic turbidity as observed in the rowing channel had a greater adverse effect than the inorganic turbidity on zooplankton density and diversity.

Introduction

Shallow lakes are often turbid. The turbidity could be due to re-suspension of inorganic sediment (Lövestedt and Bengtsson, 2008), or organic produced by high phytoplankton density or cyanobacterial bloom, which is characteristic of many shallow lakes (Descy *et al.* 2013). The turbid state, due to high densities of phytoplankton, results in poor water quality and fewer species (Declerck *et al.*, 2005). Cyanobacterial blooms such as those of *Microcystis* spp. result in low visibility in the water column and have an adverse effect on the feeding and mate searching behavior in visual organisms (Vasconcelos, 2006). Some strains of these surface blooms produce toxins that are harmful to zooplankton, fish, birds, cattle, pets and even humans (Huisman *et al.*, 2005). Turbidity also occurs when sediment and organic matter is re-suspended which serves as food for microorganisms and zooplankton (Donohue and Garcia-Molinos, 2009). Detritus and fine sediments may interfere with the filtering and food gathering processes for several zooplankton species (Kirk, 1990). Extended or frequent sediment re-suspension may result in less energy transfer from lower to upper trophic levels and alteration of the community structure (Levine *et al.*, 2005).

Lake Xochimilco, an ancient natural waterbody in Mexico City, is a product of centuries of land use management resulting in 207 miles of canals, eight small lakes and two seasonal wetlands. Originally it was fed by natural springs and rain water but now the level is maintained with partially treated waste water (Martínez-Arroyo and Jaurregui, 2000). The lake also supports an intricate network of floating agricultural plots on islands called Chinampas, which were developed by the Mexican tribes in the fourteenth century. Fertilizers and pesticides constantly enter the system from these fields thus increasing the problems associated with eutrophication. The entire ecosystem is in the UNESCO World Heritage List since 1987 and is on the list of International Convention on Wetlands (RAMSAR) since 2004; it is also an area with high human population densities, which gives it a high environmental and socioeconomic value.

The canals in Xochimilco are shallow, < 1m in depth for most part. Previous studies demonstrate that this waterbody supports extremely high densities and diversity of rotifers (Nandini *et al.*, 2005; Enriquez *et al.*, 2009), and a low density of microcrustaceans, especially cladocerans, probably as a result of high fish predation pressure on large zooplankton in the system. The dominant fish species include Cichlids (*Oreochromis* sp.), Cyprinids (*Cyprinus carpio*) and Poeciliids (*Xiphophorus helleri*). Annually, several tons of the exotic tilapia and common carp are fished out from the lake; close to 7.5 tons per week were harvested over a period of several months between 2006 and 2008 (Zambrano and Valiente, 2008). These high densities of fish have driven the native Axolotl, *Ambystoma mexicanum*, to the brink of extinction (Chaparro-Herrera *et al.*, 2011). Fish also exert a high predation pressure on cladocerans and thus decrease the

interference competition on zooplankton (Kirk and Gilbert, 1990). In turbid lakes, high predation losses may be partially counter balanced by high population growth rates resulting from high food levels. The success of microzooplankton in turbid lakes may also be related to their small size and their ability to avoid predation (Sarma and Nandini, 2007).

For long it has been known that abiotic and biotic factors are important in determining the diversity of zooplankton (Dumont, 1977). Clear lakes dominated by macrophytes are expected to have high species diversity. However, the high species density and diversity of rotifers in the eutrophic, highly contaminated Lake Xochimilco is hard to explain yet well documented (Nandini *et al.*, 2005). One of the factors promoting this condition is perhaps the high fish predation pressure on large zooplankton, thereby reducing the interference competition as well as the high nutrient load and diversity of phytoplankton, which probably reduces the competition for food. The effect of turbidity on fish feeding or demography of a few zooplankton species has been documented based on laboratory works (García-García *et al.*, 2006) but few studies exist on the effect of organic and inorganic turbidity on natural plankton communities (Bilotta and Brazier, 2008; Donohue and Garcia-Molinos, 2009). We studied the effect of turbidity on the community structure of zooplankton in Xochimilco lake, which has high organic and inorganic turbidity throughout the year. The aim of the work was to present data on the seasonal dynamics of zooplankton at two sites in Lake Xochimilco, one channel predominantly with inorganic turbidity (cited as Main Channel hereafter) and the other site, with organic turbidity (Rowing Channel).

Materials and Methods

Study area : Mexico City was built over an ancient system of five lakes, one of which remains is Lake Xochimilco. The channels of Xochimilco have a surface area of 55,000 m² and a maximum depth of 1.5 m (Solís *et al.*, 2006). This water body is eutrophic since it receives effluents from domestic and horticultural wastes. The temperature ranges from 12 to 20 °C, with rains from May to September. For this study, we selected two sampling stations; the first is the Rowing channel (19°16'26.9"N 99°06'17.9"W) with predominant organic turbidity. This is a small body of water created for rowing and canoeing competitions, but is filled by water from the channels of Xochimilco. The second was the Main channel (19°16'18.2"N 99°06'16.7"W) with predominant inorganic turbidity, which was near the point at which treated water entered the lake from the 'Cerro de la Estrella' water treatment plant in municipal area Iztapalapa (Mexico City). These sampling stations were at a distance of about one kilometer from each other and are shown in Fig. 1.

Field and laboratory methods : Zooplankton samples were collected every month from June 2013 to May 2014 by filtering 80 L of water from the lake surface in Rowing channel and the Main

Fig. 1 : Map of Xochimilco Lake. Sampling stations (A) Rowing channel (B) Main channel

channel through a plankton net of 50 μm pore size and fixed immediately in 10% formalin. We measured, in situ or in the laboratory, the following physico-chemical variables: temperature, pH, conductivity and dissolved oxygen using a multi-probe system model YSI 55 (YSI Incorporated, USA). Phosphate-P and nitrate-N were measured at appropriate wavelengths using a YSI 9100 photometer test kit, transparency (using Secchi disk) and turbidity was measured using a turbidimeter (Hanna, HI 93703).

For zooplankton, we counted three aliquots of 1 ml each of the concentrated samples using an inverted microscope in a Sedgwick Rafter chamber. For rotifers, where needed, we separated the trophi using 10% sodium hypochlorite solution. For some soft-bodied rotifers, it was necessary to collect live samples and in such cases, we separately collected live zooplankton.

The dominant algal species were identified during this study. The morphological identification of eukaryotic algae and cyanobacteria was made following Komárek *et al.*, 1999; Tavera *et al.*, 2000; Comas *et al.*, 2007 and Tavera and Diez, 2009. For microcrustaceans species we identified and quantified them using a light microscope (Nikon) at different magnifications (10X to 1000X). We counted all the individuals in three aliquots of 5 mL each of the concentrated samples using an inverted microscope. Copepods were classified as nauplii, copepodite and adults; only adult copepods were identified to species. For the taxonomic identification of these crustaceans we used specialized keys (Koste, 1978; Korovochinsky and Smirnov, 1998; Dumont and Negrea, 2002; Elías-Gutiérrez *et al.*, 2008).

In order to measure chlorophyll-a concentration (Chl-a), 250 ml of the water sample was taken and filtered through a Whatman GF/C glass fibre filter within 3h of collection. Pigment extraction was extracted using 90% acetone and concentrations were determined spectrophotometrically (Rice *et al.*, 2012).

Data analysis : Taxonomic data were used for the following analyses: Species diversity was calculated using Shannon-

Wiener diversity index using the following equations (Krebs, 1993):

$$H' = -\sum_{i=1}^S P_i \log_2 P_i$$

where, H' is the Shannon-Wiener Index of diversity, P_i = proportion made up of the i^{th} zooplankton species.

The trophic state of the reservoir was determined using ratios based on the number of *Brachionus* to *Trichocerca* species ($Q_{B/T}$, Sládeček, 1983).

Saprobic indices were calculated using the formula proposed by Pantle and Buck (1955):

$$S = \sum (s \cdot h) / \sum h$$

where, S is the saprobic index, s is the valence of each rotifer (Sládeček, 1983), h is the relative frequency (1 = uncommon, 3 = common and 5 = abundant), and the saprobic index (S) takes values on the following ranking scale: 1.0–1.5 = oligosaprobic, 1.6–2.5 = β -mesosaprobic, 2.6–3.5 = α -mesosaprobic and 3.6 $\geq$ 4.4 = polysaprobic.

We compared the differences of the environmental variables between each site using paired t-tests. Relationships between the physicochemical and zooplankton data were analysed using the canonical correspondence analysis (CCA) using Canoco for MVSP Shareware 2.0 (Kovachs, 1990). We conducted these analyses on the physicochemical variables tested in the study, which were chlorophyll-a, dissolved oxygen, temperature, pH and nitrate-N and phosphate-P concentrations. We incorporated monthly values for the entire 1-year study duration, but we conducted the analyses individually for both the stations. We selected genus level of cladocerans, copepods and rotifers for correspondence analysis. The heterogeneity in the community composition was tested using DCA, the result of the gradient length was 3.0, for which a unimodal method CCA with standardized data was applied. The abundance of data was transformed by $\log(x+1)$ to obtain normal distribution. In Rowing channel, a forward selection of the explanatory variables was used to assess the usefulness of each potential predictor and significant variables were selected. For the Main channel, we used the full model. The statistical significance of variables was tested with partial Monte Carlo permutation test available in the Canoco Software.

Results and Discussion

Lake Xochimilco is similar to other eutrophic lakes; in spite of the high nutrient loads and the levels of contamination (Solís *et al.*, 2006), high densities and diversity of phytoplankton and zooplankton have been recorded in many previous studies (Nandini *et al.*, 2005; Enríquez *et al.*, 2009; Tavera and Diez, 2009).

The Rowing channel sampling station was dominated by organic turbidity due to cyanobacterial blooms while turbidity in the Main channel was commonly due to sediment, mostly inorganic particles. Phytoplankton in the former was dominated by cyanobacteria *Microcystis* spp., (also reported by Arzate Cardenas et al., 2010; Pineda-Mendoza et al., 2011), *Planktothrix agardhii* (Gomont) Anagnostidis and Komárek 1988, and *Golenkinia radiata* Chodat 1894, while the Main channel had high densities of the microalgae *Desmodesmus* sp. *Golenkinia radiata*, *Coelastrum astroideum* De Notaris 1867, *Pediastrum boryanum* (Turpin) Meneghini 1840 and *Cyclotella meneghiniana* Kützing 1844.

The main difference between the two sampling stations, the Rowing channel and the Main channel was observed in terms of phytoplankton biomass (Chl-a). Although nutrient levels were higher in the Main channel, Chl-a values were highest in the Rowing channel. This is probably due to the high densities of cyanobacteria which are often inedible for zooplankton (Alva-Martinez et al., 2009). Tavera et al. (2000) have shown that cyanobacteria and green chlorococcalean algae were the dominant primary producers in Lake Xochimilco. In the Rowing channel the phytoplankton was dominated by *Microcystis*. Cyanobacteria are normally less affected by nutrients, especially nitrogen, limitation (Huisman et al., 2005) as was observed in the Rowing channel. The suppression by toxic strains of cyanobacteria may reduce the abundance of rotifers and other zooplankton (Gilbert, 1994). However, we found high densities of the rotifer *B. havanaensis* at this site, probably due to the ability of this species to tolerate *Microcystis* diets (Alva-Martinez et al., 2009) and the low toxicity of the strain of *Microcystis* in this water body (Fernandez et al., 2014). In the Main channel, on the other hand, we found Chlorophytes such as *Desmodesmus acutus*, *Golenkinia radiata* and *Cyclotella meneghiniana*, which are known to be better competitors in shallow lakes with high TP concentrations and pH (Jensen et al., 1994).

During this study 51 species of rotifers, 6 species of cladocerans and 2 species of copepods were identified from the lake (Table 1). Rotifers mainly included taxa from two families, Brachionidae and Lecanidae, together accounting for more than half the species richness of rotifers (25 species). The species present throughout the year included *Brachionus calyciflorus*, *Brachionus havanaensis*, *Keratella tropica*, *Keratella cochlearis*, *Lecane bulla* and *Polyarthra vulgaris*. Zooplankton densities of most species were higher in the rainy than the dry season. In the rainy season (June to November) we found *Keratella tropica* to be the most abundant species (800 ind. l⁻¹); in the Rowing channel *Brachionus havanaensis* and *Lecane bulla* were abundant. In the Main channel higher densities of *Brachionus angularis* and *Euchlanis dilatata* were present. In the dry season (February to April) the Rowing channel had high densities of *Keratella tropica*, *Keratella cochlearis* and *Brachionus havanaensis*. *Polyarthra*

vulgaris (140 ind. l⁻¹) was the most abundant species, present throughout the study period. In the Main channel we found *Brachionus durgae*, *Lecane bulla* and *Keratella tropica* (Fig. 2). Throughout the year, the densities of most species were higher in summer than in winter. The density of brachionids was lower in the presence of high levels of organic turbidity, which coincides with the presence of high densities of *Microcystis*, a potentially toxic cyanobacteria. Similar conditions had little effect on the genus *Keratella* (Fig. 2).

The Shannon-Wiener diversity index ranged between 1.2 to 3.4 in the Main channel, and 1.3 to 2.5 in the Rowing channel; species diversity was significantly lower in the latter (Students *t* test = 0.019, df = 11, *p* < 0.05) (Fig. 3). Diversity was higher in August and February in the Main channel and in December in the Rowing channel station (Table 2). The edible algal density and diversity greatly influence the species richness of zooplankton (Wallace et al., 2006). We found lower diversity of rotifers in the Rowing channel, suggesting control from other abiotic or biotic variables between sampling stations. It is likely that the presence of high levels of organic matter reduced the species diversity in the Rowing channel. This could be related to the decrease in the diversity of available food resources.

In the Main channel, which had a greater diversity of green algae, we found a greater richness of rotifer species including *Brachionus durgae*, *Lecane bulla*, *Keratella tropica* as well as the genera *Trichocerca*, *Lepadella*, *Euchlanis*, *Mytilina*, *Platylas* and *Testudinella*, the latter taxa are common in macrophyte-associated habitats (Green, 2003). In the Rowing channel the dominant species are *Keratella cochlearis*, *K. tropica*, *P. vulgaris* and *Brachionus havanaensis*. *K. cochlearis* was the third most abundant species that we found throughout the year in higher densities at the Rowing channel station, which suggests that these rotifers are adapted to exploit low-food conditions (Kirk, 2002). These species are generalist feeders with a low threshold food concentration and thus capable of surviving long starvation periods (Kirk, 2002). They are also less susceptible to *Microcystis* blooms than other rotifers (Alva-Martinez et al., 2007). Another species that we found in high densities in this station was *Polyarthra*, which was dominant due to its preference for a wider size range of food (approximately 1–40 µm) (Arndt, 1993) as well as its capacity to avoid predation (Brandl, 2005). Low densities of cladocerans in this lake could be attributed to fish predation (Nandini et al., 2005; Enríquez et al., 2009). The lake supports high densities of carps and tilapia, so much so that these non-native species are being fished out to provide native species such as the Axolotl (*Ambystoma mexicanum*) a chance of recovery (Parra-Olea et al., 2012). The rotifers may benefit from high pressure of predation on cladocerans, since it reduces the exploitative and interference competition pressure on them (Hurtado-Bocanegra et al., 2002). Microcrustaceans were dominated by copepods which are more efficient at avoiding fish

Fig. 2 : Physico-chemical variables over the sampling period (June of 2013 to May of 2014) in Xochimilco Lake. All measurements were taken at two sites: Rowing channel (organic turbidity) and Main channel (inorganic turbidity)

Fig. 3 : Total density of selected zooplankton observed during this study. Shown are mean $\pm$ SD of the densities recorded at two different sites

Fig. 4 : Species diversity of zooplankton (Shannon-Wiener index)

Fig. 5 : Pantle and Buck Saprobic Index at the Rowing channel and Main channel stations over a period of 1 year

(Reid and Williamson, 2010). Though they prey on rotifers (Dussart and Defaye, 2001), in this study there was no significant relationship between copepods and the rotifer density, most probably due to the extremely high rotifer densities, often recorded in this water body (Nandini *et al.*, 2016).

The Q_{RT} ratio in this lake (both Main channel and rowing canal) was 3.5 (7 species of *Brachionus* and 2 of *Trichocerca*; Table 1) affirming the highly eutrophic nature of this water body. All

species listed are beta-mesosaprobic and alpha-mesosaprobic. The saprobic indices ranged from 1.86 to 2.0 in the Main channel and 1.7 to 2.5 in the Rowing channel station; both sites can be classified as β -meso-saprobic (Fig. 4). Rotifers are used as indicators of trophic status (Chen *et al.*, 2012) since they have a short life cycle and may respond concurrently to environmental changes. May and O'Hare (2005) opine that rotifer abundances may even be more sensitive indicators of the changes in the trophic state, compared to species composition. Studies

Table 1 : Statistical comparisons of the physico-chemical variables between the test sites. Comparisons were made using t-tests or Mann-Whitney Rank sum tests

	Group name	N	Mean	Std Dev	SEM	t	df	P
Students t-test								
Temp	MC	12	22	2.15	0.62	-1.59	22	0.13
	RC	12	23.22	1.55	0.44			
pH	MC	12	7.84	0.86	0.25	-1.53	22	0.14
	RC	12	8.6	1.49	0.43			
Secchi Depth	MC	12	42.75	12.15	3.51	2.37	33	0.03
	RC	12	32.75	8.058	2.32			
Conduct.	MC	12	0.75	0.071	0.02	-4.38	22	0.001
	RC	12	0.86	0.056	0.016			
Depth	MC	12	119.16	10.18	2.94	13.35	22	0.001
	RC	12	64.83	9.74	2.81			
Mann-Whitney Rank Sum Test								
Dissolved oxygen	Group	N	Median	25%	75%	98.5	12	0.003
	MC	12	3.41	2.82	7.55			
	RC	12	11.4	10.1	13.48			
Chlorophyll-a	Group	N	Median	25%	75%	222	12	0.001
	MC	12	690	475	925			
	RC	12	115	97.5	135			
Phosphates	MC	12	18	17	28.75	17.5	12	0.24
	RC	12	19.2	7.35	23.6			
Nitrates	MC	12	2.7	1.93	4.9	194	12	0.01
	RC	12	1.3	0.67	2			
NTU	MC	12	18	16	26	131	12	0.28
	RC	12	30	12	40			

Table 2 : List of zooplankton species recorded in Xochimilco from June 2013 to July 2014. "+" indicates the presence of a given zooplankton species in the Rowing channel, "x" for the Main channel and (-) indicates absence of a given species.

Taxa	Sampling stations											
	Sampling months											
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Family: Epiphanidae												
<i>Liliferotrocha subtilis</i> (Rodewald, 1940)	-	-	-	-	-	-	x	-	-	-	-	-
Family Brachionidae												
<i>Brachionus angularis</i> Gosse, 1851	-	x	-	-	+	x	+	x	-	-	-	-
<i>B. budapestinensis</i> Daday, 1885	-	-	-	-	x	-	-	-	-	-	-	-
<i>B. calyciflorus</i> Pallas, 1766	-	-	-	-	+	x	+	x	+	x	+	-
<i>B. caudatus</i> Barrois & Daday, 1894	-	x	-	-	+	x	-	-	-	x	+	x
<i>B. durgae</i> Dhanapathi, 1974	-	-	-	-	-	-	-	-	-	-	-	-
<i>B. havanaensis</i> Rousselet, 1911	+	x	+	x	+	x	-	x	-	-	-	-
<i>B. quadridentatus</i> Hermann, 1783	-	x	-	x	+	-	+	x	-	-	-	-
<i>Keratella americana</i> Carlin, 1943	-	-	-	-	+	x	+	-	+	x	+	-
<i>K. cochlearis</i> (Gosse, 1851)	+	-	+	-	-	x	+	-	-	x	+	-
<i>K. tropica</i> (Apstein, 1907)	+	x	+	x	+	x	+	-	+	x	-	x
<i>Plationus patulus</i> (Muller, 1786)	+	x	+	x	-	x	-	-	-	+	+	-
<i>Platylas quadricornis</i> (Ehrenberg, 1832)	+	x	-	x	-	x	-	-	-	+	-	-
Family Euchlanidae												
<i>Dipleuchlanis propatula</i> (Gosse, 1886)	-	-	-	-	-	x	-	x	-	-	-	-
<i>Euchlanis dilatata</i> Ehrenberg, 1832	+	x	+	x	+	x	-	x	-	-	-	-
Family Mytilinidae												
<i>Mytilina bisulcata</i> (Lucks, 1912)	-	-	-	-	-	-	x	-	-	-	-	-
<i>M. mucronata</i> (Müller, 1773)	-	-	-	x	-	-	-	-	-	-	-	-
Family Colurellidae												
<i>Colurella obtusa</i> (Gosse, 1886)	-	-	-	-	-	-	-	x	-	-	-	-
<i>Lepadella acuminata</i> (Ehrenberg 1834)	-	-	-	-	-	-	x	-	-	-	-	-
<i>Lepadella ovalis</i> (Müller, 1786)	-	-	-	x	-	-	-	x	-	-	-	-
<i>L. patella</i> (Müller, 1773)	-	-	-	-	x	-	-	x	-	-	-	-
<i>L. rhomboides</i> (Gosse, 1886)	-	x	-	-	-	-	-	-	-	-	-	-
Family Lecanidae												
<i>Lecane bulla</i>	+	x	+	x	+	x	+	x	+	-	-	x

(Gosse, 1851)																									
<i>L. closteroerca</i>	+	x	+	-	+	x	+	x	+	x	+	x	-	x	+	x	+	-	+	x	+	x	+	-	
(Schmarda, 1859)																									
<i>L. elegans</i> Harring, 1914	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>L. flexilis</i> (Gosse, 1886)	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x	-	-	-	x	-	-	
<i>L. hamata</i> (Stokes, 1896)	-	-	-	-	-	-	+	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>L. inermis</i> (Bryce, 1892)	-	x	-	-	-	x	-	x	-	x	-	x	-	x	+	x	-	x	-	x	-	x	-	-	
<i>L. ludwigii</i>	+	x	-	-	+	x	-	x	-	x	-	x	-	x	+	x	-	-	-	x	-	x	-	-	
(Eckstein, 1883)																									
<i>L. luna</i> (Müller, 1776)	+	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	x		
<i>L. curvicornis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	x	+	x	-		
(Murray, 1913)																									
<i>L. obtusa</i> (Murray, 1913)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	x	
<i>L. ohioensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	+	x	+	-	
(Herrick, 1885)																									
<i>L. pyriformis</i>	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	x	-	x	-	-	
(Daday, 1905)																									
<i>L. quadridentata</i>	+	x	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	x	
(Ehrenberg, 1830)																									
<i>L. stokesii</i> (Pell, 1890)	-	x	+	-	-	x	-	-	-	x	-	x	-	-	-	-	-	x	-	-	-	x	-	-	
<i>L. unguitata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	
(Fadeev, 1925)																									
Family: Lindiidae																									
<i>Lindia torulosa</i>	+	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Dujardin, 1841																									
Family Notommatidae																									
<i>Cephalodella catellina</i>	-	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	
(Müller, 1786)																									
<i>Cephalodella gibba</i>	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	
(Ehrenberg, 1830)																									
Family Trichocercidae																									
<i>Trichocerca bicristata</i>	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	
(Gosse, 1887)																									
<i>T. tenuior</i> (Gosse, 1886)	-	-	-	-	-	x	-	-	-	-	-	x	-	x	-	-	+	x	-	-	-	-	-	-	
Family Synchaetidae																									
<i>Polyarthra vulgaris</i>	-	-	-	-	+	x	-	x	-	x	+	-	-	x	+	x	-	x	+	x	-	-	+	x	
Carlin, 1943																									
Family Asplanchnidae																									
<i>Asplanchna brightwellii</i>	-	-	-	-	+	x	+	-	+	x	+	x	-	-	-	-	-	x	-	-	-	-	-	x	
Gosse, 1850																									
<i>A. sieboldii</i>	+	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x	-	-	+	x
(Leydig, 1854)																									
Family Dicranophoridae																									
<i>Dicranophorus forcipatus</i>	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	
(Müller, 1786)																									
Order Gnesiotrocha																									
Family Testudinellidae																									
<i>Testudinella patina</i>	-	-	-	-	+	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	x	+	-
(Hermann, 1783)																									
<i>Testudinella mucronata</i>	-	x	-	-	-	x	+	-	+	-	-	-	-	-	+	x	-	-	+	x	+	x	-	-	
(Gosse, 1886)																									
Family Filiniidae																									
<i>Filinia cornuta</i>	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	+	-	-	-	-	-	-	-	
(Weisse, 1847)																									
<i>F. longiseta</i>	-	x	-	-	-	x	-	-	-	x	-	-	+	-	-	x	+	x	-	-	-	x	+	-	
(Ehrenberg, 1834)																									
<i>F. terminalis</i>	-	-	-	-	-	x	-	-	-	-	-	-	+	-	-	-	-	x	-	-	-	-	-	-	
(Plate, 1886)																									
Cladocera																									

Order Anomopoda																				
Family Daphniidae																				
<i>Simocephalus vetulus</i> (Müller, 1776)	-	-	-	x	+	-	-	-	-	-	-	-	-	x	-	-	-	x	-	x
<i>Scapholeberis kingii</i> Sars, 1888	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Family Moinidae																				
<i>Moina micrura</i> Kurz, 1875	+	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	x	-
Family Chydoridae																				
<i>Chydorus brevilabris</i> Frey, 1980	-	-	-	-	+	x	-	-	-	-	-	+	x	-	-	-	-	+	x	-
<i>Alona rectangula</i> Sars, 1862	-	x	-	-	+	x	+	x	-	x	+	-	-	x	+	x	+	x	+	x
<i>Pleuroxus varidentatus</i> Frey, 1993	+	-	-	-	+	x	+	x	-	x	-	x	-	x	+	x	+	x	+	x
Copepoda																				
<i>Acanthocyclops americanus</i> (Marsh, 1893)	+	x	-	x	+	x	-	x	-	x	-	x	-	x	-	x	-	x	+	x
<i>Microcyclops rubellus</i> (Lilljeborg, 1901)	-	x	-	x	+	x	+	x	+	x	-	x	-	x	-	x	-	x	-	-

describing the relationship between trophic status and the rotifer community index, are reliable in several water bodies (Duggan *et al.*, 2001). Another way to classify the trophic status of a waterbody is based on rotifer abundances: 500–1000 ind. l⁻¹ indicates mesotrophic conditions, 1000–2500 ind. l⁻¹ moderately eutrophic and 3000–4000 ind. l⁻¹ eutrophic (May and O'Hare, 2005; Wen *et al.*, 2011). Our results for the most abundant species fall within the range of eutrophic levels. On the other hand, indices using rotifers, such as the saprobic index and Q_{BIT} (Sládeček, 1983) indicate that the water body is eutrophic. Our results for the most abundant species fall within the range of eutrophic levels. Furthermore, a diversity of aquatic environments, such as channels with different physicochemical variables, high turbidity and macrophytes, may provide more niches and microhabitats as well refuge against predators to rotifers which according to the intermediate disturbance hypothesis (Connell, 1978) should promote biodiversity. The average species diversity of zooplankton in the lake varied between 1.2 and 3.5; this range was recorded in other high altitude waterbody in Mexico (Ramírez-García *et al.*, 2002; Nandini *et al.*, 2008) previously also in Xochimilco (Nandini *et al.*, 2005; Enríquez *et al.*, 2009). These values indicate that the lake was mesotrophic.

Data on the physicochemical analyses are presented in Fig. 5. Water temperature during the study period ranged from 19 to 26° C. The pH values were often highly alkaline for the Rowing channel while in the Main channel they were neutral in almost all cases with values less than 9. We also observed a generally lower and less fluctuating pH values in the Main channel compared to the Rowing channel. Dissolved oxygen (DO) concentrations

ranged from 9.0 to > 17.0 mg L⁻¹ for the Rowing channel and from 2 to 5 mg L⁻¹ for the Main channel site during most of the study period except for occasional peaks of 10–14 mg l⁻¹. High level of dissolved oxygen has been reported in water bodies with algal blooms (Nandini *et al.*, 2016). Secchi transparency levels were usually between 0.2 and 0.5 m, which often represented 50% of the total depth which ranged from 0.45 to 0.60 m. For the Main channel, levels were between 0.30 to 0.50 m and represented 30% of the total depth. These were 1.20 to 1.40 m for a Rowing channel (Fig. 2). The chlorophyll-a concentration ranged from 350 to 1200 µg l⁻¹ in the Rowing channel and between 50–350 µg l⁻¹ in the Main channel; it was significantly higher in the former site throughout the study period (Student's *t* test = 6.30, df = 11, *p* < 0.001). The turbidity was similar at both sites, ranging between 5–45 NTU in the Rowing channel and between 5–30 NTU in the Main channel; it was frequently higher at the former site (Fig. 2). Significant differences were observed between the study sites in Secchi depth, conductivity, depth, dissolved oxygen and chlorophyll-a (*p* < 0.05; Students *t*-test or Mann Whitney test, Table 2). The concentration of nitrate-N varied from 0.2 to 4 mg l⁻¹ but in October and December reached up to 9 mg l⁻¹. Phosphate-P varied from 18 to 19.2 mg l⁻¹ (5.94 to 6.33 mg l⁻¹ of Phosphorous). However, according to the concentrations of the nutrients Xochimilco is a hypertrophic lake with nitrogen and phosphorus levels close to the maximal permissible limits (The OECD model suggests threshold of 0.035 mg l⁻¹ Phosphorus concentrations for eutrophic lakes (Tavera and Díez, 2009; USEPA, 2010). Annual mean total phosphorus concentration in excess of only 0.02 mg l⁻¹ may trigger eutrophication in some lakes (Mainstone and Parr, 2002).

In our study, we observed that high turbidity adversely affected the cladocerans more than the rotifers, evident in the CCA analyses. Our canonical correlation analyses (CCA) also indicates that most taxa are ordinated based on the level of nutrients, more so in the Rowing channel than the Main channel. The phosphorus levels in the Main channel, correspond to hypertrophic conditions, but this is not corroborated by the chlorophyll concentrations; a trend also reported in the Chimaliapan wetland (García-García *et al.*, 2012). However, the Main channel shows an inverse relation between nutrients and chlorophyll. This could be due to the high density of macrophytes at this site, which shade out phytoplankton production regardless of an abundance of nutrients (Cozar *et al.*, 2007). Such conditions also promote the growth of *Microcystis* spp. which can avoid the high light intensity and move up to the water surface, when underwater light conditions are poor (Brookes and Ganf, 2001).

The canonical correspondence analysis (CCA) in the Rowing channel station, showed that the first two ordination axes explained 46% of the variance of the species data in CCA (Fig. 6a). The eigenvalues for the first two axes are 0.062 and 0.085. The first and second axes are well correlated with the environmental data ($r=99.5$ and $r=93.6$). The Monte Carlo permutation test was significant on the first axis ($F = 2.92$, $P = 0.02$). Only the variable Secchi disc was significant. This variable explains the distribution of species. However, we have decided to show the graph with all variables to indicate trends. There was a clear inverse relation between Secchi depth and Chlorophyll-a concentration in the Rowing channel during the study period. Nutrients (Nitrate-N and Phosphate-P) were negatively correlated with the rainfall (precipitation). The cladocera and copepod genera as well as the rotifers *Brachionus*, *Keratella* and *Polyarthra* formed clusters in regions representing high productivity (low Secchi transparency or high Chlorophyll-a) and high turbidity.

For the Main channel the CCA showed that the first two ordination axes explained 48% of the variance of the species data (Fig. 6b). The eigen values for the first two axes are 0.20 and 0.15. The Monte Carlo permutation test was not significant ($F = 0.40$, $P = 0.56$). For this station, also we performed forward selection but it was not significant. Observation of their general distribution suggests that there is a continuous variation of the species composition in the whole data set and therefore we were unable to find distinct clusters in the data set. As at the previously analyzed site, the cladocerans were associated with high productivity while the rotifers, *Brachionus* and *Polyarthra* were more correlated to high Nitrate-N levels and pH.

In Lake Xochimilco, the zooplankton community was dominated by rotifers; cladocerans and copepods were few, as was found in previous studies. This lake has the characteristics of a eutrophic water-body, with a dominance of rotifer genera such as *Keratella*, *Brachionus*, *Polyarthra* with the highest densities.

Our study shows that organic turbidity had an adverse effect as compared to inorganic turbidity on zooplankton density and diversity. This has a widespread impact considering the increasing levels of contamination of freshwater ecosystems worldwide.

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