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Seasonal variations of rotifers from a high altitude urban shallow water body, La Cantera Oriente (Mexico City, Mexico)*

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Abstract La Cantera Oriente is a shallow freshwater volcanic water body located at an altitude of 2 270 m above sea level in the Ecological Reserve of San Angel Pedregal of Mexico City (Mexico). In order to ensure the conservation of its biological heritage including zooplankton, the present work was undertaken to quantify the seasonal changes in the diversity and density of rotifers and the selected physico-chemical variables during 2013–2014. Qualitative analysis of the zooplankton samples yielded 68 rotifer species which represented 24 genera in 15 families. *Brachionus calyciflorus* Pallas, 1766, *B. quadridentatus* Hermann, 1783, *Polyarthra vulgaris* Carlin, 1943, *Lecane closterocerca* (Schmarda, 1859) and *Keratella cochlearis* (Gosse, 1851) were the most common species. Preston plots of species frequency-density revealed that as many as 30% of the rotifer taxa were dominant throughout the year. The species with high population densities were *Brachionus quadridentatus*, *Lecane closterocerca*, *Keratella cochlearis*, and *Lepadella patella*; their peak densities were 2 000, 1 000, 180 and 90 ind./L, all occurring in summer. Canonical correspondence analysis showed that *Platyias quadricornis* was related to the concentration of phosphates available in the environment and the conductivity, while *B. quadridentatus* was positively correlated with chlorophyll-*a*. The trophic status of the lake was eutrophic based on Chl-*a* content but oligotrophic with relation to the *Brachionus*:*Trichocerca* ratio.

Keyword: high altitude; zooplankton; seasonal density dynamics; limnology; rotifera

1 INTRODUCTION

Limnological research in Mexico has been increasing over the last two decades because of the realization that many freshwater bodies remain unexplored (Alcocer and Bernal-Brooks, 2010). Mexico has approximately 14 000 reservoirs, of which over 80% are less than ten hectares area (De la Lanza and García-Calderón, 2002). Studies on large, deep Mexican lakes, which are fewer than 50 in number, has contributed to the bulk of the national limnological data (Alcocer and Bernal-Brooks, 2010). Studies on the zooplankton of shallow lakes have been few and usually sporadic; long-term studies on shallow lakes such as Lake Xochimilco are not common (Nandini et al., 2005; García et al., 2009).

Shallow lakes often have a greater variety of habitats and thus permit a greater diversity of zooplankton, which is composed mainly of protozoans, rotifers and crustaceans such as copepods and cladocerans (Moss, 2010). They often have a large variety of aquatic vegetation which in turn offers protection to zooplankton against fish predation (Gulati et al., 1990). Typically, Mexican shallow lakes are dominated by rotifers since crustaceans are vulnerable to predation around the year by fish (Zambrano et al., 1998; Contreras et al., 2009).

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Rotifers from shallow lakes get benefit not only from reduced competition from crustaceans but also feed on the detrital resources which are generated by the decomposing macrophytes (Wetzel, 2001). Therefore, it is not surprising that more than 100 rotifer species have been reported from point collections in just four Mexican shallow water bodies (Sarma and Elías-Gutiérrez et al., 1999).

Rapid population growth and industrialization in major cities around the world take a toll on freshwater bodies with changes in water quality or begin to shrink considerably (Brown, 2008; Li et al., 2014). In spite of being a megacity, Mexico City still contains a few shallow lakes such as Lakes Xochimilco, Texcoco and La Cantera Oriente. La Cantera Oriente (altitude 2 270 m above sea level) is located within the Ecological Reserve of San Angel Pedregal zone of the Mexico City. It is an important heritage site with great biological diversity (administratively known as REPSA) and is presently protected and managed by the administration of the National Autonomous University of Mexico (Hortelano-Moncada et al., 2009). In order to ensure the conservation of biological heritage present in the REPSA, an inventory of species is available which contains algae, ciliates, insects, crustaceans, fish, amphibians, reptiles and birds (Lot, 2007). However, there are no records of rotifer species found in these ponds. Rotifers are good indicators of water quality (Sládeček, 1983) and hence it is useful to have an inventory of species and study their diversity over time. This information is needed to define management plans and appropriate conservation actions for the protection of this area.

For some high altitude water bodies exhaustive rotifer faunal listings are available but seasonal studies are few. For example, taxonomic information on rotifers is documented for many water bodies in Central Mexico, including descriptions of new records (Sarma and Elías-Gutierrez, 2000) but the seasonal variations of plankton is documented only in a few lakes and reservoirs such as Lake Xochimilco (Nandini et al., 2005) and the Valle de Bravo reservoir (Ramírez et al., 2002). In temporary water bodies, zooplankton sampling is done only during the period when water is present (see Kuczyńska-Kippen et al., 2013). However in permanent water bodies seasonal studies are also needed because they indicate how zooplankton species in nature vary both in terms of taxonomic diversity and species abundance, depending on the physico-chemical factors through the seasons. For example, Sarma et al. (1996) sampled two high-altitude (4 690 m above sea level) water bodies (La Luna and El Sol) in Central Mexico and reported a total of 35 rotifer species, but no taxon was common in both lakes. However, monthly collections for one year from the same water bodies revealed as many as 14 species in common for both lakes (Dimas-Flores et al., 2008). Therefore seasonal studies that describe patterns in rotifer community composition are better than sporadic collections.

The aim of this work was therefore to quantify the seasonal changes in the richness and density of rotifers in relation to selected physico-chemical variables during an annual cycle (2013–2014).

2 MATERIAL AND METHOD

2.1 Study site

The rocks in the area of La Cantera Oriente (Mexico City, Mexico) (19°19′13.35″N and 99°10′25.34″W) were formed from the lava of Xitle volcano and are of basaltic type (Cervantes and Wallace, 2003). The volcanic rocks from this region were used for the construction of our University City and other surrounding urban development towards end of the first half of the twentieth century. These activities resulted in the excavation of rocks and the subsequent formation of ponds due to an underground spring and filtered water run-off. All five interconnected ponds are of different depths, but usually up to 6 m in maximum depth. These water bodies occupy an area of 11 906 m^2 which represents about 14% of the total Ecological Reserve of REPSA (Lot, 2007). These are shallow ponds and are locally known as the lake. These ponds are located at an altitude of 2 270 m above sea level. The ponds have fish species belonging to the families Goodeidae and Cyprinidae (Pérez, 2009).

2.2 Rotifer collection and measurement of physico-chemical parameters

Zooplankton collections were carried out monthly for one year (September 2013–August 2014) from each of the five ponds (Fig.1). Zooplankton samples were obtained by filtering 80 L of surface water from the ponds through a plankton net of 50-μm mesh size, concentrated to 180 mL volume and immediately fixed in 4% formalin. Simultaneously, selected physico-chemical variables (dissolved oxygen and oxygen saturation percentage, temperature, pH and conductivity, alkalinity, nitrates and phosphates,

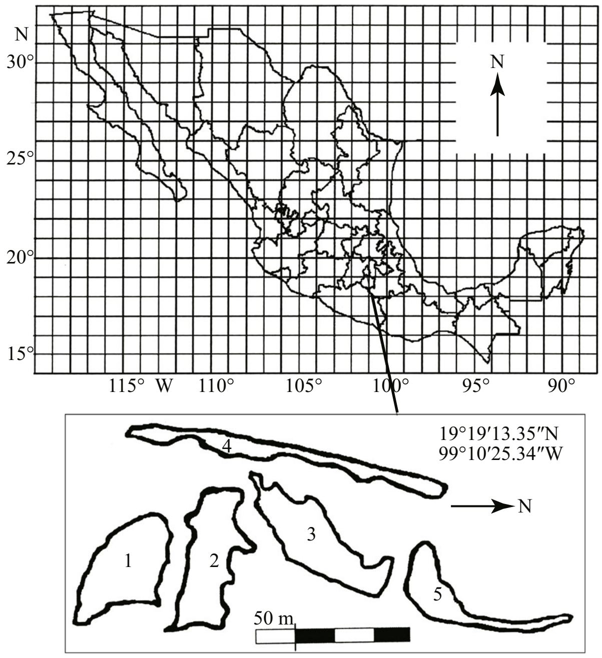

Fig.1 Map of sampling stations from La Cantera Oriente (Mexico City, Mexico)

Numbers 1 to 5 indicate the sampling stations of the five ponds. From each pond the zooplankton samples were collected from different points and then pooled them into a single sample.

chlorophyll-*a* and turbidity) were measured (American Public Health Association et al., 2012).

2.3 Analysis of rotifers

The rotifers were identified, as far as possible to the species level, using standard taxonomic keys (Koste, 1978; Segers, 1995; Wallace et al., 2016). The species specific densities of the rotifers were quantified in 3 aliquots samples of 1 ml of each using a Sedgewick-Rafter chamber and an inverted microscope (Wetzel and Likens, 2000). The data on the physico-chemical variables and the species-specific densities of rotifers were subjected to canonical correspondence analysis (CCA) using CANOCO program ver. 4.5 to determine the influence of different variables on the rotifer densities. Shannon-Wiener species diversity index was derived using the following formula (Krebs, 1989):

$$H' = -\sum_{i=1}^{s}(P_i)(\log_2 P_i),$$

where H'=species diversity index (bits/ind.); P_i=proportion of numerical density of each species within the total density of all species present in the sample.

In order to determine the trophic status of the water bodies we used the index of *Brachionus* to *Trichocerca* ratio or $Q_{B/T}$ (Sládeček, 1983). We also used other recent works involving the total rotifer density as an index of trophic status of freshwater bodies (Ejsmont-Karabin, 2012).

3 RESULT

3.1 Physico-chemical characteristics and rotifer species diversity

Data on the selected physico-chemical variables pooled from different sites of the La Cantera Oriente are presented in Table 1. Qualitative analysis of the zooplankton samples collected during the study period from different sites yielded 68 rotifer species which represented 24 genera spreading over 15 families (Table 2). The most frequently encountered species were *Brachionus calyciflorus*, *B. quadridentatus*, *Polyarthra vulgaris*, *Lecane closterocerca* and *Keratella cochlearis*. On the other hand, species that appeared rarely in these ponds were: *Sinantherina semibullata*, *Pleurotrocha petromyzon*, *Lecane pyriformis*, *L. unguitata*, *Lophocharis oxysternon*, *L. salpina* and *Cephalodella remanei*. Data on the frequency of rotifer species in relation to their log density, i.e., Preston plot, revealed that as many as 30% of the rotifer species became dominant throughout the year and among them were *L. closterocerca*, *C. uncinata*, *C. obtusa*, *L. patella* and *K. cochlearis*. In addition, more than 50% of the rotifers were infrequently present throughout the year (Fig.2).

3.2 Rotifer density

Changes in the densities of the four common rotifer species (*Brachionus quadridentatus*, *Keratella cochlearis*, *Lecane closterocerca* and *Lepadella patella*) are presented in Figs.3 and 4. In general, all the four species showed higher densities at site 2. The peak densities for *B. quadridentatus* (ca. 2 000 ind./L), *L. closterocerca* (ca. 1 000 ind./L), *K. cochlearis* (ca. 180 ind./L), and for *L. patella* (ca. 90 ind./L) were observed during the summer months (May–July). Regardless of the sampling period, all the rotifers generally had the lowest densities at site 5. Canonical correspondence analysis of the relationship between some physico-chemical variables and the rotifer species showed that *Platyias quadricornis* was closely related to the quantity of phosphates available in the environment. On the other hand *Lecane pyriformis*, *L. flexilis*, *Trichocerca pusilla* and *Brachionus*

Table 1 Selected physico-chemical variables from the five stations of the La Cantera Oriente, Mexico City, during 2013–2014

Physico-chemical variable	Sampling station					Annual mean
	1	2	3	4	5	
Temperature (°C)	16.0–21.7	16.0–23.5	16.2–22.3	16.4–18.1	15.5–21.1	18.7
Conductivity (μS cm)	365–440	358–430	370–456	374–445	379–428	404.5
Dissolved O_2 (mg/L)	7.2–13.2	8.7–18.7	5.5–15.1	4.2–6.3	4.4–17.5	10.1
pH	6.4–8.2	7.8–9.9	7.3–9.5	6.4–8.2	6.5–9.1	7.9
Alkalinity (mg/L)	60–84	80–104	76–92	76–88	70–100	83
NO_3 (mg/L)	7.3–9.4	2.6–12.2	4.4–10.1	6.1–11.4	2.4–10.3	7.6
PO_4 (mg/L)	0.1–0.5	0.03–0.43	0.08–0.47	0.12–0.84	0.08–0.54	0.32
Turbidity (NTU)	1.5–5.6	10.5–27.5	3.2–6.8	<1.0–1.4	2.4–4.1	6.4
Chlorophyll-*a* (μg/L)	0.74–25.4	9.6–104.5	0.65–126.9	0.38–73.4	2.5–98.5	44.3
Hardness (mg/L)	100–200	100–200	120–190	110–200	130–190	154

budapestinensis were strongly influenced by alkalinity. *Brachionus quadridentatus* was positively correlated with chlorophyll-*a*, while *Lecane quadridentata* preferred areas with high levels of dissolved oxygen (Fig.5). Shannon-Wiener species diversity index ranged from 1.1 to 3.7 bits/ind., depending on the sampling station and the period of sampling. In general, during the months of April and May, the average species diversity index of all the sampling stations was about 2.9 bits/ind. (Table 3).

4 DISCUSSION

A large set of data on the basic limnology of many different kinds of water bodies, rivers, lakes, ponds and temporary water bodies in Mexico is available (Alcocer and Bernal-Brooks, 2010). However, many of them are just based on one-time-sampling carried out during contrasting periods (e.g., winter vs summer collections). In addition, many studies do not identify and quantify rotifers in zooplankton collections because the interest of most limnological research is generally on functional groups rather than from a taxonomic point of view. The present work is one of the few aimed at understanding the seasonal changes in the rotifer diversity from a high altitude shallow water body. In spite of the ecological importance of shallow lakes, such as higher biodiversity and nutrient dynamics (Moss, 2010), researches on these water bodies from Mexico are scarce since these are thought to be poor sources for commercial activities such as harvesting fish or aquaculture. La Cantera Oriente is a man-made shallow water body largely neglected by limnologists as it is of little importance to fishery biologists since it harbors few fish species and almost no commercial (e.g., fishing) or recreational activity

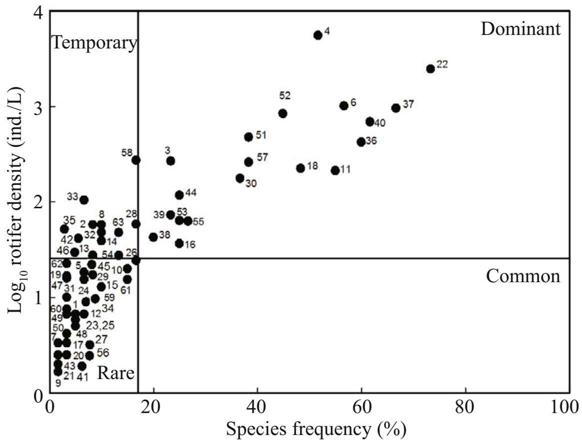

Fig.2 Data on the frequency of rotifer species in relation to their log density

1. *Brachionus angularis*; 2. *B. budapestinensis*; 3. *B. calyciflorus*; 4. *B. quadridentatus*; 5. *Keratella americana*; 6. *K. cochlearis*; 7. *K. tropica*; 8. *Platyias quadricornis*; 9. *Collotheca* sp; 10. *Cephalodella catellina*; 11. *C. gibba*; 12. *C. remanei*; 13. *C. ventripes*; 14. *Eosphora thoides*; 15. *Pleurotrocha petromyzon*; 16. *Dicranophorus grandis*; 17. *Euchlanis calpidia*; 18. *E. dilatata*; 19. *Filinia longiseta*; 20. *Lecane aculeata*; 21. *L. bifurca*; 22. *L. closterocerca*; 23. *L. curvicornis*; 24. *L. decipiens*; 25. *L. flexilis*; 26. *L. furcata*; 27. *L. hamata*; 28. *L. inermis*; 29. *L. luna*; 30. *L. lunaris*; 31. *L. nana*; 32. *L. pyriformis*; 33. *L. quadridentata*; 34. *L. stichaea*; 35. *L. unguitata*; 36. *Colurella obtusa*; 37. *C. uncinata*; 38. *Lepadella acuminata*; 39. *L. ovalis*; 40. *L. patella*; 41. *L. rhomboides*; 42. *L. triba*; 43. *L. triptera*; 44. *Squatinella mutica*; 45. *Limnias ceratophylli*; 46. *L. melicerta*; 47. *Sinantherina semibullata*; 48. *Lophocharis oxysternon*; 49. *L. salpina*; 50. *Mytilina mucronata*; 51. *M. ventralis*; 52. *Polyarthra vulgaris*; 53. *Proales decipiens*; 54. *Testudinella mucronata*; 55. *T. patina*; 56. *Trichocerca elongata*; 57. *T. porcellus*; 58. *T. pusilla*; 59. *T. ruttneri*; 60. *T. similis*; 61. *T. weberi*; 62. *Trichotria pocillum*; 63. *T. tetractis*. Five other species not included due to extremely rare occurrence (one specimen each).

(e.g., boating) are permitted (Lot, 2007). Because of the uneven floor, the maximum depth of this water body varies from 0.5 to 6.0 m depending on the zone.

Table 2 List of rotifer species recorded from the high altitude water body, La Cantera Oriente, Mexico City, during 2013–2014

Family: Brachionidae	*L. lunaris* (Ehrenberg, 1832)
Brachionus angularis Gosse, 1851	Family: Lecanidae
B. budapestinensis Daday, 1885	*L. nana* (Murray, 1913)
B. calyciflorus Pallas, 1766	*L. pyriformis* (Daday, 1905)
B. quadridentatus Hermann, 1783	*L. quadridentata* (Ehrenberg, 1830)
Keratella americana Carlin, 1943	*L. stichaea* Harring, 1913
K. cochlearis (Gosse, 1851)	*L. unguitata* (Fadeev, 1925)
K. tropica (Apstein, 1907)	
Platyias quadricornis (Ehrenberg, 1832)	Family: Proalidae
	Proales decipiens (Ehrenberg, 1832)
Family: Euchlanidae	
Euchlanis calpidia Myers, 1930	Family: Notommatidae
E. deflexa (Gosse, 1851)	*Cephalodella catellina* (Müller, 1786)
E. dilatata Ehrenberg, 1832	*C. forficula* (Ehrenberg, 1830)
	C. gibba (Ehrenberg, 1830)
Family: Mytilinidae	*C. remanei* Wiszniewski, 1934
Lophocharis oxysternon (Gosse, 1851)	*C. ventripes* (Dixon-Nuttall, 1901)
L. salpina (Ehrenberg, 1834)	*Eosphora thoides* Wulfert, 1935
Mytilina mucronata (Müller, 1773)	*Pleurotrocha petromyzon* (Ehrenberg, 1830)
M. ventralis (Ehrenberg, 1830)	
	Family: Trichocercidae
Family: Trichotriidae	*Trichocerca elongata* (Gosse, 1886)
Trichotria pocillum (Müller, 1776)	*T. porcellus* (Gosse, 1851)
T. tetractis (Ehrenberg, 1830)	*T. pusilla* (Jennings, 1903)
	T. ruttneri Donner, 1953
Family: Colurellidae	*T. similis* (Wierzejski, 1893)
Colurella obtusa (Gosse, 1886)	*T. weberi* (Jennings, 1903)
C. uncinata (Müller, 1773)	
	Family: Synchaetidae
Family: Lepadellidae	*Polyarthra vulgaris* Carlin, 1943
Lepadella ovalis (Ehrenberg, 1834)	
L. ovalis (Müller, 1786)	Family: Dicranophoridae
L. patella (Müller, 1773)	*Dicranophorus grandis* (Ehrenberg, 1832)
L. rhomboides (Gosse, 1886)	
L. triba Myers, 1934	Family: Testudinellidae
L. triptera (Ehrenberg, 1832)	*Testudinella mucronata* (Gosse, 1886)
Squatinella mutica (Ehrenberg, 1832)	*T. patina* (Hermann, 1783)
Family: Lecanidae	Family: Flosculariidae
Lecane aculeata (Jakubski, 1912)	*Limnias ceratophylli* Schrank, 1803
L. bifurca (Bryce 1892)	*L. melicerta* Weisse, 1848
L. closterocerca (Schmarda, 1859)	*Ptygura furcillata* (Kellicott, 1889)
L. curvicornis (Murray, 1913)	*Sinantherina semibullata* (Thorpe, 1893)
L. decipiens (Murray, 1913)	
L. flexilis (Gosse, 1886)	Family: Filiniidae
L. furcata (Murray, 1913)	*Filinia longiseta* (Ehrenberg, 1834)
L. hamata (Stokes, 1896)	
L. inermis (Bryce, 1892)	Family: Collothecidae
L. luna (Müller, 1776)	*Collotheca ambigua* (Hudson, 1883)

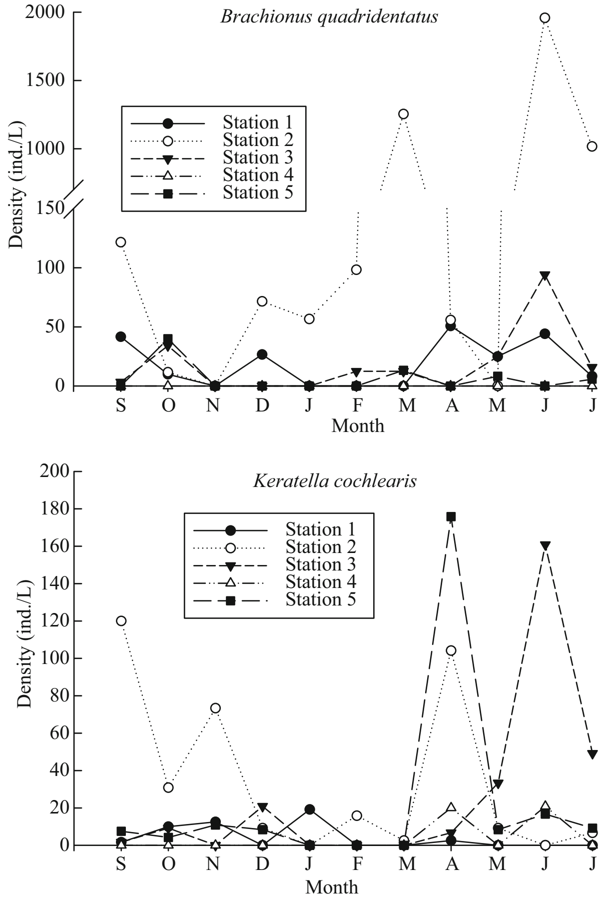

Fig.3 Seasonal changes in the densities (ind./L) of *Brachionus quadridentatus* and *Keratella cochlearis* from La Cantera Oriente during 2013–2014

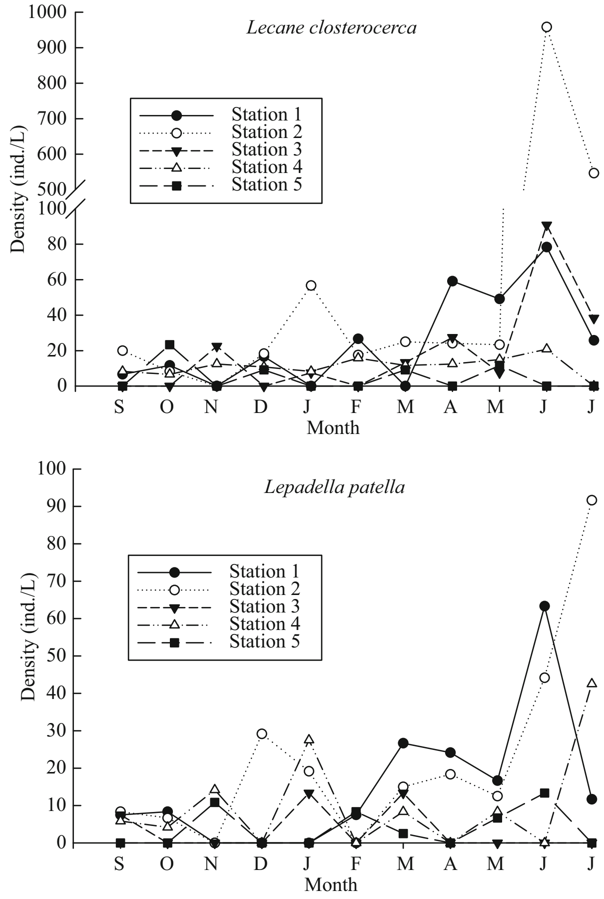

Fig.4 Seasonal changes in the densities (ind./L) of *Lecane closterocerca* and *Lepadella patella* from La Cantera Oriente during 2013–2014

The lake is fed by rainwater, wastewater and a few underground springs. Due to this, the water body has high nutrient levels during certain months of the year.

The data on the seasonal variations of the selected physico-chemical variables in this study agree in general with those reported in this region (De la Lanza-Espino and García-Calderón, 2002). For example, Nandini et al. (2005) have mentioned that the Lake Xochimilco has temperature, dissolved oxygen, pH, nitrates and phosphates in the range of 14–22°C, 1–15 mg/L, 7–9, 3–8 mg/L, and 2–4 mg/L, respectively.

Earlier ecological works from this water body dealt with sporadic collections of crustaceans and other arthropods but no rotifers were mentioned (Lot, 2007). This is the first comprehensive study on the diversity rotifers from this shallow water body. We were able to observe more than 60 rotifer species during one-year sampling. In the Ethiopian lakes located at 2 800 m above sea level, Degefu et al. (2014) recorded only 11 rotifer species, while in the

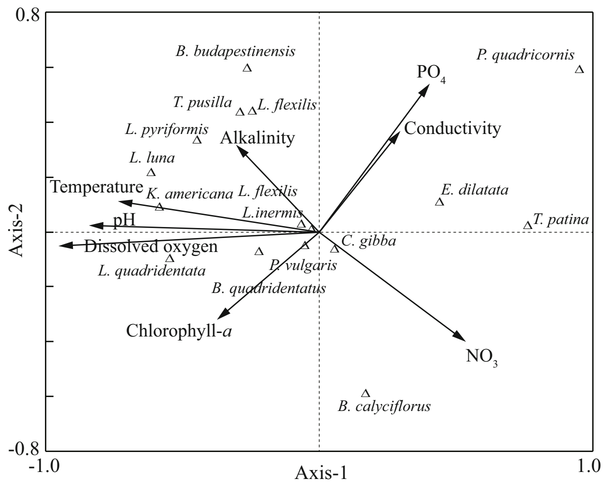

Fig.5 Canonical Correspondence Analysis for the relationship between selected physicochemical variables and rotifer species from the ponds of La Cantera Oriente, Mexico City (Mexico) during 2013–2014

present high-altitude water body we found much higher rotifer diversity. We also recorded some rare rotifer species in Mexican waters such as *Eosphora thoides* and *Lecane bifurca* (Sarma and Elías-Gutiérrez, 1999, 2000). Most Mexican high altitude freshwater bodies have a rotifer species richness of up to 30 species and in rare cases higher than 70 (Sarma and Manuel, 1998). For example, in the Valle de Bravo reservoir, a high altitude drinking water reservoirs (about 1 830 m above sea level), the rotifer diversity was about 30 species (Nandini et al., 2008). For the shallow water bodies of comparable altitude, the rotifer diversity appears to be higher. For example, about 60 rotifer species have been reported from the shallow water body the lake Xochimilco (altitude 2 200 m above sea level) (Flores-Burgos et al., 2003; Nandini et al. 2005).

Among the rotifer genera recorded from La Cantera Oriente, *Lecane* was the most diverse. *Lecane* is the second most diverse genus in Rotifera (Segers, 1995). In Mexican waters too this genus is more diverse than many other genera of rotifers (Sarma et al., 2009; Vázquez-Sánchez et al., 2014). The distribution of the genus *Brachionus* in the high altitude water bodies of Mexico is intriguing. *Brachionus* is a warm-water genus (Xi and Huang, 2004) and hence its presence at low temperatures (<15°C) in high-altitude water bodies is surprising (Koste, 1978; Wallace et al., 2006). For example, in Valle de Bravo, *Brachionus* is poorly represented (only two species: Jiménez-Contreras et al., 2009). On the other hand, Lake Xochimilco, with comparable altitude has as many as 13 species of *Brachionus* (Flores-Burgos et al., 2003). In the present study from La Cantera Oriente we encountered only four species. Water depth is an important factor determining the occurrence of *Brachionus* in high altitude ponds (Claps et al., 2011). The Valle de Bravo reservoir has a depth of 38 m (Merino-Ibarra et al., 2008) while lake Xochimilco and La Cantera Oriente are <6 m deep (Lot, 2007). Yet, in another high-altitude shallow (mean depth: <5 m) water body, Chimaliapan (a Ramsar site, altitude 2 560 m above sea level, Zepeda-Gómez et al., 2012), *Brachionus* was represented by 6 species (García-García et al., 2012). Therefore, the distribution of *Brachionus* in high altitude water bodies in Mexico requires further study. In addition, the conventional classification of rotifers into planktonic and semiplanktonic (Pontin, 1978; Koste, 1978) does not strictly apply for the shallow lakes (Nandini et al., 2005; Pociecha et al., 2015) because plankton collections made from the open waters of La Cantera Oriente contained several non-planktonic species including the dominant genus *Lecane*. In addition, non-planktonic rotifer genera such as *Lecane* and *Lepadella* are also occasionally found in planktonic collections even in deep lakes. For example, in Laguna Petén-Itza, a deep Guatemalan lake (40 m, max. depth), García-Morales and Elías-Gutiérrez (2007) reported as many as 17 species of *Lecane* and 3 species of *Lepadella*. Rotifer species of volcanic crater lakes at or near sea level may have genera such as *Anuraeopsis*, *Brachionus*, *Polyarthra* and *Trichocerca*. For example, Sichrowsky et al. (2014) have shown that the volcanic crater lakes of Uvea Island have 17 rotifer taxa including 3 species of *Trichocerca* (*T. chattoni*, *T. pusilla* and *T. tenuior*) and one species each from *Anuraeopsis*, *Brachionus* and *Polyarthra*. Ejsmont-Karabin and Kuczyńska-Kippen (2001) have noted that most urban waters in Poland contain *Brachionus angularis*, *Keratella cochlearis*, *Colurella uncinata*, *Lecane closterocerca* and *Lepadella patella*. In this present work too, we observed that all these rotifer species were common, suggesting that they possibly tolerate a wide range of physico-chemical factors in nature.

Table 3 Shannon-Wiener diversity index values derived from the high altitude water body, La Cantera Oriente, Mexico City, during 2013–2014

Month	Sampling stations				
	1	2	3	4	5
Sep.	3.34	2.05	2.25	2.13	3.23
Oct.	3.25	3.04	2.67	2.41	3.10
Nov.	2.88	2.52	3.04	3.09	2.64
Dec.	2.77	3.12	2.53	3.1	2.71
Jan.	2.32	2.78	2.51	2.87	2.61
Feb.	3.05	2.53	2.70	3.16	2.56
Mar.	2.60	1.09	3.66	3.49	1.95
Apr.	2.75	3.54	3.13	2.73	2.39
May	2.77	3.33	2.64	2.84	3.01
Jun.	2.51	1.68	2.68	2.59	2.13
Jul.	2.45	2.42	3.21	1.95	1.63
Aug.	3.04	2.37	2.44	2.24	3.27

The trophic status of the water bodies can be assessed using different methods: chemical constituents (e.g., phosphate levels) and occurrence (absence or presence) of certain biota (e.g., bioindicators) or their densities (e.g., Secchi transparency) or their pigments (e.g., chlorophyll *a*) (Wetzel, 2001; Moss, 2010). The Redfield ratio for this shallow water body could not be derived as we did not measure total nitrogen and phosphorus levels. However, the chlorophyll-*a* levels for most part of the year represent a eutrophic condition (Wetzel, 2001). Sládeček (1983) developed an index of *Brachionus* to *Trichocerca* ratio or $Q_{B/T}$, for determining the trophic status of freshwater bodies. When the ratio is <1, it indicates oligotrophic condition, 1–2 mesotrophic and >2 the eutrophic level. In this study, the $Q_{B/T}$ ratio (0.8) for this water body indicates an oligotrophic level. It is also not reliable in the Valle de Bravo reservoir which is meso- to eutrophic but has a higher number of *Trichocerca* than *Brachionus* species (Ramírez et al., 2002) and further studies are needed to ascertain the feasibility of applying the $Q_{B/T}$ ratio in high altitude tropical waters. Because of the difficulty in identification, the use of rotifers as indicators of trophic status in tropical and subtropical regions of the world is still limited (Snell and Joaquim-Justo, 2007). There are methods using the total rotifer density as a measure of trophic status of a given water body. It is known that in eutrophic waters, rotifer density is high but the diversity is low. On the other hand, in most oligotrophic lakes and ponds, the rotifer density is low (Wallace et al., 2006). Therefore, independent of species diversity, if the total density of rotifers from a given water body is <500 ind./L, then it reflects an oligotrophic condition, while 500–1 000 ind./L is mesotrophic, 1 000–2 500 ind./L is eutrophic and 3 000–4 000 ind./L is hypertrophic (Ejsmont-Karabin, 1995; May and O'Hare, 2005; Ejsmont-Karabin, 2012). In this work, the mean total density of rotifers from all measured sites for most months was <400 ind./L. However, in the month of July, it exceeded this value but was below <1 000 ind./L. This also suggests, though the water body has oligotrophic conditions for most months and in summer, it tends to be mesotrophic. Ejsmont-Karabin (2012) noted that in Polish water bodies, *Keratella cochlearis* f. *tecta* become more abundant in summer months. In this study, we did not identify rotifers to infra-specific level. However, in another on the morphometric variations of loricate rotifers from the same water body, Sarma et al. (2015) have indeed noted the predominance of *Keratella cochlearis* f. *tecta* (=unspined form) especially during summer months. Ejsmont-Karabin (2012) also developed a rotifer trophic-state index (TSI_{ROT}). If the values of TSI_{ROT} <45 vary between 45–55, 44–55, 55–65 or >65, then the water body is, respectively, mesotrophic, meso-eutrophic, eutrophic or hypertrophic. For deriving this TSI_{ROT} for the present water body, we applied the rotifer numbers in the equation developed by Ejsmont-Karabin (2012) ($TSI_{ROT}=5.38\ln(N)+19.28$). We obtained a mean annual value of <40 TSI_{Rot}. This too suggests that the water body is mesotrophic.

On average, sampling station 1 had the highest species diversity index of rotifers (2.81 bits/ind.) since the presence of macrophytes in this pond favored the high diversity of Rotifera (Bakker et al., 2013). A low mean annual species diversity index was observed at station 2 (2.54 bits/ind.). In this pond we observed a high density of *Brachionus* which exploited the food resources and kept other species at low density (Pejler and Bērziņš, 1989; Nandini et al., 2005). The mean annual species diversity index of the five water bodies in La Cantera Oriente was about 2.7, which indicates the ecosystem is relatively little contaminated (Wetzel, 2001). The zooplankton species diversity index values in other high altitude water bodies in Mexico vary considerably. For example, Nandini et al. (2016) have recorded a mean species diversity of about 2 for the lake Xochimilco, for the high altitude drinking water reservoir, while Figueroa-Sánchez et al. (2014) recorded a wide range (0.57 to 2.47 bits/ind.). Kuczyńska-Kippen et al. (2013) found relatively much lower rotifer species diversity values (0.17 to 1.94) for four crater ponds in Poland. They attributed the low rotifer diversity to the temporary nature of the water bodies, that is, the water bodies periodically dry.

We did not estimate the density of algae in our study. However, it is known that La Cantera Oriente a diverse community (>135 taxa) of microalgae of which most species belong to the Chlorophyta and the Bacillariophyceae (Novelo et al., 2009). Most members of Chlorophyta can provide food for rotifers of the Brachionidae, the Lecanidae, the Lepadellidae and the Trichocercidae (Wallace et al., 2006). The range of tolerance of freshwater rotifers to certain physico-chemical variables including temperature, dissolved oxygen, hardness and conductivity varies depending on the species. The results of the CCA showed that *L. pyriformis*, *L. flexilis*, *T. pusilla* and *B. budapestinensis* were positively affected by alkalinity. Bērziņš and Pejler (1989 a, b) have documented the occurrence of various rotifers including *Lecane*, *Trichocerca* and *Brachionus* with respect to different abiotic factors including pH, temperature, conductivity and dissolved oxygen. The occurrence of different rotifer species in La Cantera Oriente agrees with the data presented in Bērzinš and Pejler (op.cit.). Some of the most common rotifers such as *Testudinella patina*, *Euchlanis dilatata* and *Cephalodella gibba* showed no clear relation in relation to the chosen physico-chemical variables. It is known that some of these species have a wide range of tolerance to temperature, dissolved oxygen and chlorophyll *a* levels (Koste, 1978). Species of *Cephalodella* and *Euchlanis* are benthic-littoral, living where the physico-chemical variables vary considerably (Moss, 2010) and therefore it is not surprising that these rotifers show little relation to the measured abiotic factors.

5 CONCLUSION

This study reveals that the shallow lakes of La Cantera Oriente have more than 60 rotifer species including the taxa rare for Mexico such as *Eosphora thoides* and *Lecane bifurca*. The physico-chemical data agree with those available for similar water bodies in Central Mexico. The trophic status of this shallow lake, based on chlorophyll *a* is eutrophic while the $Q_{B/T}$ ratio and the rotifer densities suggest an oligotrophic condition for most part of the year. When the trophic state index (TSI_{ROT}) is applied the water body it indicates a mesotrophic condition. This warrants further studies, especially with reference to the nutrient dynamics in this shallow lake.

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