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Invasive alien species water hyacinth *Eichhornia crassipes* as abode for macroinvertebrates in hypertrophic Ramsar Site, Lake Xochimilco, Mexico

A. Rocha-Ramírez[1]*, E. Robles-Valderrama[2] and E. Ramírez-Flores[3]
[1]Laboratorio de Ecología, Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México, Av. de los Barrios # 1, los Reyes Iztacala, CP 54090 Tlalnepantla, Estado de México, México
[2]Laboratorio de Calidad del Agua, UIICSE, Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México, Av. de los Barrios # 1, los Reyes Iztacala, CP 54090 Tlalnepantla, Estado de México, México
[3]Proyecto Conservación y Mejoramiento del Ambiente, UIICSE, Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México, Av. de los Barrios # 1, los Reyes Iztacala, CP 54090 Tlalnepantla, Estado de México, México
*Corresponding Author E-mail: arocha@unam.mx

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Abstract

This paper presents information on the density, diversity and functional feeding groups of macroinvertebrate assemblages associated with water hyacinth in Antiguo Canal Cuemanco, part of Lake Xochimilco in Mexico City. Rare (low frequency and density) and dominant (high frequency and density) taxa prevailed in the assemblages, with the most predominant being *Hyalella azteca*, *Chironomus plumosus* and *Ischnura denticollis*. Nonmetric Multidimensional Scaling confirmed two climatic seasons: warm-rainy and cold-dry; the former with the highest diversity and density of taxa. Canonical Correspondence Analysis showed that conductivity, nitrates and turbidity explained the density variations of taxa. Antiguo Canal Cuemanco waters are spatially homogeneous with the characteristics of hypertrophic shallow lakes, inhabited by scrapers and gathering-collectors. The species found were tolerant to organic pollution.

Key words

Aquatic macroinvertebrates, Anthropogenic eutrophication, Biodiversity *Eichhornia crassipes*, Diversity, Functional feeding groups, Hypertrophic, Lake Xochimilco, Ramsar Site

Introduction

Water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laubach, 1883), native to South America, is a common aquatic invasive species in many parts of the world. It is a free-floating vascular plant known to cause drastic ecological and socio-economic changes (Center, 1994). Growing population of water hyacinth have the potential to affect both ecological and human communities in the areas where they become established, and can be perceived either positively or negatively depending on how the water bodies are used (Ogutu-Ohwayo *et al.,* 1997). Among its negative impacts, water hyacinth may endanger biodiversity, cause eutrophication, shelter pests, hinder agriculture and aquaculture, clog waterways, and hamper shipping and recreational activities (Patel, 2012). Its success as an invasive species is attributed to its ability to compete with native vegetation and phytoplankton (Wilson *et al.,* 2005). On the other hand, positive impact like changes in macrophytes composition and structural complexity can also alter macroinvertebrate assemblages (i.e., species diversity and composition), and water hyacinth may provide additional habitats for macroinvertebrates. The species diversity of macroinvertebrates increases when habitat heterogeneity increases (Brendonck *et al.,* 2003). Schultz and Dibble (2012) undertook a comprehensive review of research on invasive species of macrophytes and their impact on the fish and macroinvertebrate communities.

Aquatic plants provide ideal habitats for macroinvertebrate colonization (Sharitz and Batzer, 1999; Lot and Novelo, 2005). The complex structure provided by roots and leaves in particular creates habitats for the epiphytic oligochaetes and turbellarians (de Marco *et al*., 2001), cladocerans and molluscs (Brendonck *et al*., 2003), and amphipods (Toft *et al*., 2003). There are several literatures that deal with the macroinvertebrate assemblages associated with water hyacinth root masses. These studies have considered different aspects, including: taxonomic composition of the macroinvertebrate communities, identification of functional groups, relationship between species and environmental factors, and relationships between plant decomposition and macroinvertebrate colonization (Masifwa *et al.,* 2001; Poi de Neiff and Neiff, 2006; Marçal and Callil, 2008). Other works have focused on macroinvertebrate patterns on a temporal and spatial scale (Poi de Neiff and Carignan, 1997; de Marco *et al.,* 2001; Rocha-Ramírez *et al*., 2007). Villamagna and Murphy (2010) reviewed the water hyacinth and summarized the existing information on this invasive plant and discussed its problematic aspects including ecological and socio-economic impacts.

Water hyacinth was introduced to reservoirs in1898 in the Valley of Mexico and since then it has been established in various areas (Miranda and Lot, 1999), affecting over 40,000 ha of dams, lakes, canals, and drains (Gutiérrez *et al.,* 1996). Lake Xochimilco is one of the affected areas, polluted by domestic, industrial, and agricultural wastewater and leakage from drainage systems, leading to the spread of water hyacinth and reducing biodiversity (Juárez-Figueroa *et al.,* 2003). The aim of this study was to enumerate the structure and diversity of the macroinvertebrate assemblages associated with water hyacinth roots masses in the Antiguo Canal Cuemanco, a canal forming part of Lake Xochimilco, Mexico City, Mexico. The macroinvertebrate fauna in relation to the seasonal changes in physico-chemical characteristics of the water was analyzed and the trophic attributes of the ecosystem in terms of functional feeding group densities was identified.

Materials and Methods

Study site : Lake Xochimilco is one of a series of five lakes in the Valley of Mexico. It is a remnant of a pre-Hispanic farming system first established during the 13th century on the edge of the lake basin, where a special form of agriculture using "*chinampas*", or floating islands, has been practiced since Aztec times (Rojas-Rabiela, 1991). It is located in the southeast of Mexico City, at 2,270 m.a.s.l, between 19°08' N, 99°00' W and 19°17' N, 99°09' W. The lake consists of a network of canals or waterways between 3 m and 60 m wide, creating a total water surface area of about 190 ha. The average depth is 2.5 m, with a maximum depth of 4 m. Most of the substrate consists of anoxic clay sediments, with high concentrations of sulphate-reducing and sulphate-oxidative bacteria. The Antiguo Canal Cuemanco, where this study was carried out, is part of Lake Xochimilco (Fig. 1). The lake's water sources are a sewage treatment plant Cerro de la Estrella (Martínez-Arroyo and Jauregui, 2000). The vegetation in the canals is dominated by free-floating hydrophytes *E. crassipes* and *Hydromystria laevigata* (Humb. Bonpl. ex Willd.) Hunz., 1981, and 2 species of Lemnaceae : *Lemna gibba* Linnaeus, 1753 and *Wolffia columbiana* Karst., 1865.

Physico-chemical variables : We sampled monthly at 3 sites from September 2008 to August 2009. Two of the sites were located in the Antiguo Canal Cuemanco itself, and the third was in an adjacent canal, which was both narrower and shallower (Fig. 1). The following physico-chemical parameters were analyzed *in situ* at 30 cm depth: temperature (T); dissolved oxygen (DO) and saturation percentage (DOsp) with an Oakton DO-100 oxymeter; pH, with a digital Oakton potentiometer; turbidity, with a Lamotte Turbidimeter (TU) 2020; and depth (DE), with a Speedtech Instruments depth sonar. In addition, 3 replicates of water samples were taken using a van Dorn sampling bottle to determine: total alkalinity (TA) as mg $CaCO_3$ l^{-1}; conductivity (EC) with a Conductronic CL 35 calibrated at 25 °C; nitrate (NO_3^-) by brucine method; nitrites (NO_2^-) by diazotization method; orthophosphate (OP) by stannous chloride method and total phosphate (TP) by digestion method (APHA, 2005). Average monthly rainfall data was taken from the National Water Commission (Comisión Nacional del Agua, CONAGUA) website.

Macroinvertebrate sampling : From each site samples of *E. crassipes* were collected by submerging an Aquatic Kick-Net (25.4 cm X 45.7 cm with a 500 µm mesh size) below the roots. The root masses were separated from the rest of the plant, and the aerial parts were discarded. The roots were washed in a container and filtered with a 500 µm mesh and the remains roots of triplicate and macroinvertebrates were concentrated. The samples were fixed in 70% ethyl alcohol. The root samples were dried at room temperature and weighed to estimate the root biomass (g m^{-2}). The macroinvertebrates from the concentrate, were counted, and identified using appropriate taxonomic keys: Polhemus (1984), Burch and Cruz (1987), Pennak (1991), Thorp and Covich (1991) and Elías-Gutiérrez *et al.* (2009).

Data analysis : The observed differences in environmental and ecological variables statistically were evaluated. We assessed the normality of data using the Shapiro-Wilk W test; for the non-normal data we employed the Kruskal-Wallis test (α = 0.5). Indirect ordination Nonmetric Multidimensional Scaling (NMDS) was used with the Bray-Curtis similarity values, obtained from mean monthly values of physico-chemical variables. This enabled us to determine the differences among months and to define the seasonality of the study area. Average macroinvertebrate abundance of the 3 samples per site were calculated; these values were standardized and expressed as density (ind m^{-2}). We quantified diversity using the Shannon-Wiener diversity index [H' bits org^{-1}] and dominance [D = 1 – J'] values. The software PRIMER 6.0 (Clarke and Warwick, 1994) was used to calculate all data.

To compare the diversity values between each pair of sample sites, Student's *t*-test ($\alpha = 0.05$) was performed according to Hutchenson (1970), using null hypothesis H_o: $H'_1 = H'_2$ (the diversity of Site 1 is statistically equal to Site 2). Correlation coefficients using least-squares method regression analysis for all the environmental variables *vs.* density of the dominant taxa and total density was also calculated. The

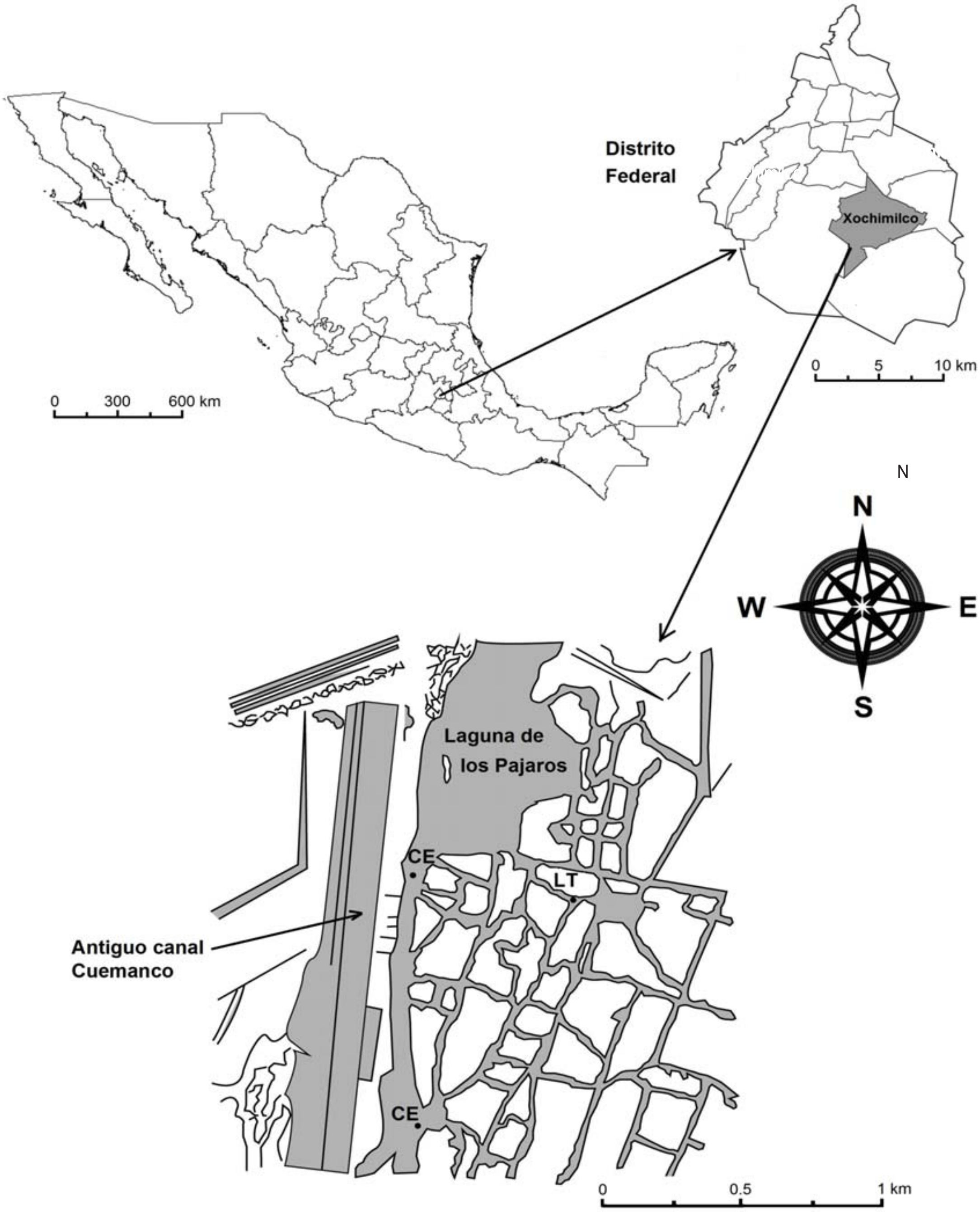

Fig. 1 : Map of the Lake Xochimilco showing location of sampling sites: EC) Embarcadero Cuemanco, CE) Club España, LT) Laguna Tlilac

significance was demonstrated with Student's *t*-tests (α = 0.05) where null hypothesis had a slope value of 0. All statistical calculations for these tests were carried out with Number Cruncher Statistical System software (NCSS, 2007).

The proportions of functional feeding groups (shredders, which chew conditioned litter or live vascular plant tissue, or gouge wood; filtering collectors and suspension feeders, which filter particles from the water column; gathering collectors and deposit feeders, which ingest sediment or gather loose particles in depositional areas; scrapers, which graze rock and wood surfaces or stems of rooted aquatic plants; and predators, which capture and engulf prey or tissue, or ingest body fluids) were calculated according to Cummins *et al.* (2005) to determine the stability of water hyacinth roots as a substrate and trophic attributes of the ecosystem. A graphic analysis was used to classify the taxa found in the study into four temporal criteria. Temporal classification was carried out by plotting the median values for each taxon for frequency percentage (per month and for site), on the x axis, against transformed density [log (density + 1)], on the y axis. Two axes were established with the median values for both variables to differentiate four quadrats; the taxa were classified according to their position, with the upper left quadrant representing the seasonal, lower left the rare, upper right the dominant, and lower right the common taxa. Finally, we compared the densities of the dominant taxa (density values were transformed by the fourth root) with the environmental variables. Interactive Analysis-Forward-Selection was used to select environmental variables for the Canonical Correspondence Analysis (CCA); for both analysis and direct ordination biplot, we used the software CANOCO v 5.01 (Canonical Correspondence, ter Braak and Smilauer, 2012).

Results and Discussion

The physico-chemical conditions of the study sites are summarized in Table 1. The monthly concentrations of CO, pH and T among the sampling sites did not differ significantly (Kruskal-Wallis test, z < 1.96). While rest of the physico-chemical parameters (TA, N, NI, OP, TP, DO, DOsp, TU, and DE) varied significantly, at least at one sampling site (Kruskal-Wallis test, z > 1.96). The Bray-Curtis similarity in sampling sites varied from 81 to 98%. The lowest similarity value of 81%, was found for the CE site in May. In all the samples, this had the highest values for OP (2.54 mg $PO_4^-P\ l^{-1}$), TP(3.08 $PO_4^-P\ l^{-1}$), TH (135 mg $CaCO_3\ l^{-1}$), N (1.4 mg $NO_3^-N\ l^{-1}$), and NI (0.52 mg $NO_2^-N\ l^{-1}$), and the lowest values for CO (783 µS cm^{-1}), and TU (5.15 UNT). The LT site in November also had a low similarity value (82%), registering highest CO (738 µS cm^{-1}) and lowest NI values (0.015 mg NO_2-N l^{-1}).

The NMDS ordination analysis of the environmental variables (Fig. 2) affirmed the marked seasonal conditions in the study area. The "stress" value obtained (= 0.07) corresponds to a good ordination (Clarke and Warwick, 1994). The diagram generated by analysis shows two groups that represent two climatic seasons. The warm-rainy season from May to September was characterized by lower values of, N, NI, OP, TP, TU, and DO and by higher CO and T. The cold-dry season covered the remaining months and was characterized by inverse behavior of the variables mentioned above. In April, mean precipitation was 5.9 mm, and in May 41.7 mm, clearly delimiting the beginning of 2009 rainy season. Kruskal-Wallis tests showed significant differences in key factors between the seasons, reflecting their differing hydrological dynamics: CO (z = 5.02), NI (z = 2.5), OP (z = 2.8), DO (z = 2.7), T (z = 3.05), and TU (z = 2.9). Moreover, all environmental variables did not significantly differ between

Table1 : Summary of the environmental variables of the study sites, Antiguo Canal Cuemanco, Lake Xochimilco. EC) Embarcadero Cuemanco, CE) Club España, LT) Laguna Tlilac

	Warm-rainy						**Cold-dry**					
	Ec		**Ce**		**Lt**		**Ec**		**Ce**		**Lt**	
Parameter	**Mean**	**Sd**	**Mean**	**Sd**	**Mean**	**Sd**	**Mean**	**Sd**	**Mean**	**Sd**	**Mean**	**Sd**
T (°C)	19.00	1.64	18.92	1.50	20.14	4.04	16.51	3.34	16.49	3.55	17.00	1.50
pH	8.08	0.19	8.24	0.15	8.22	0.63	8.16	0.76	8.34	0.82	8.87	0.68
TA (mg $CaCO_3\ l^{-1}$)	186.92	32.35	196.42	22.76	175.42	34.99	182.84	30.79	203.23	43.05	188.13	39.35
EC (µS cm^{-1}))	832.40	54.73	872.80	70.23	830.00	54.43	708.57	11.47	714.57	12.70	716.86	25.43
NO_3^- (mg $N^-NO_3\ l^{-1}$)	1.08	0.59	0.44	0.51	0.30	0.20	1.68	0.33	0.31	0.13	0.71	0.32
NO_2^- (mg $N^-NO_2\ l^{-1}$)	0.03	0.02	0.02	0.02	0.01	0.01	0.17	0.06	0.02	0.02	0.06	0.02
OP (mg $PO_4\ l^{-1}$)	1.46	0.99	1.27	0.67	0.80	0.48	2.27	0.58	1.93	0.66	1.32	0.36
TP (mg $P^-PO_4\ l^{-1}$)	2.06	1.23	1.56	0.83	1.21	0.63	3.00	0.86	3.16	1.23	1.96	0.53
DO (mg l^{-1})	8.84	2.30	7.85	2.72	7.73	2.52	11.60	2.59	12.46	3.73	8.40	1.12
DOsp (sat. %)	97.70	30.32	89.80	27.22	79.20	43.73	121.99	28.36	126.16	35.68	85.40	13.30
TU (NTU)	7.99	1.81	9.37	1.81	9.20	4.81	10.92	4.14	13.64	3.73	17.21	4.39
Depth (m)	1.65	0.40	1.49	0.40	1.44	0.36	1.52	0.44	1.36	0.45	1.35	0.40
Root biomass (g m^{-2})	4.19	1.55	5.15	2.14	3.01	1.19	4.69	2.93	5.97	1.44	3.44	1.75

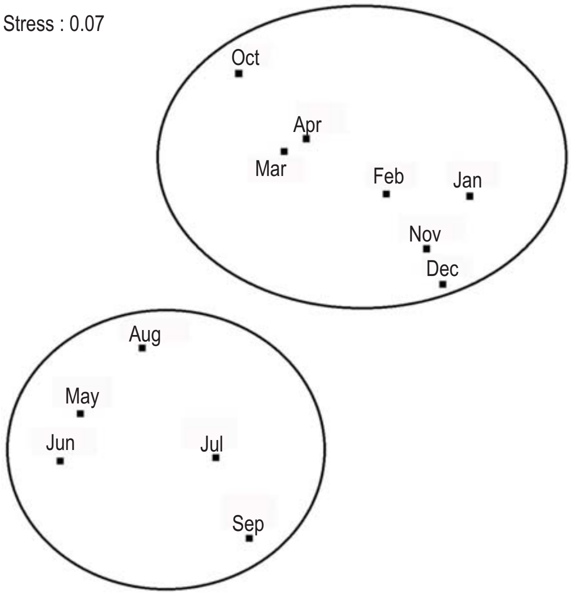

Fig. 2 : NMDS ordination plot of the monthly average values of the physico-chemical variables.

months and sites within each climatic season (Kruskal-Wallis test, $z < 1.96$).

The water of Antiguo Canal Cuemanco did not significantly vary in physico-chemical parameters, suggesting that the hydrology of the study area is spatially homogeneous, Oliva-Martínez *et al.* (2008) reported similar seasonal variability in hydrology in another urban lake Tezozomoc, Mexico City. The values of physico-chemical parameters were similar to those reported in previous studies in Lake Xochimilco (Nandini *et al.*, 2005; Martínez-Cruz *et al.,* 2006; Quiroz-Flores et al., 2008; López-Hernández *et al.,* 2010). Lake Xochimilco could be considered subtropical, with a monthly average temperature range of 13.4-21.5 °C (Hutchinson, 1957). Water conductivity, in addition to hardness is frequently used as classification criteria for natural waters, based on their mineralization status and potential productivity (Nisbet and Verneaux, 1970). In this sense, the Antiguo Canal Cuemanco exhibits a very high mineralization capacity. The lake is alkaline (pH = 7.4-9.2) for most of the year.

The annual variation in Lake Xochimilco in average dissolved oxygen concentrations (5.2-12.5 mg l^{-1}) is typical of eutrophic shallow lakes in Mexico (Alcocer and Bernal-Brooks, 2010), corresponding to waters with high production; likewise, it relates to high level of oxygen saturation (100-140%).The concentration of both TP (1.3-3.4 PO_4^-P mg l^{-1}) and OP (0.1-2.3 mg $PO_4^-Pl^{-1}$) were extremely high, caused by local agricultural activities (phosphate fertilizer is used in the *chinampas*) and residual treated waters coming from a nearby waste treatment plant (Quiroz-Flores *et al.,* 2008). López-Hernández *et al.* (2010) also demonstrated that the treated water that reaches the canals contains high concentrations of inorganic nutrients and organic matter. Another important factor is a program for the removal of water hyacinth from the lake by trituration, which generates increased nutrient concentrations in water has also been observed in Valsequillo, another Mexican reservoir (Mangas-Ramírez and Elías-Gutiérrez, 2004).

The relatively low nitrogen concentrations (0.5-1.0 mg $NO_3^-l^{-1}$ and 0.014-0.16 mg $NO_2^-l^{-1}$), high TP and DOsp values, and from these values derived low Redfield proportion N:P (< 16), suggest that aquatic productivity in the study area is probably limited by nitrogen. However, phytoplankton activity was intense as noted from the high chlorophyll concentrations > 88 mg l^{-1} (Cruz-Muñoz and Martínez-Arroyo, 1999), it was difficult to explain, but could contribute to N decrease. According to Nürnberg's classification criteria for trophic states of lakes (1996) Lake Xochimilco can be considered as a hypertrophic water body.

Root biomass of water hyacinth was highest during the warm-rainy season, and lowest at the LT site at both seasons (Table 1). Twenty four taxa of aquatic macroinvertebrates were collected, belonging to 22 families and 14 orders. These included 12 taxa of Insecta, 6 Crustacea, 6 Hirudinea, 2 Turbellaria and 2 Gastropoda. A list of taxa, their functional feeding groups and temporal classifications, is given in Table 2.

Temporal classification of the macroinvertebrate assemblages associated with the water hyacinth roots indicated that rare (54%) and dominant (33%) taxa predominate. Classification of the taxa into functional feeding groups were dominated mainly by predators (58%) and gathering collectors (21%). However, in terms of density the most prevalent groups were shredders, namely, amphipod *Hyalella azteca* (Saussure, 1858), and gathering collectors, dominated by immature stages of dipteran midge *Chironomus plumosus* (Linnaeus, 1758) (Table 2). The autotrophy to heterotrophy index (P/R = scrapers/total collectors + shredders) was over 0.75 every month, while the coarse particulate organic matter (CPOM) to fine particulate organic matter (FPQM) index (CPOM/FPOM = shredders/total collectors) was over 0.25. The stability of the water hyacinth roots as substrate (SS = scrapers+filtering collectors/gathering collectors + shredders) was over 0.5 for most of the year, except in July, August and October.

The taxonomic richness of each sample varied from 6 to 12 taxa (Fig. 3a); the highest values were registered at the LT site during the warm-rainy season (May and November). The taxonomic richness did not differ significantly between the sampling sites (Kruskal-Wallis test, $z = 0.917$). The most prevalent taxa were *H. azteca*, *C. plumosus*, and the odonate naiads *Ischnura denticollis* (Burmeister, 1839), with relative abundances of 61, 35 and 4%, respectively. The *H. azteca* densities were highest in October and February, at 971 and 1,193 ind m^{-2}, respectively, at EC site (Fig. 3c). During these months, young specimens prevailed, probably representing the period of greatest reproductive activity. The *C. plumosus* density maximum for different larval stages occurred in September and November (872 and 732 ind m^{-2} respectively). Variations in the density of *I. denticollis* showed no clear pattern. Macroinvertebrate density was always highest at EC site, followed by LT and CE (Fig. 3b). Regarding the relationship between physico-chemical variables and density (total and dominant taxa), all the values of Student *t*-test of the regressions was not significant (p> 0.45).

Shannon-Wiener diversity values varied greatly between sites (Fig. 4a). The minimum value was registered at CE site in March (0.23 bits org^{-1}) and maximum in May at LT site (3.1 bits org^{-1}). Diversity values per site over warm-rainy season between May and September differed significantly (p= 0.01); only at LT site, which registered values from 1.4 to 2.1 bits org^{-1}. During cold-dry season the same site differed significantly from January to March (p= 0.01), with values varying from 0.05 to 2.0 bits org^{-1}. The overall diversity values significantly differed between climatic seasons (p= 0.02), averaging 2.1 bits org^{-1} during warm-rainy season and 1.3 during cold-dry. The diversity at different sites was not correlated with taxonomic richness or with environmental variables (p>0.34 in all cases). Community dominance of the commonest taxon varied from 0.1 to 0.7, with the lowest values registered during cold-dry season (Fig. 4 b).

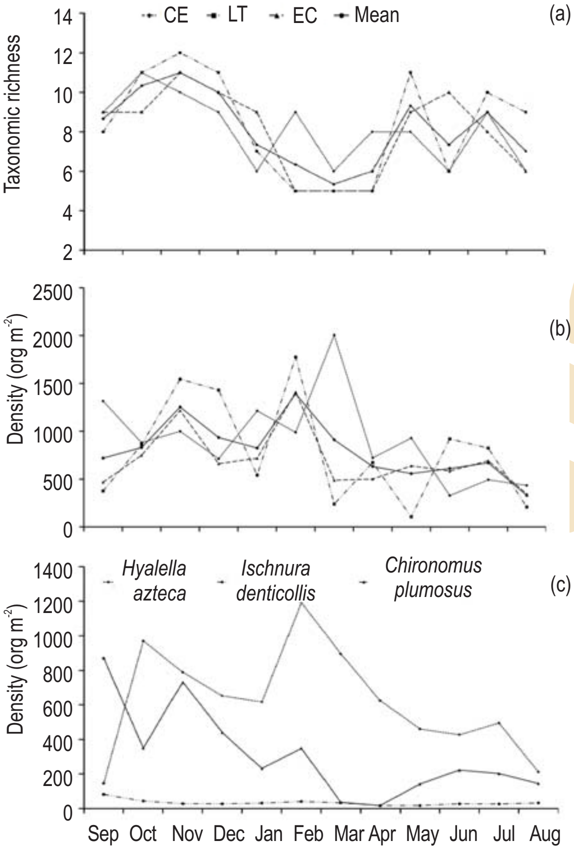

Fig. 3 : a) Monthly variation of taxonomic richness of macroinvertebrates per sampling site, b) monthly variation of macroinvertebrates density, c) monthly variation of highest density species

While the common water hyacinth has permanently established in the canals of Lake Xochimilco, it presents very drastic changes in coverage and plant size during the study period. This was due to two factors: during cold months (December to February) the rate of growth is very low, which increases loss of biomass (Wilson *et al.,* 2001), so smaller plants with reduced coverage were observed during the cold-dry season, and a permanent water hyacinth removal program is in place in the area, consisting of manual and mechanical gathering and deploying a crusher (it is unclear when this was first used and how often it is used). This removal was feasible only in the main canals (EC and CE sites). Despite the prevailing conditions leading to decrease in water hyacinth mass, this plant in the canals of Lake Xochimilco tends to persist, and confirms the recalcitrant nature of this aquatic weed as well as the difficulty of its eradication for an efficient management of Lake Xochimilco.

Water hyacinth root masses in the Antiguo Canal Cuemanco were colonized by a poor macroinvertebrate assemblage. Greater taxonomic richness has been recorded at other localities (Table 3); this difference may be due to discrepancies in sampling, local characteristics, taxonomic

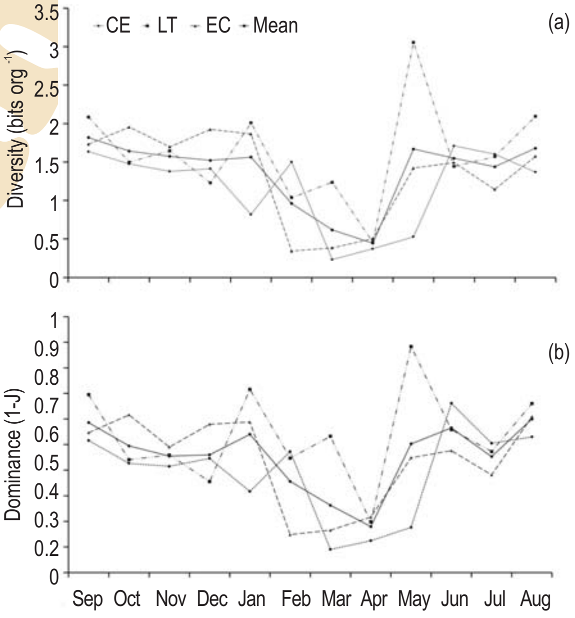

Fig. 4. a) Monthly variation Shannon-Wiener diversity index per sampling site, b) monthly variation community dominance

resolution, and the degree of decomposition of the water hyacinth roots. Brendonck *et al.* (2003) and Uwadiae *et al.* (2011) have shown that in water bodies with some degree of eutrophication, species richness is not always low, demonstrating that the presence of water hyacinth can increase the density and diversity of invertebrate assemblages. The trophic state of Lake Xochimilco is determined in large part by the dominance of *H. azteca* and *C. plumosus*, and in general by the simplicity of the invertebrate assemblages; in other words, low biological diversity. According to Medianero and Samaniego (2004), *H. azteca* and *C. plumosus* are biological indicators of polluted ecosystems. Further, the occurrence in Lake Xochimilco of the copepod *Acanthocyclops robustus* (Sars, 1863), which is confined to alkaline waters (Brandl, 2005), the dipteran *Eristalis* sp., and the mollusks *Physa osculans* Haldeman, 1842 and *Gyraulus* sp. confirm the environmental degradation of the lake, since they all are ecologically successful inhabitants of water bodies with a high level of organic pollution (Paggi, 1999; Dillon, 2000; Naranjo, 2003).

Moreover, the P/R (autotrophy to heterotrophy) index indicates that Lake Xochimilco is an autotrophic system. The CPOM/FPOM (coarse particulate organic matter to fine particulate organic matter) index (Cummins *et al.,* 2005) indicates the existence of an association between shredders and water hyacinth roots. Likewise, the water hyacinth roots tends to be a stable substrate for macroinvertebrates for most months of the year, except for July, August, and October, when the total proportion of scrapers + filtering collectors/gathering-collectors + shredders is less than 0.5. According to Vannote *et al.* (1980), low levels of shredders and abundance of scrapers and gatherers-collectors are associated with trophic alterations that reflect the negative effects of nutrient enrichment of water bodies.

The variations we found in diversity and community dominance suggest the existence of a seasonal pattern where the assemblage complexity diminished during winter months, tending to remain higher and uniform during the rest of the year. Such a pattern, in principle, would appear to be determined by temperature, although there was no significant correlation between the measured environmental variables and diversity. The smallest water hyacinth plants and the lowest root biomass values were also registered in the cold months. Under these conditions, it is probable that the structural complexity of macroinvertebrate habitats declines, and subsequently the community dominance of a few species increases. Dibble and Thomaz (2006) demonstrated that plant architecture can directly influence the colonization and composition of epiphytic invertebrate assemblages. Also, the temporal patterns of invertebrate densities were determined by reproductive pulses

Table 2 : Macroinvertebrate taxa associated with *Eichhornia crassipes* root masses in Antiguo Canal Cuemanco, Lake Xochimilco PR = predators, SC = scrapers, GA/CO = gathering-collectors, SH = shredders, RAR = rare, DOM = dominant, COM = common, SEA = seasonal

Order	Taxa	Functional feeding group	Temporal classification
Turbellaria	*Dugesia dorotocephala* (Woodworth, 1897)	PR	RAR
	D. tigrina (Girard, 1850)	PR	RAR
Hirudinea	*Helobdella fusca* (Castle, 1900)	PR	DOM
	Erpobdella ochoterenai (Caballero, 1932)	PR	COM
Gastropoda	*Physa osculans* Haldeman, 1842	SC	DOM
	**Gyraulus* sp.	SC	RAR
Branchiopoda	**Simocephalus vetulus* (Müller, 1776)	SC	RAR
Maxilopoda	*Acanthocyclops robustus* (Sars, 1863)	PR	RAR
Ostracoda	*Cypridopsis vidua* (Müller, 1776)	GA/CO	RAR
Amphipoda	*Hyalella azteca* (Saussure, 1858)	SH	DOM
Isopoda	*Caecidotea xochimilca* Rocha-Ramírez Peñaloza-Daniel, 2011	GA/CO	RAR
Decapoda	*Cambarellus montezumae* (Saussure, 1857)	SC	SEA
Odonata	*Ischnura denticollis* (Burmeister, 1839)	PR	DOM
	Aeschna multicolor Hagen, 1861	PR	SEA
Hemiptera	*Microvelia* sp.	PR	DOM
	Mesovelia sp.	PR	RAR
	**Belostoma* sp.	PR	RAR
	**Buenoa* sp.	PR	DOM
Diptera	*Chironomus plumosus* Linnaeus, 1758	GA/CO	DOM
	Eristalis sp.	GA/CO	RAR
Coleoptera	*Stenus* sp.	PR	RAR
	**Dytiscus* sp.	PR	RAR
	**Enochrus mexicanus* (Sharp, 1882)	GA/CO	DOM
	Paracymus sp.	PR	RAR

*Not reported by Salcedo (1978)

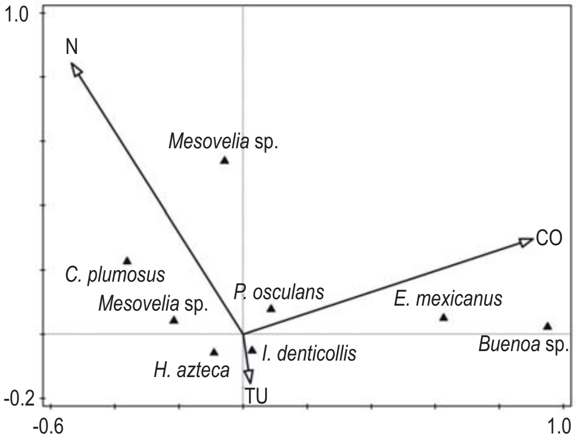

Fig. 5: CCA biplot of environmental variables and the dominant macroinvertebrate taxa.TU, turbidity; CO, conductivity; N, nitrates

(Levin *et al.,* 2001), which could also help to explain the annual pattern in diversity. In contrast, variation in the monthly average macroinvertebrate density do show a significant relationship with the climatic seasons according to the NMDS analysis with the cold-dry season presenting highest densities of the year. These values are a function of the fluctuations of the population sizes of *H. azteca* and *C. plumosus*, which have the highest relative abundances (61% and 35%, respectively) in the macroinvertebrate assemblages associated with water hyacinth roots.

As previously mentioned, environmental variables and density of invertebrates did not significantly vary. However, the program for the removal of water hyacinth in the main canal will affect the associated fauna it was probably because of this activity that the highest values for density and diversity were recorded at LT site, which is located in a secondary canal.

The relationships between environmental variables and species densities analyzed with the CCA direct ordination indicated that, of the 13 environmental variables considered in this analysis, only 3 variables explain best the variation of macroinvertebrate densities associated with water hyacinth roots (Fig. 5). The three environmental variables together explained > 80% of the variation of macroinvertebrates, CO (46%, pseudo-F = 4.5, p = 0.004), N (20%, pseudo-F = 3.8, p = 0.01) and TU (19.5%, pseudo-F = 3.9, p = 0.02). Total inertia was 0.14 and the first 3 axes of the CCA explained 83.5% of the environmental variables-species relationship. Additionally, the Monte Carlo test of significance gave a significant result for the first axis of the CCA (F = 4.23, p = 0.004) and also for all canonical axes (F = 1.6, p = 0.018).

In lakes of other countries, the macroinvertebrate assemblages on water hyacinth roots were dominated by different taxonomic groups. The composition of macroinvertebrate assemblages depends on depth, water movement, physico-chemical conditions, density and length of plant roots, evidence of other aquatic macrophyte-fauna exchange, plankton-roots-benthos relationships, and the presence of different functional feeding groups. Various studies have documented correlation between density and certain environmental variables, for example: the surface area of floating vegetation (Crowder and William,1982); temperature, conductivity and pH (de Marco *et al.,* 2001); conductivity, temperature, ammonium concentration, and dissolved oxygen (Kouamé *et al.,* 2010); dissolved oxygen and turbidity (Poi de Neiff and Carignan, 1997); salinity, dissolved oxygen and turbidity (Rocha-Ramírez *et al.,* 2007). Due to the homogenous nature of the sampling sites in this water body, according to the CCA biplot, marked positive correlation between environmental variables and the densities of the dominant taxa of macroinvertebrates were noted in only in the following cases: *Enochrus mexicanus* (Sharp, 1882) and *Physaosculans*

Table 3 : Comparison of the number of taxa (the taxonomic resolution varied among groups), dominant groups, and localities of the invertebrates associated with *Eichhornia crassipes* root masses

Reference	Locality	Number of taxa reported	Dominant groups
Salcedo (1978)	Lake Xochimilco, Mexico	23	Insecta, Chironomidae, Platyhelmintes, Annelida and Mollusca
Poi de Neiff and Carignan (1997)	Two lakes of the Parana River, floodplain Argentina	64	Ostracoda, Conchostraca and Chironomidae
de Marco *et al.* (2001)	Pampulha reservoir, Brazil	17	Oligochaeta and Turbellaria
Rocha-Ramírez *et al.* (2002)	Coyuca Lagoon, Pacific coast, Mexico	21	Amphipoda and Isopoda
Brendonck *et al.* (2003)	Lake Chivero, Zimbabwe	34	Cladocera and Mollusca
Pamplin *et al.* (2006)	Americana Reservoir, SP, Brazil	19	Oligochaeta, Hirudinea and Ephemeroptera
Rocha-Ramírez *et al.* (2007)	Alvarado Lagoon, Gulf of Mexico coast	96	Isopoda, Amphipoda and Cladocera
Marçal and Callil (2008)	15 shore lakes along the Paraguay River, Argentina	15	Hydrobiidae, Ostracoda and Hydracarina
Kouamé *et al.* (2010)	Taabo Lake, Ivory Coast	68	Coleoptera, Diptera, Heteroptera and Odonata
Ohtaka *et al.* (2011)	Lake Tonle Sap, Cambodia	19	Ostracoda, Cladocera and Oligochaeta
Uwadiae *et al.* (2011)	Lekki lagoon, Southern Nigeria	>53	Amphipoda, Isopoda and Oligochaeta
Present study	Lake Xochimilco, Mexico	24	Amphipoda and Chironomidae

Haldeman, 1842 with CO; *I. denticollis* with turbity; *C. plumosus* and *Microvelia* sp. and *H. azteca* with N. Finally, *Mesovelia* sp. and *Buenoa* sp. did not show direct relationship with the variables considered.

In conclusion, this study demonstrates the need for environmental protection. The hypertrophic state of Lake Xochimilco can be attributed to anthropogenic activities. The most serious ecological problems have been agricultural runoff, urbanization, exploitation of aquifers, and input of low-quality treated wastewater into canals. Although in 1987 UNESCO declared Xochimilco a place of Universal Human Patronage and it is listed as a Ramsar Site, creating pressure from the international community, the Mexican government has yet to take measures for ecological protection and restoration of the lake. Lastly, the case of Lake Xochimilco provides an example of environmental degradation common in other water bodies in Central Mexico.

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