Aquatic biodiversity in cenotes from the Yucatan Peninsula (Quintana Roo, Mexico)

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Abstract

Karstic water bodies represent the most relevant limnologic feature of the Yucatan Peninsula, Mexico. These systems harbor endemic species and are the main regional epigean source of freshwater. In this work, the morphometry, basic limnological features, and the zooplankton and fish fauna of five aquatic karstic systems from the central zone of Quintana Roo State, Mexico (in the heart of the Zona Maya) were surveyed. The possible relation between species richness and morphometric features was tried to be established. Overall, 79 taxa were found, 64 belong to zooplankton, and 15 to nekton. All studied systems were oligotrophic, with high transparency, and low nutrients and chlorophyll a concentration, thus differing from other water bodies in central Mexico. The two different types of karstic systems studied were the typical "cenote", and the "aguada". Both showed differences in biological, physical, and chemical variables. A one-way ANOVA test demonstrated significative differences in nutrients (nitrates, $F = 61.52$, $p < 0.001$; nitrites, $F = 7.361$, $p < 0.001$) and conductivity ($F = 497.491$, $p < 0.001$) among systems. A simple concordance cluster analysis showed that species richness and community composition were also different between these two types of aquatic systems. In contrast to previous results found in central and southeastern Mexico, no correlation between species richness and morphometric parameters (area and shoreline development) were found. In the south-central region of the Yucatan Peninsula, the aquatic karstic systems are poorly known (physically, chemically and biologically). In fact, this is the first approach to understand the limnology and the relation between species richness and morphometric variables of the sinkholes from the region.

Key words: cenotes, freshwater, karst, aquatic biodiversity, limnology.

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Biodiversidad acuática en cenotes de la Península de Yucatán (Quintana Roo, México)

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Resumen

Los cuerpos de agua kársticos representan la característica limnológica más relevante en la península de Yucatán, México. Estos sistemas albergan especies endémicas y son la principal fuente regional epigea de agua dulce. En este trabajo se estudian la morfometría, las propiedades limnológicas básicas, así como el zooplancton y la fauna de peces en cinco sistemas acuáticos kársticos de la zona centro del estado de Quintana Roo, México (en el corazón de la zona maya). Se trató de establecer la relación entre la riqueza de especies y las propiedades morfométricas. En general se encontraron 79 especies, 64 corresponden a zooplancton y 15 a necton. Todos los sistemas estudiados son oligotróficos de alta transparencia con bajas concentraciones de nutrientes y clorofila a diferenciándose así de otros cuerpos de agua en el centro de México. Los dos sistemas kársticos estudiados fueron los cenotes y las aguadas. Ambos mostraron diferencias en las variables biológicas, físicas y químicas. Una prueba ANOVA unidireccional demostró diferencias significativas en nutrientes (nitratos, $F = 61.52$, $p < 0.001$; nitritos, $F = 7.361$, $p < 0.001$) y conductividad ($F = 497.491$, $p < 0.001$) entre los sistemas. Un análisis simple de concordancia de grupos mostró diferencias en riqueza de especies y composición de la comunidad entre los dos sistemas acuáticos. En contraste con resultados previos encontrados en el centro y sureste de México, no se encontró correlación entre riqueza de especies y parámetros morfométricos (desarrollo del área y litoral). Se conoce poco de los sistemas acuáticos kársticos de la región sur-centro de la Península de Yucatán (física, química y biológicamente). De hecho, este es el primer intento por estudiar la limnología y la relación riqueza de especies y variables morfométricas de los cenotes de la región.

Palabras clave: cenotes, agua dulce, karst, biodiversidad acuática, luminología

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Introduction

Karstic surfaces occupy 10% of the world land mass and contain up to 25% of the freshwater available for human use (White et al., 1995: 451; González & Hernández 1998: 57-58). Part of this amount is found in karstic aquatic systems known in the Yucatan Peninsula as "cenotes" and "aguadas", both formed by dissolution of Eocene limestone rocks (Hall 1936: 5; Gaona-Vizcaino et al.,1980: 32). This kind of systems harbour endemic taxa of fish and invertebrates (Suárez-Morales & Rivera-Arriaga 2000: 152).

The Mayan zone is located in the center region of the state of Quintana Roo, Mexico, it has a large number of aquatic karstic systems, many of them unknown and without any studies (Cervantes-Martínez, et al., 2002: 170). This zone is composed by the municipalities of Felipe Carrillo Puerto (including part of the Sian Ka' an, Biosphere Reserve) and the town of José María Morelos.

Most of the recent publications on Mexican karstic systems deal with taxonomy (Suárez-Morales et al., 1996: 296; Schmitter-Soto 1998: 238; Suárez-Morales & Rivera-Arriaga 2000: 151; Sarma & Elías-Gutiérrez 1999: 187; Elías-Gutiérrez & Suárez-Morales 2000: 64). Conversely, non-taxonomical aspects are scarce (Chumba-Segura & Medina-González 2000: 9). It is clear that any kind of integrative approach will allow general comparisons at the biological, and ecological levels of the karst hydrology in the region and it will generate limnological knowledge, which is still scarce in tropical latitudes.

So, the proposal of this work was to analyze the species richness of zooplankton and fishes from five cenotes located in the central zone of Quintana Roo, Mexico (Figure 1), to determine their possible relation to limnological and morphometric characteristics.

Methods

Five karstic systems (named Esperanza, Galeana, Donato, km 157 and Mini-cenote) were selected and sampled biweekly from February to May 2001 (dry season). The study area is located between 19° 28'-19° 45' N and 87° 53'-87° 59' W in the state of Quintana Roo, Mexico. According to Hall (1936: 5) Galeana (1), Esperanza (2), Km 157 (3), and Donato (4) are classified as type "aguada" and minicenote (5) as vase-shaped sinkhole.

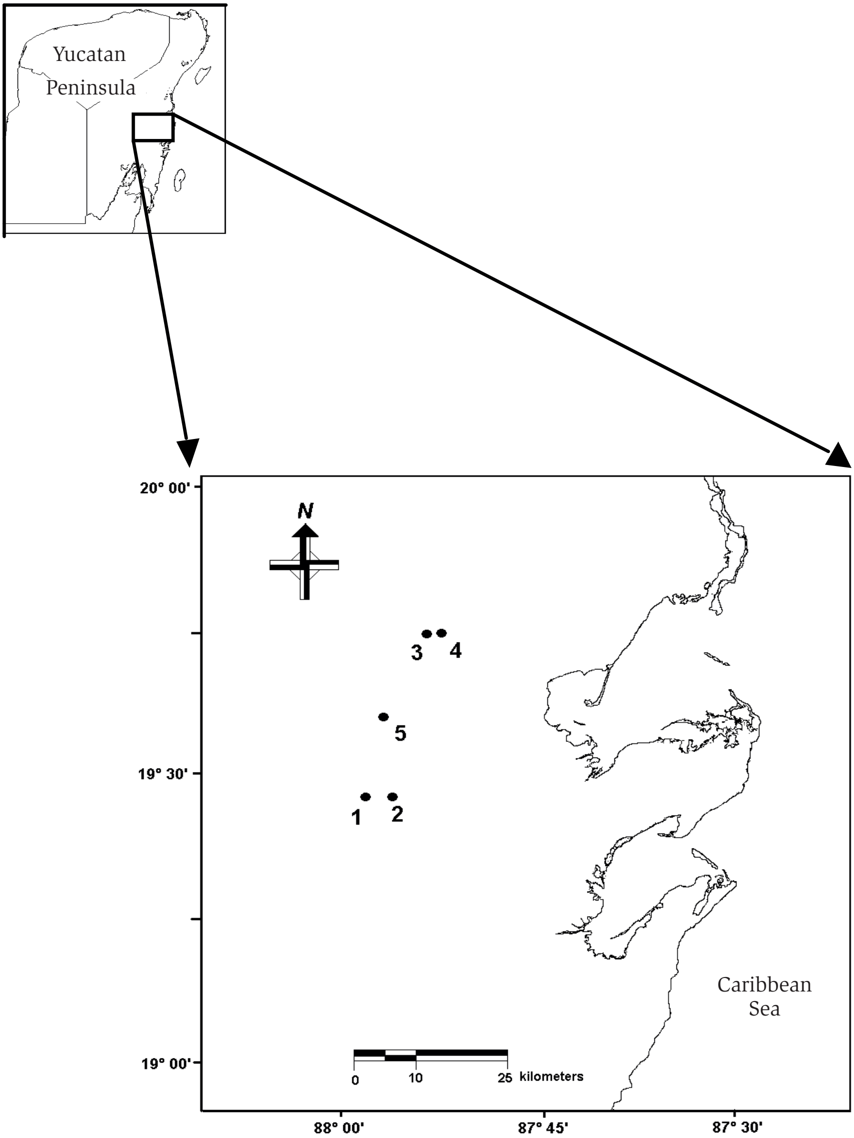

FIGURE 1. Location of the aquatic systems: 1) Galeana, 2) Esperanza, 3) km 157, 4) Donato and 5) Minicenote

Zooplankton samples were collected from both the limnetic and the littoral zones, with a filtering mesh of 50 µm. Samples were preserved in 4% sucred formalin, followed by species level identification at the laboratory. Hook-and-line gear, hand net, throw net, and visual records were used to collect and determine the fish fauna. A simple concordance cluster analysis was used to estimate the similitude in species richness and composition among systems (Legendre & Legendre, 1998: 853). The analysis was performed with the Statistical Package MVSP 3.21.

Physical and chemical parameters such as temperature (°C), conductivity (mS cm^{-1}), pH, and dissolved oxygen, (mg l^{-1}) were measured *in situ* at three layers (surface, middle, and bottom) along the water column using an Hydro lab Sonde Recorder™. Transparency was measured with a Secchi disk (Lind 1985: 199).

Chlorophyll *a* and nutrients (NO_3, NO_2 and PO_4^{3-}) were determined by spectrophotometry (A.P.H.A. 1990: 1193). Water samples were also taken at three layers (superficially, middle and bottom) at the deepest point of the water column; using a 2 l Van Dorn sampler. All (biological, physical, and chemical) samples were taken by triplicate. A single average value of physical and chemical variables was obtained for each system (Armengol & Miracle 1999: 2245).

Morphometric data of the water bodies such as depth (m), area (m^2), and shoreline development (D_L) were measured *in situ* and/or estimated using standard methods (Lind 1985: 199). Differences in nutrients concentration (nitrates, nitrites, phosphates), chlorophyll *a* concentration, and water conductivity among systems were tested through a one-way ANOVA analysis. Relations between species richness (α diversity) vs. system area, and vs. shoreline development (D_L) (all data was transformed to log) were estimated using Spearman rank correlations (r_s) (Legendre & Legendre, op. cit). All statistical analyses were performed with the Statistical Package MVSP 3.21.

Results

Seventy-nine taxa were recorded, 43 species were rotifers, 18 cladocerans, 2 copepods 1 ostracod, and 15 fish (Table 1). They belong to 11 orders, 28 families, and 45 genera. The number of species was different in each system:

49 in Galeana, followed by Minicenote (36), Donato (25), km 157 (15), and Esperanza (12). The general distribution of the species recorded here is as follows: most species recorded have cosmopolitan distribution (mainly rotifers), followed by circumtropical (cladocerans), neotropical (fish), and one endemic species (cladoceran) (see Table 1).

Table 1. Species registered in the cenotes of Quintana Roo. Dist= Distribution; St= Subtropical; C= Cosmopolitan; Tn= Tropicopolitan; T=Tropical; An= Antarctic; Ne-P= Nearctic-Palearctic region; N= North America; Ne-Tn= Nearctic-tropicopolitan; N-He= North-hemisphere; A-A= America-Africa; Ct= Circumtropical; Tr-C= Tropical-Caribbean; A= America; Ne= Neotropical; E= Endemic; ND= Not determined

Taxon	Dist	1	2	3	4	5
Phylum: Rotifera						
Clase: Monogononta						
Orden: Ploimida						
Familia: Brachionidae Harring, 1913						
Anuraeopsis fissa (Gosse, 1851)	St			+		
Brachionus falcatus Zacharias, 1898	C	+				+
B. havanaensis Rousselet, 1991	St	+				+
Keratella americana Carlin, 1943	C	+	+	+	+	
K. lenzi (Hauer, 1953)	St					+
Familia: Euchlanidae Ehrenberg, 1832						
Dipleuchlanis propatula (Gosse, 1886)	C			+		
Euclanis incisa Carlin, 1939	C	+				
Tripleuchlanis plicata (Levander, 1894)	C				+	
Familia: Mytilinidae Bory de St. Vincent, 1826						
Mytilina ventralis (Ehrenberg, 1838)	C	+				
Familia: Colurellidae Bory de St. Vincent, 1824						
Lepadella heterostyla Murray, 1913	ND	+				
L. quadricarinata (Stenroos, 1898)	ND			+		
L. latusinus (Hilgendorf, 1899)	ND	+				
L. patella (O. F. Muller, 1786)	C					+
L. triptera (Ehrenberg, 1830)	C					+
Familia: Lecanidae Nizsch, 1827						
Lecane aculeata (Jakubski, 1912)	C	+				

(continue)

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(Continue)

Taxon	Dist	1	2	3	4	5
L. arcula Harring, 1914	C		+	+		+
L. bulla (Gosse, 1851)	C	+	+	+	+	+
L. closterocerca (Schmarda, 1859)	C	+				+
L. cornuta (O. F. Muller, 1786)	C	+	+	+		+
L. crepida Harring, 1914	Tn		+		+	+
L. furcata (Murray, 1913)	C	+			+	+
L. hamata (Stokes, 1896)	C		+	+	+	
L. hornemanni (Ehrenberg, 1834)	C	+	+	+	+	+
L. leontina (Turner, 1892)	T	+	+			+
L. luna (O. F. Muller, 1776)	C	+				
L. lunaris (Ehrenberg, 1836)	C			+		+
L. monostyla (Daday, 1897)	St	+				
L. obtusa (Murray, 1913)	C		+		+	+
L. pyriformis (Daday, 1905)	C			+		
Familia: Proalidae Harring & Myers, 1924						
Prolaes dicipiens (Ehrenberg, 1831)	C	+				
Familia: Notommatidae Remane, 1933						
Eothinia carogaensis Myers, 1937	ND					+
Notomata pachyura (Gosse, 1886)	C	+		+		
Familia: Scaridiidae						
Scaridium botsjani Dames & Dumont, 1974	A					+
Familia Trichocercidae Lamarck, 1801						
Trichocerca capucina (Wierzejski, & Zacharias, 1853)	C	+				
T. iernis (Gosse, 1887)	C					+
T. weberi (Jennings, 1903)	C					+
Familia: Synchaetidae Ehrenberg, 1832						
Polyarthra cf. *dolichoptera* Idelson, 1925	C			+		
Familia: Dicranophoridae Nitzsch, 1827						
Dicranophorus prionacis Harring & Myers, 1928	Ne-P					+
Orden: Flosculariaceae						

(continue)

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(Continue)

Taxon	Dist	1	2	3	4	5
Familia: Testudinellidae Bory de St. Vincent, 1826						
Testudinella patina (Hermann, 1783)	C		+			+
Familia: Flosculariidae						
Ptygura furcillata (Kellicott, 1889)	N	+				+
P. libera (Myers, 1934)	Ne-Tn		+		+	
Familia Hexarthridae Schmarda, 1854						
Hexarhtra intermedia Wiszniewski, 1929	St				+	
Subclase: Bdelloidea						
Familia: Philodinidae Ehrenberg, 1830						
Dissotrocha aculeata (Ehrenberg, 1832)	ND	+		+	+	+
Superclase: Crustacea						
Clase: Branchiopoda						
Superorden: Cladocera						
Orden: Anomopda						
Familia: Daphnidade						
Ceriodaphnia dubia Richard, 1894	C	+				
Simocephalus mixtus Sars, 1903	N-He	+				
S. serrulatus (Koch, 1841)	C				+	
Familia: Bosminidae Sars, 1865						
Eubosmia (*Neobosmina*) *tubicen* Brehm 1953	A-A	+		+	+	+
Familia: Ilyocryptidae Smirnov, 1992						
Ilyocryptus spinifer Herrik, 1882	C	+	+		+	
Familia: Macrothricidae Norman & Brady, 1867						
Macrothrix cf. *flabelligera* Sminorv, 1992	Ct	+		+	+	+
Familia: Chydoridae Stebbing, 1902						
Alonella cf. *excisa* Fischer 1854	ND	+				
Chydorus sp.	ND	+		+		+
Ch. cf. *kallipigos* Brehm 1934	ND	+				
Ch. eurynotus Sars, 1901	Ct		+			
Ephemerophorus hybridus Daday, 1905	A	+				
Dunhevedia odontoplax (Sars, 1901)	Ne	+				

(continue)

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(Continue)

Taxon	Dist	1	2	3	4	5
Alona cf. *ossiani* Sinnev, 1998	ND	+	+	+		
A. cf. *verrucosa* Sars, 1901	ND	+	+			+
A. pectinata Elías-Gutiérrez & Suárez-Morales, 1999	E	+	+			
A. cf. *karua* (King, 1853)	ND	+				
Camptocercus cf. *dadayi* (Stingelin, 1913)	Ne	+				
Graptoleberis occidentalis Sars, 1901	Ne	+				
Ostracoda						
Cypridopsis sp.	C	+				+
Subclase: Copepoda						
Infraclase: Neocopepoda						
Superorden: Gymnoplea						
Orden: Calanoida*						
Familia: Diaptomidae G. O. Sars, 1903						
Subfamilia: Diaptominae Kiefer, 1932						
Mastigodiaptomus nesus Bowman, 1986	Ne	+	+	+	+	+
Superorden: Podoplea						
Orden: Cyclopoida						
Familia: Cyclopidae G. O. Sars, 1913						
Subfamilia: Eucyclopinae Kiefer, 1927						
Thermocyclops inversus Kiefer, 1936	Tr-C	+	+	+	+	+
Chordata						
Astyanax aeneus (Günther, 1860)	Ne	+		+	+	
Rhamdia guatemalensis (Günther, 1864)	Ne			+	+	
Belonesox belizanus Kner, 1860	Ne				+	
Gambusia sexradiata Hubbs, 1936	Ne	+	+	+	+	
G. yucatana Regan 1914	Ne	+				+
Poecilia mexicana Steindachner, 1863	Ne	+	+	+		+
P._orri Fowler, 1943	Ne					+
"*Cichlasoma*" *friedrichsthali* (Heckel, 1840)	Ne		+		+	
"*C.*" *salvini* (Günther, 1862)	Ne	+				+
"*C.*" *synspilum* (Hubss, 1935)	Ne	+		+	+	

(continue)

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Taxon	Dist	1	2	3	4	5
"*C.*"_*urophthalmus* (Günther, 1862)	Ne	+	+	+		
Petenia splendida Günther, 1862	Ne	+		+	+	+
Thorichthys affinis (Günther, 1862)	Ne			+		
T._meeki (Brind, 1918)	Ne	+			+	+
Gobiomorus dormitor (Lacepéde, 1800)	Ne		+			

Esperanza, Donato, and km 157 are the most similar systems in terms of species richness/systems; Minicenote is separated from this first cluster (vase-shaped), as well as Galeana an "aguada" type with the higher species richness (Figure 2).

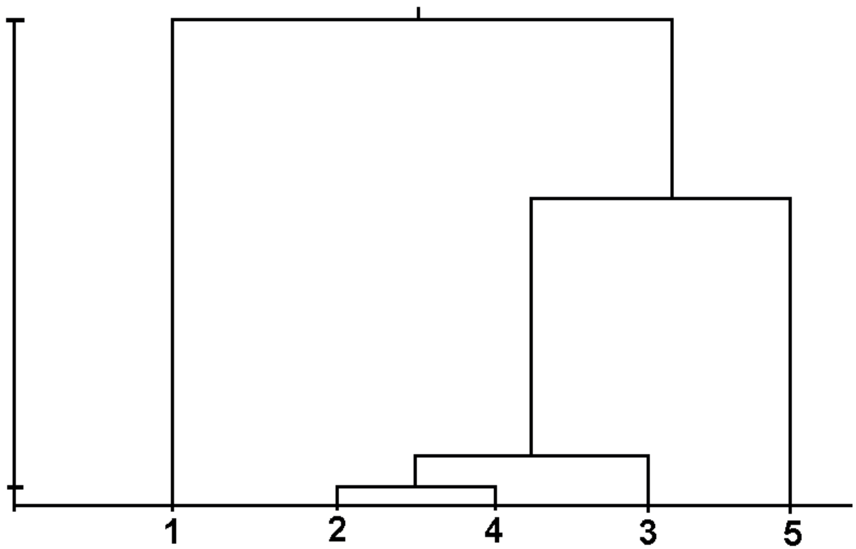

FIGURE 2. Simple concordance analysis (medium linkage clustering). 1) Galeana, 2) Esperanza, 3) km 157, 4) Donato, and 5) Minicenote.

We found no statistical correlation between species richness and system area (r_s = -0.07, p>0.05, n= 5), or with shoreline development (r_s = 0.2143, p0.05, n= 5).

Minicenote was the deepest system and Galeana the shallowest. The major area and shoreline development was observed in Donato, and the lowest was found in Minicenote (see Table 2). Shoreline values show that all surveyed systems are almost circular (Table 2).

Table 2. Morphometric and geographic data of cenotes

Site	Depth (m)	Area (m^2)	Shoreline development (D_L)	Latitude N	Longitude W
1. Galeana	9.5	5375	1.04	19° 28´ 07´´	87° 01´ 46´´
2. Esperanza	14	12450	0.99	19° 29´ 09´´	87° 59´ 19´´
3. Km 157	16	10925	1.01	19° 45´ 38´´	87° 54´ 15´´
4. Donato	17	28895	1.28	19° 46´ 36´´	87° 53´ 55´´
5. Minicenote	40	264	0.98	19° 36´ 23´´	87° 59´ 18´´

Secchi transparency fluctuated between 1.7 m (Galeana) and 7.5 m (Esperanza) (Table 3). Mean water temperature was 27° C (Table 3) with a maximum of 32.8°C (Galeana) and a minimum of 23.4°C (km 157).

Conductivity varied between 0.8 and 2.0 mS cm^{-1}. In average, Minicenote displayed the highest values of conductivity; the lowest occurred in Galeana, Donato, and km 157. The pH values ranged between 6.4 and 13.0, all systems were considered alkaline type (Table 3). The maximum value of dissolved oxygen was found in Minicenote (15.3 mg l^{-1}), and the minimum in km 157 at the bottom (1.3 mg l^{-1}). In average, Esperanza showed the highest values (Table 3).

In general, nitrate, nitrite, and orthophosphate measurements were low, except the nitrate in Minicenote (Table. 3). A one-way ANOVA test showed significative differences in nitrates (F = 61.52, p<0.001), and nitrites concentration (F= 7.361, p<0.001) among systems. A Tukey test allowed to confirm that Minicenote (the vase-shaped system) had the highest nitrates and nitrites values.

Orthophosphates concentrations had similar values to all the systems ($F = 1.64$, $p > 0.05$), and relative low when compared to the other nutrients values. The major value of chlorophyll *a* was recorded in Minicenote (maximum value = 0.43 mg m^{-3}), and the minimum in Donato (0.01 mg m^{-3}). In average, Minicenote presented the highest values, followed by Galeana, km 157, Esperanza, and Donato (Table 3).

Table 3. Values of environmental parameters of five systems. 1= Galeana, 2= Esperanza, 3= km 157, 4= Donato, and 5= Minicenote

	Transparency (m)	Water temperature (°C)	Dissolved Oxygen (mg l^{-1})	pH	Conductivity (mS cm^{-1})	$N0_3^-$ (µM)	**NO_2^-** (µM)	**PO_4^{3-}** (µM)	Chl-a (mg m^{-3})
1	2.2 ± 0.3	27.3 ± 2.7	7.3 ± 2.7	9.0 ± 1.0	0.8 ± 0.0	4.3 ± 4.2	0.12 ± 0.05	0.007 ± 0.006	0.31 ± 0.12
2	6.5 ± 0.8	27.6 ± 1.3	9.7 ± 1.4	8.9 ± 0.6	1.5 ± 0.1	6.5 ± 4.4	0.12 ± 0.05	0.008 ± 0.017	0.04 ± 0.02
3	2.7 ± 0.5	25.9 ± 2.5	5.5 ± 2.8	9.6 ± 1.2	0.9 ± 0.0	3.7 ± 3.5	0.11 ± 0.06	0.006 ± 0.007	0.16 ± 0.07
4	5.4 ± 0.7	27.5 ± 2.0	7.4 ± 2.4	9.3 ± 0.7	0.8 ± 0.0	3.8 ± 2.8	0.08 ± 0.05	0.008 ± 0.019	0.03 ± 0.03
5	6.4 ± 1.5	25.5 ± 2.5	6.2 ± 2.7	8.4 ± 1.1	1.7 ± 0.4	27 ± 13	0.15 ± 0.11	0.005 ± 0.006	0.32 ± 0.10

Water temperature was homogeneous along the water column of Esperanza and Minicenote (Figure 3), whereas stratification occurred in Galeana, km 157, and Donato.

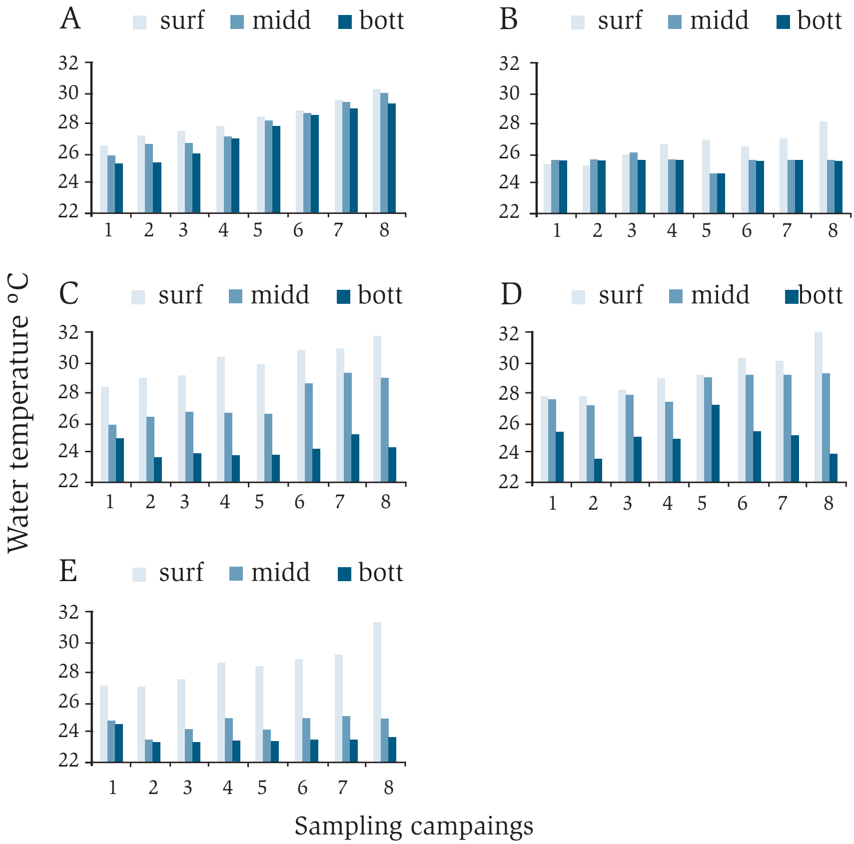

Figure 3. Vertical profile of temperature (surf=surface, midd=middle, and bott=bottom): A) Esperanza, B) Minicenote, C) Galeana, D) Donato, E) km 157. The number represents the sampling campaings

Discussion

Three aguada-type systems (Esperanza, Donato, and km 157) had similar species richness. The fourth (Galeana) was the richest system and Minicenote was different from the rest. The number of zooplankton species found in this study (17-38 species) is similar to that recorded in dams and lagoons from the central part of Mexico (Elías-Gutiérrez et al., 1997: 68) even though it is a much smaller lake compared to the aquatic systems from the center of the country (e.g. Díaz-Pardo et al. 1991: 70; Flores-Tena & Silva-Briano, 1995: 238; Dodson & Silva-Briano 1996: 168). A direct correlation between zooplankton species richness and system area or littoral development, has been reported in lakes and ponds from central and southeastern Mexico (Dodson & Silva-Briano 1996: 170; Gutiérrez-Aguirre & Suárez-Morales 2001: 662). This correlation was not observed in the karstic systems surveyed here. Conversely, the smaller systems had more species. Probably, other factors such as the maturity and eutrophy level of the systems (Contreras-Espinosa et al., 1994: 62), the effect of predation (Mazumder & Havens 1998: 1658) or refuge availability in submersed vegetation are more important to determine the species richness in these water bodies.

On the other hand, these isolated systems can become highly diversified with some possible endemic species (Fiers et al., 1996: 72; Elías-Gutiérrez & Suárez-Morales 1999: 109). The high species richness in zooplankton and fish in Galeana, in comparison with the other systems evaluated here is interesting and shows the great biodiversity that these systems contain. The composition and distribution of the different aquatic taxa surveyed here can be the result of dispersion processes related to the peninsular geological history (Suárez-Morales, 2003).

Most rotifer species found here are considered as cosmopolitan (see Table 1). In cladocerans, an important number of the total are restricted to the tropics (39%); only two species are confirmed as cosmopolitans, and a third one is an endemism (Elías-Gutiérrez & Suárez-Morales 1999: 107). Finally, fish species recorded in these systems are considered as neotropical, with previous records in the Mexican Southeast, Guatemala, Belize, and Costa Rica (Schmitter-Soto 1998: 296) (see Table 1). These results confirm the rich fauna dwelling in the surveyed cenotes, and the need to conduct more faunistic studies.

Temperatures recorded here are typical of tropical systems; however, a slight thermic stratification was found in three of them (Galeana, Donato, and km 157). In Esperanza and Minicenote no thermal differences were found among layers; both were the systems with higher Secchi values. Apparently, transparency plays an important role in determining the thermic nature of the water column: in karst systems suspended matter prevents free light penetration to the bottom, thus favoring the formation of water strata (Navarro-Mendoza 1987: 167; Mazumder & Havens 1998: 1558, Lampert & Sommer, 2007: 223). On the other hand, Esperanza has scarce peripheral vegetation; this condition allows a greater water-air exchange, allowing a permanent water mixing (Torres-Orozco & García-Calderón 1995: 130; Díaz-Arce et al., 2000: 2).

According to the area values, all studied systems can be considered as small (less than one km^2). D_L values suggest a regular shoreline, typical in volcanic and dissolution lakes (Arredondo et al., 1983: 42; Torres-Orozco & Garcia-Calderón 1995: 66). The depth of the systems surveyed is similar to other Mexican volcanic lakes (Arredondo et al., 1983: 42), and other dissolution lakes (Armengol & Miracle 1999: 2253).

In addition to physical differences (in the area, D_L, and depth), it was possible to observe differences in conductivity and nutrients between the vase-shape and aguada-shape. Vase-shape cenote is smaller in area, irregular, deep, and with major conductivity and nutrients than the "aguada" type.

The higher conductivity value found in Minicenote (see Table 3), in comparison with the rest of the systems ($F = 497.49$, $p < 0.001$) is probably related to a greater dissolution of rock, since this cenote is vase-shaped, and pores or fracture in the walls are not sealed, allowing a major dissolution of the calcareous wall. This would also favor also a greater input of ground water and minerals into the system (Flores-Nava et al. 1989: 227; Díaz-Arce et al. 2000: 3). In addition, Navarro-Mendoza (1987: 161) suggested that depth can be another factor related to high conductivity in karst systems, because the ground water currents in contact with them allows the input of ions already dissolved.

Conductivity values (from 0.8 to 1.7 mS cm^{-1}) suggest the presence of dissolved carbon dioxide (CO_2) and bicarbonates (HCO^{3+}) into the water (Lampert & Sommer, 2007: 34), which is characteristic of the freshwater systems from Yucatan Peninsula (Alcocer & Escobar 1996: 62). The basic pH values were present in all systems, which is expected, according to the karstic nature of the systems studied (Alcocer & Escobar 1996: 65).

Except for Minicenote, all the systems showed the same range of nutrient concentrations. Values found there was lower than in lagoons or dams from in the central region of Mexico (Tavera & Castillo 2000: 107), but similar to that found in other karstic systems from the Yucatan Peninsula (Herrera-Silveira et al., 1998: 1349). The higher nitrates and nitrites concentrations in Minicenote could be related to its vase-shaped and small area, with a smaller trophogenic zone, compared to the volume of the system, so the intake of nutrients by phytoplankton could be limited. According to Contreras et al. (1994: 61) all values of chlorophyll obtained in these cenotes are characteristic of oligotrophic systems. Therefore, the relative low Secchi transparency (mainly in Galeana) was not related to chlorophyll *a*, but to other organic and inorganic suspended materials such as solids or even mineral precipitation that could reduce its values (Armengol & Miracle 1999: 2257).

Contrary to other published works, this result suggests that each of these systems is unique with their characteristics, even when they are close to each other. A general approach on their species richness and limnology should take into this account this wide range of variability.

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