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Limnological and morphometrical data of eight karstic systems 'cenotes' of the Yucatan Peninsula, Mexico, during the dry season (February–May, 2001)

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Abstract

The karstic nature of the Yucatan Peninsula allows the formation of natural sink-holes from the dissolution of calcareous rock. These systems are almost the only epigean source of fresh water available in this region. In spite of their biological importance, little is known about the morphometric and limnologic characteristics of these karstic systems. We measured limnological variables in eight cenotes in central Quintana Roo during February–May, 2001. Zooplankton biomass and chlorophyll *a* were also measured in order to determine if the behavior of primary and secondary production was related to environmental parameters. Important short-term changes were observed in nutrients (NO_3^-, NO_2^-, PO_4^{3-}), biomass, and chlorophyll *a*. The morphometrically conditioned productivity (MCP), which evaluates the cumulative effect of several morphometric variables on production (area, maximum length, shoreline development, perimeter), showed a negative correlation with respect to zooplankton biomass, as did also both pH and temperature. Conversely, NO_3^- and NO_2^- had a positive correlation with zooplankton biomass. No correlation was found for chlorophyll *a*. Significant differences in NO_3^- ($F = 61.52$, $p < 0.001$), NO_2^- ($F = 7.36$, $p < 0.001$), zooplankton biomass ($F = 17.57$, $p < 0.001$), chlorophyll *a* ($F = 62.19$, $p < 0.001$), and conductivity ($F = 497.49$, $p < 0.001$) were found among the systems. These results indicate the existence of sharp differences between these karstic systems (oligotrophic, with smaller area, deep and less productive) and non-karstic ones, (eutrophic, larger area, shallow and more productive) but are similar to previous data from other karstic systems of Mexico and other parts of the world. However, understanding of these fragile tropical systems is in the initial phase. It is necessary to increase the intensity of these studies in order to allow a full explanation of their limnological behavior.

Introduction

The Yucatan Peninsula is part of the Mexican southeast region, which receives more than 50% of the total rain water volume of Mexico (Alcocer & Escobar, 1996). Geologically, this plain was recently formed, during the Miocene-Pleistocene and it is constituted by limestone, mainly $CaCO_3$ and dolomite (Weidie, 1974; Gaona-Vizcayno et al., 1980). Dissolution of these carbonated rocks forms underground (caves) or epigean systems (sinkholes and shallow water deposits). The epigean, exposed water systems are locally termed 'cenotes' and 'aguadas', and they are the main source of fresh water in this region (White et al., 1995). However, little is known about the environmental conditions that determine the characteristics of these freshwater bodies.

In spite of the interesting hydrogeology of the Yucatan Peninsula, only a few limnological studies have been done (Flores-Nava et al., 1989; Herrera-Silveira et al., 1998; Díaz-Arce et al., 2000); some others deal with groundwater flows and pollution (Stringfield & Legrand 1974; Maryn & Perry, 1994; Birgit et al., 1996; Herrera-Silveira & Comín, 2000). Schmitter-

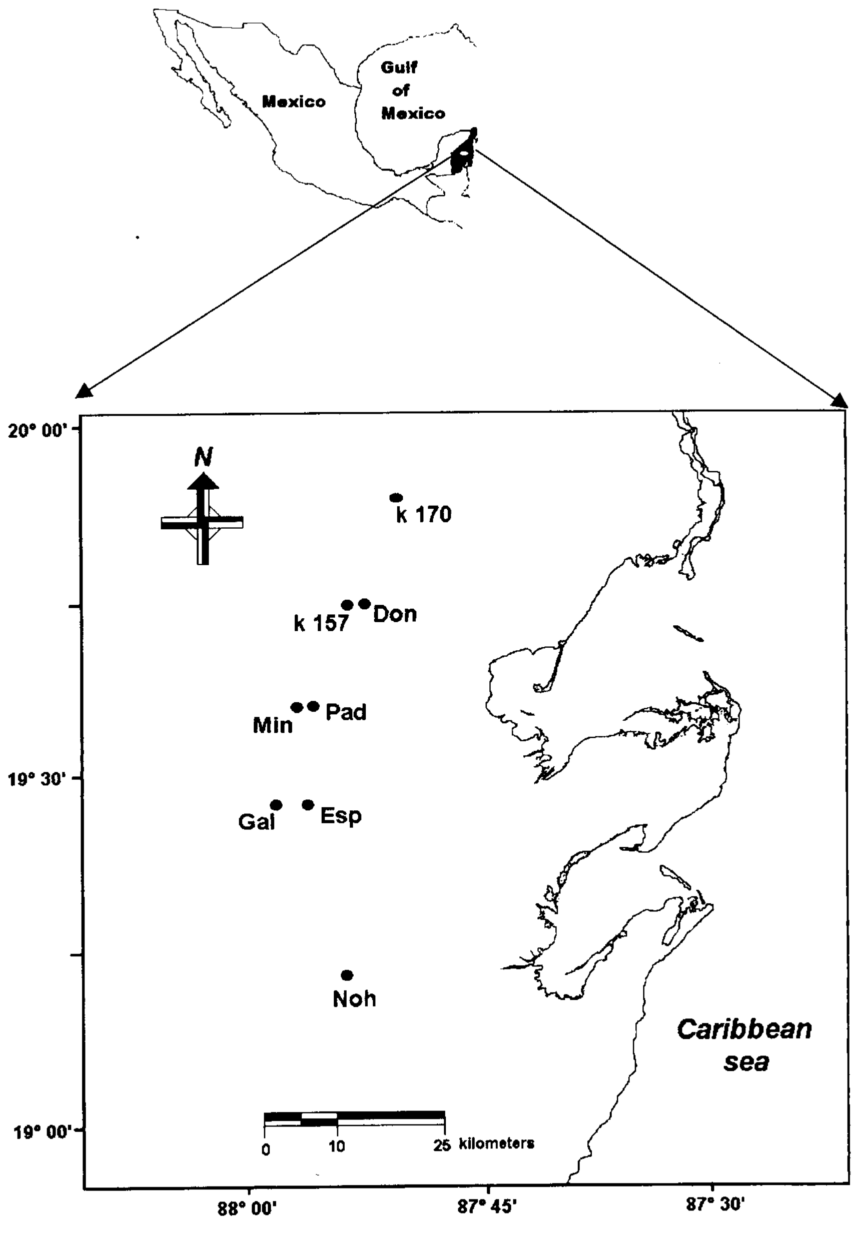

Figure 1. Locations of the eight karstic systems studied in central Quintana Roo, Mexico. Esperanza (Esp), Galeana (Gal), km 170 (k 170), Donato (Don), km 157 (k 157), Minicenote (Min), Padre (Pad) and Noh ts' onot (Noh).

Soto et al. (2002) provided an overview of the general limnology of these systems, and summarized most of the existing information. They concluded that knowledge on them is still scarce and fragmentary. The aim of the present work was to generate information on the basic limnology and morphometry of eight karstic systems in central Quintana Roo, one of the three Mexican states in the Yucatan Peninsula. This information was analyzed to determine which variables (physical, chemical, or morphometric), are likely to influence the general productivity of these peculiar systems.

Methods

Seven karstic systems (Esperanza, Galeana, km 170, Donato, km 157, Minicenote, and El Padre) were sampled biweekly from mid-February to May, 2001 (dry season, according to Schmitter-Soto et al., 2002).

Table 1. Morphometric parameters in eight cenotes of the Yucatan Peninsula. Maximum depth (z_m), mean depth (z), maximum length (l), maximum width (b), area (A), shoreline (L), development of shoreline (D_L), volume (V), development of volume (D_V). Esperanza (Esp), Galeana (Gal), km 170 (k 170), Donato (Don), km 157 (k 157), Minicenote (Min), Padre (Pad) and Noh ts' onot (Noh)

Site	z_m (m)	z (m)	l (m)	b (m)	A (m^2)	L (m)	D_L	V (m^3)	D_V
Esp	14	10.39	142.5	143.7	12450	394.25	0.99	129393.7	2.22
Gal	9.5	3.31	93	78.4	5375	270.3	1.04	17823.7	1.04
k 170	11.5	8.42	22.5	17.6	306	63.77	1.02	2579.5	2.19
Don	17	4.43	305	133.0	28895	775.5	1.28	128004.4	.78
k 157	16	9.45	123	120.0	10925	377.7	1.01	103325.0	1.77
Min	47	16.73	18.5	15.6	264	54.8	0.98	4419.8	1.06
Pad	15	8.77	111.5	108.4	9100	339.8	1.0	79856.3	1.75
Noh	19	3.07	194.0	180.0	25968	610.4	1.06	233046.9	0.48

An additional system (Noh ts' onot) was visited three times (June 1999, April and May, 2001). All systems are located between 19° 15′–19° 50′ N and 87° 45′–87° 59′ W in Quintana Roo State, Mexico (Fig. 1). They were selected on the basis of a lack of previous studies and accessibility.

Zooplankton samples were collected by duplicate oblique tows at the deepest part of each system, using a conical plankton net with a mesh of 50 μm in all systems. The volume of water filtered by the net (5–10 m^3) was calculated with an Hydro-Bios flowmeter attached to the mouth of the net. Samples were kept on ice. Wet weight was obtained with an analytic weight scale A & D Model ER120 (±0.0001 g). Samples were then fixed and preserved in 4% formalin.

Physical and chemical parameters, such as depth, temperature, conductivity, pH, and dissolved oxygen were determined *in situ* at three depths (surface, middle depth, and bottom) in the center of each system, using a Hydrolab Sonde Recorder. Water transparency was measured with a Secchi disk. In thermally stratified systems, a vertical profile was obtained, at one-meter intervals from surface to bottom.

Chlorophyll *a* and nutrients (NO_3^-, NO_2^- and PO_4^{3-}) were measured by spectrophotometry (A.P.H.A., 1989) at the three layers. All samples were taken in triplicate. Following Armengol & Miracle (1999), a mean value for each variable was obtained for each system

Aerial photographs were taken *in situ* with a radio-controlled aircraft in order to obtain the perimetral profile of each system. The approximate scale of photographs varied from 1:30 to 1:100. Bottom sounding was performed with a portable echosonde Umminbird® across 6 to 12 parallel transects, according to the size of the system. This information was used to develop bathymetric maps.

Morphometric data such as perimeter (L), maximum length (l), maximum width (b), area (A), and shoreline development (D_L), maximum depth (z_m), mean depth (z), volume (V), and volume development (D_V) were estimated for each system using standard methods (Lind, 1985).

The morphometrically-conditioned production (MCP) is the potential production that any lake can develop based only upon its morphometric characteristics. Calculation of the MCP assumes that some morphometric parameters such as l, L, D_L, A and D_V, are directly related to productivity, whereas others, such as V and z, are inversely correlated with productivity (Alcocer & Escobar, 1993).

Differences among systems in terms of nutrient concentration (nitrates, nitrites, phosphate), chlorophyll *a*, and zooplankton biomass were tested with a one-way ANOVA. Tukey's test was performed in order to determine which system was different from the others. The relationship between nutrients, chemical, physical, morphometric features, and MCP data vs. biomass of zooplankton and chlorophyll *a* (all in log-transformed means) were estimated by the Spearman rank correlation (r_s) in order to determine which variable was related to zooplankton biomass and chorophyll *a*. Noh ts' onot was excluded from this statistical analysis.

Results

Morphometric data

Bathymetric maps of all the systems are shown in Figure 2. Minicenote was the deepest and Galeana the

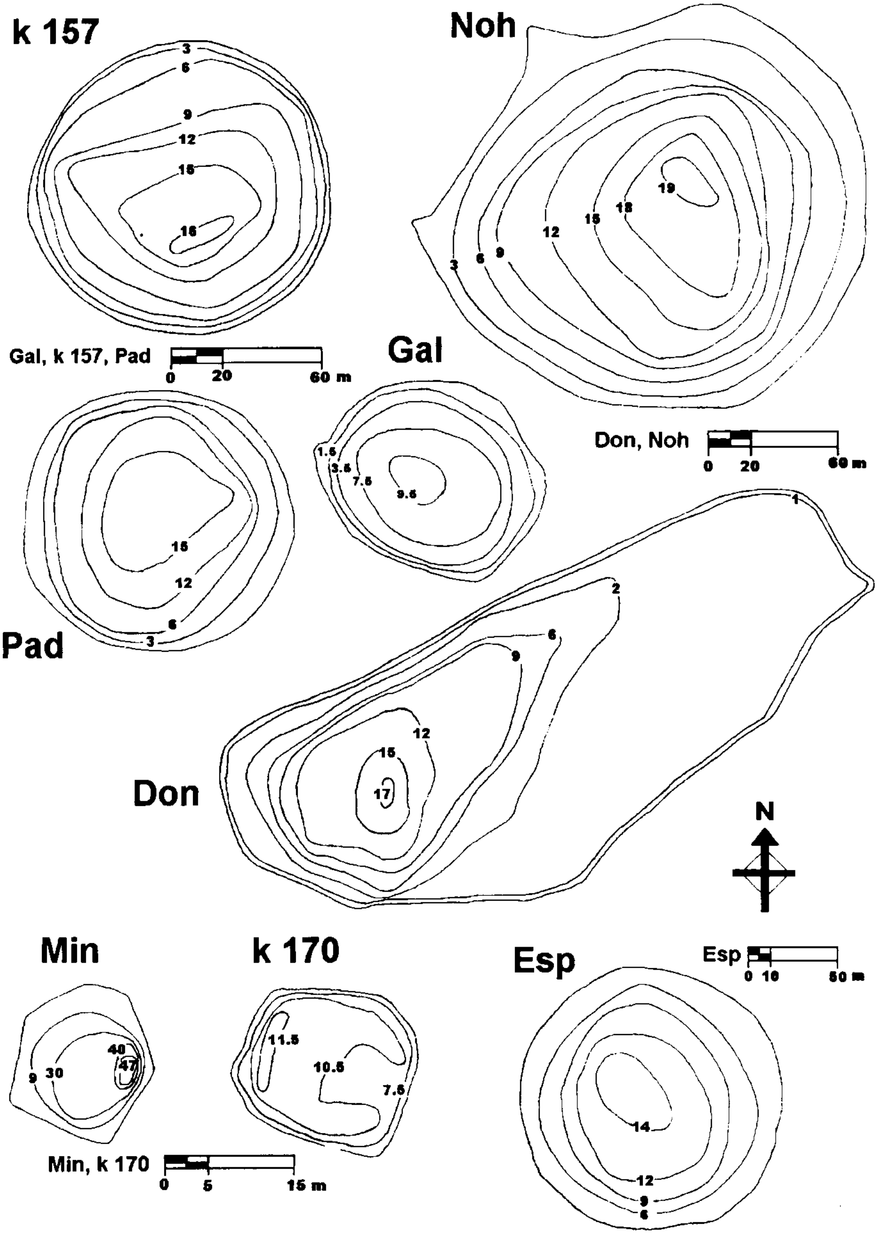

Figure 2. Bathymetric charts of the systems studied. Abbreviations as in Figure 1.

shallowest. Donato had the largest area, perimeter, maximum length, and shoreline development. Minicenote presented the lowest values of these morphometric data (see Table 1). Noh ts' onot had the highest volume; and km 170 the lowest. Noh ts' onot was also the widest system, followed by Donato. Lowest width values were found in Minicenote, km 170, Galeana, El Padre, and Esperanza. The highest volume development was found in Esperanza, the lowest in Galeana (Table 1). All the systems are nearly circular, except for the irregularly-shaped Donato and Galeana (see Figure 2).

Physical and chemical data: Overall mean water temperature was 27 °C, with a maximum of 32.8 °C at the surface (Galeana) and a minimum of 22.2 °C at the bottom (Noh ts' onot) (Table 2). In Esperanza, km 170, and Minicenote, water temperature was homogeneous along the water column, whereas a vertical thermal

Table 2. Means and standard deviations of environmental parameters of eight karstic systems (abbreviations as in Table 1). Transparency (Secchi), Water Temperature (Temp), Dissolved Oxygen (O_2), Conductivity (Cond), Nitrates (NO_3^-), Nitrites (NO_2^-), Orthophosphates (PO_4^{3-}), and Chlorophyll *a* (Chl-*a*)

	Secchi (m)	Temp (°C)	O_2 (mg l^{-1})	PH	Cond (mS cm^{-1})	NO_3^- (μM)	NO_2^- (μM)	PO_4^{3-} (μM)	Chl-*a* (mg m^{-3})
Esp	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
Gal	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
k 170	9.7 ± 0.8	24.7 ± 0.3	3.2 ± 1.4	8.3 ± 0.9	0.8 ± 0.0	4.9 ± 3.7	0.11 ± 0.06	0.006 ± 0.008	0.17 ± 0.08
Don	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
k 157	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
Min	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
Pad	1.5 ± 0.4	25.5 ± 2.5	4.4 ± 3.7	9.5 ± 1.2	1.2 ± 0.1	5.3 ± 5.11	0.15 ± 0.08	0.011 ± 0.020	0.52 ± 0.16
Noh	3.0 ± 0.1	24.5 ± 3.2	4.6 ± 2.7	10.2 ± 0.2	3.7 ± 0.2	1.6 ± 0.8	0.05 ± 0.05	0.008 ± 0.011	0.44 ± 0.08

Table 3. Correlation coefficients (r_s) among the mean values chemical, physical, and biological parameters in cenotes of Quintana Roo, Mexico. Values marked with an asterisk and double asterisk were statistically significant ($p \leq 0.05$; $p \leq 0.01$). Zooplankton biomass (Bio) and Morphometrically-conditioned productivity (MCP). Abbreviations as in Tables 1 and 2

	Chl-*a*	Bio	Secchi	z_m	Temp	pH	Cond	O_2	NO_3^-	NO_2^-	MCP	A
Chl-*a*	1											
Bio	0.23	1										
Secchi	−0.47	0.45	1									
z_m	0.40	0.09	−0.04	1								
Temp	−0.14	−0.91**	−0.71*	−0.21	1							
PH	0.23	−0.78*	−0.69	0.35	0.71*	1						
Cond	0.30	−0.02	−0.02	0.76*	−0.14	0.40	1					
O_2	−0.19	−0.02	−0.23	−0.14	0.14	0.00	0.23	1				
NO_3^-	0.30	0.80*	0.00	0.11	−0.42	−0.54	0.07	0.45	1			
NO_2^-	0.14	0.78*	0.23	0.30	−0.66	−0.52	0.11	0.33	0.85*	1		
MCP	−0.45	−0.85*	−0.10	−0.15	0.53	0.56	0.23	0.26	−0.71*	−0.69	1	
A	−0.48	−0.83*	−0.11	0.00	0.42	0.64	0.33	0.28	− 0.69	−0.54	0.95*	1

stratification was observed in Galeana, Donato, km 157, El Padre, and Noh ts' onot (Fig. 3). Stratification was slight in Galeana and Donato (Fig. 4A, C), and stronger in km 157 (Fig. 4B), El Padre and Noh ts' onot (Fig. 5A, B). The remaining three systems (Esperanza, km 170, and Minicenote) were permanently mixed during this study.

Secchi disk depth was between 1.0 m (Galeana) and 7.5 m (Esperanza). Conductivity varied between 0.8 and 3.9 mS cm^{-1}; on average, Noh ts'onot displayed the highest values, km 157 the lowest (Table 2). A positive significant correlation was found between conductivity and depth (Table 3). The maximum (13) and minimum (6.7) pH values were recorded in Galeana and Minicenote respectively; on average, the values ranged between 8.3 and 10.2 (Table 2).

The maximum value of dissolved oxygen was found in La Esperanza at the surface (13.1 mg l^{-1}), and the minimum at the bottom of El Padre (0.8 mg l^{-1}). On average, La Esperanza showed the highest values (Table 2). An oxycline was detected in El Padre (Fig. 5A) and Noh ts'onot (Fig. 5B) during the sampling period. Changes affecting the oxycline and thermal stratification are also represented in this latter figure. In addition, El Padre showed the maximum values of dissolved oxygen, and a much lower Secchi depth (Fig. 5A).

In general, nitrate, nitrite, and orthophosphate concentrations were low, except in Minicenote (Table 2, Fig. 6A). The one-way ANOVA test showed significant differences in concentrations of nitrates ($F = 61.52$, $p < 0.05$) and nitrites ($F = 7.36$, $p < 0.05$)

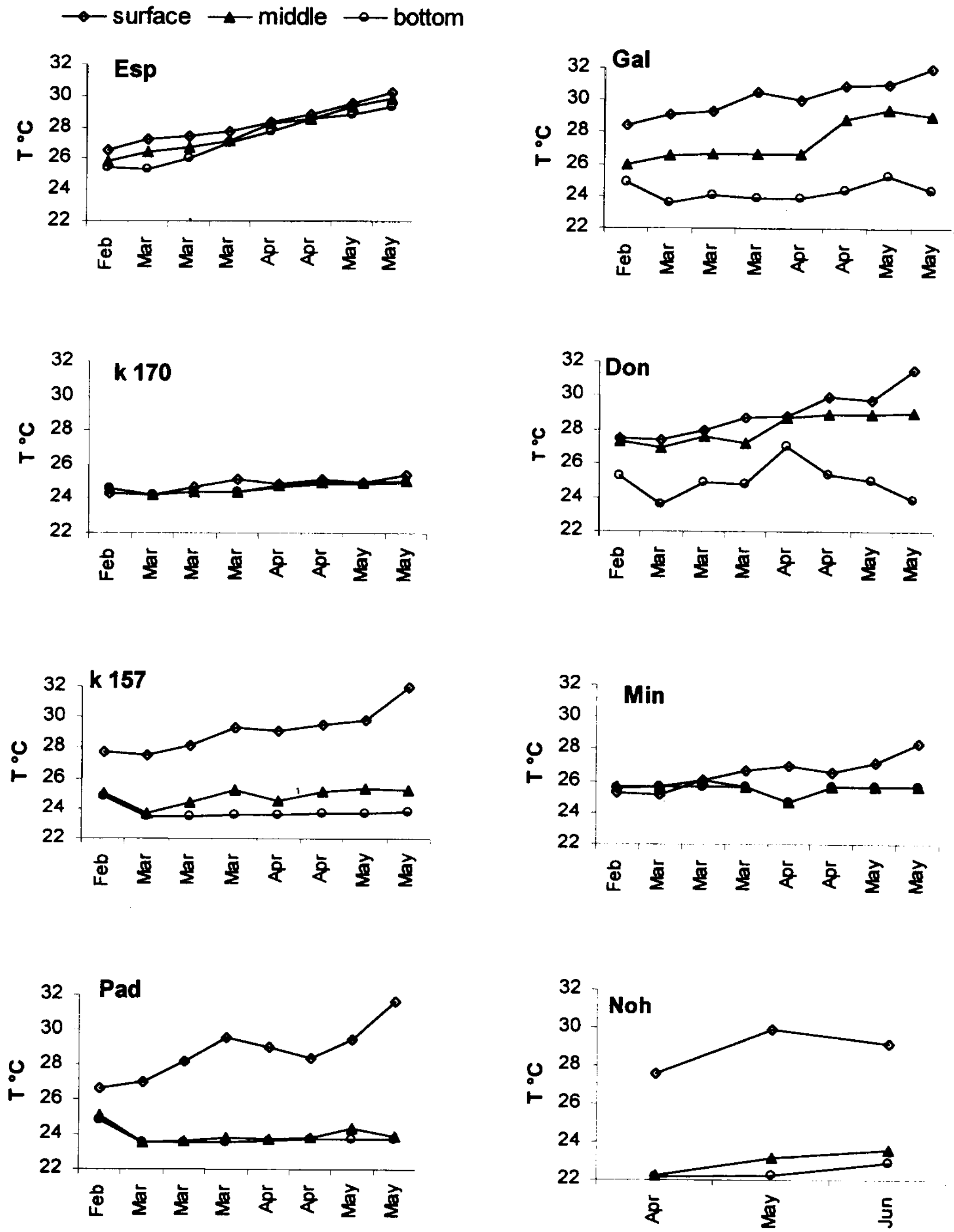

Figure 3. Vertical temperature profiles (surface, middle, and bottom) of the systems. Abbreviations as in Figure 1.

among systems (Fig. 6A, B). Low concentrations of orthophosphates were found in all the systems; orthophosphates were undetectable in April in several systems (Fig. 6C). Orthophosphate concentrations among systems showed no statistical differences ($F = 1.64$, $p > 0.05$). On average the N/P ratio was 1066 N: 1 P. In general terms, all nutrients showed a similar pattern throughout the sampling period, with higher concentrations at the beginning, and a decrease toward its end (Fig. 6A–C).

Maximum values of chlorophyll *a* (0.87 mg m^{-3}) were found at El Padre. In March and May, chlorophyll *a* was undetectable in Donato (Fig. 7A). Chlorophyll *a* concentrations were similar in all systems,

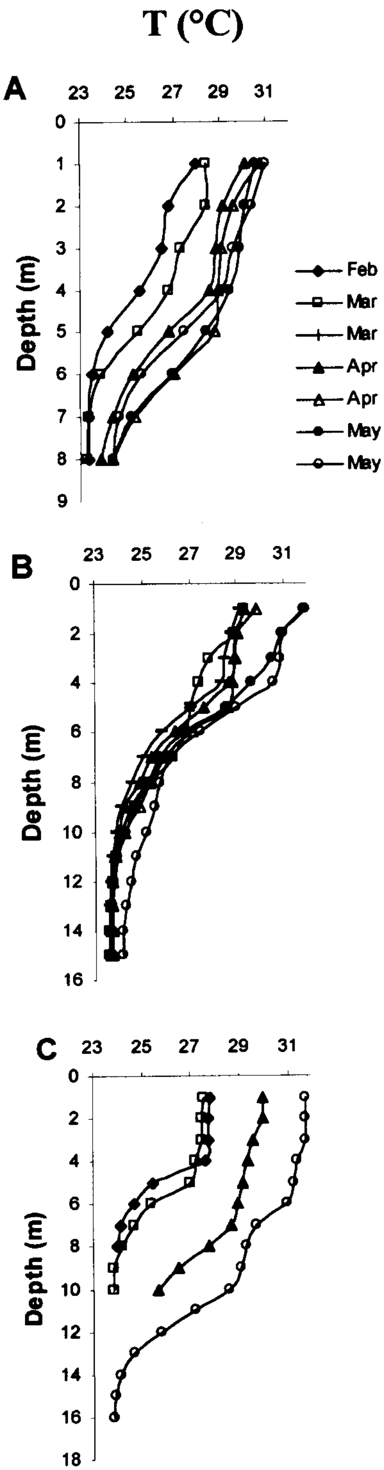

Figure 4. Vertical profiles showing thermal stratification in three karstic systems: Galeana (A); km 157 (B), Donato (C). February (Feb), March (Mar), April (Apr), May (May). Each line represents a single sample.

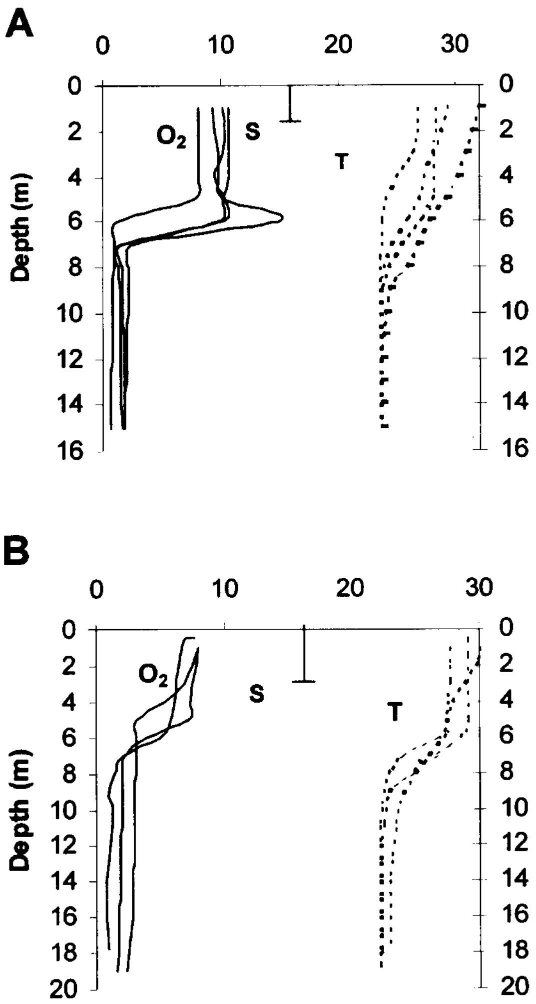

Figure 5. Changes in oxycline and thermal stratification during the sampling period in cenote El Padre (A) and Noh ts' onot (B). Dissolved oxygen in mg l^{-1} (O_2, solid line), transparency in m (S), temperature in centigrade degrees (T, broken line).

except for El Padre, where the highest levels were reached in early March and late April (Fig. 7A). The one-way ANOVA test showed statistical differences in chlorophyll *a* concentration among systems ($F = 62.19$, $p < 0.001$). A Tukey's test confirmed that El Padre had the highest values of chlorophyll *a* concentrations, followed by Minicenote and Galeana (both with similar values).

Highest values of zooplankton biomass were found in Minicenote and km 170 (0.19 and 0.17 mg m^{-3} respectively), both are vase-type systems. Zooplankton biomass showed wide variations in three systems, while it remained almost constant in the others (Fig. 7B). A one-way ANOVA test showed statist-

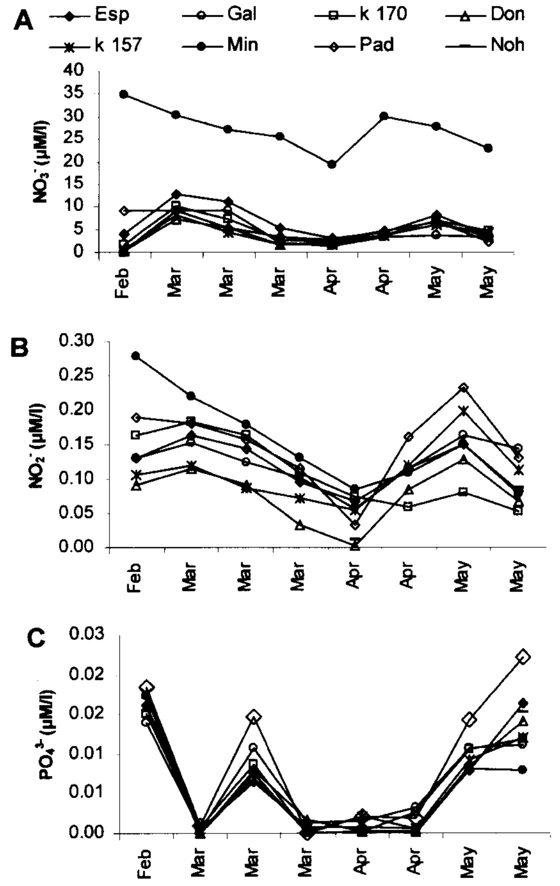

Figure 6. Nutrient concentrations found in the systems; Nitrates (A), Nitrites (B), and Orthophosphates (C). Abbreviations, following symbology, as in Figure 1.

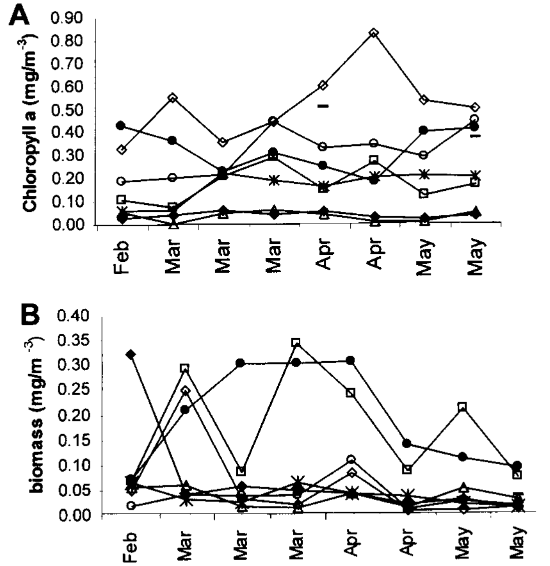

Figure 7. Concentrations of chlorophyll *a* (A), and zooplankton wet weight biomass (B), in the systems. Symbology as in Figure 6.

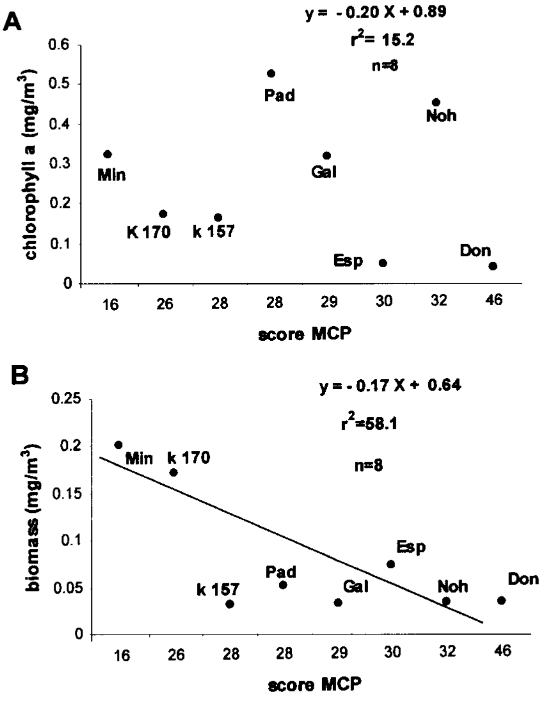

Figure 8. Relationship between chlorophyll *a* (A) and zooplankton wet weight biomass (B) with morphometrically-conditioned production (MCP).

ical differences in zooplankton biomass ($F = 17.57$, $p < 0.001$) among systems. A Tukey's test confirmed Minicenote as the system with the highest biomass content.

Maximum MCP values were estimated for Donato, the minimum was found in Minicenote (Table 5). A significant inverse correlation was found between zooplankton biomass and MCP (Fig. 8B). Temperature, pH, area, maximum length, and shoreline development were also negatively correlated with zooplankton biomass (Tables 3, 4); no significant correlation was found between chlorophyll *a* and MCP (Fig. 8A), or with any other variable surveyed.

Discussion

The shape of a freshwater system is often related to its geological origin (Torres-Orozco & García-Calderón, 1995). A circular shape is common in dissolution lakes, such as most freshwater systems of the Yucatan Peninsula (Torres-Orozco & García-Calderón, *op cit.*), karstic water bodies in Spain (Armengol & Miracle,

Table 4. Correlation coefficients (r_s) among morphometric parameters and trophic indicators in cenotes of Quintana Roo, Mexico. Values marked with an asterisk were statistically significant ($p \leq 0.05$). Abbreviations as in Tables 1–3

	Chl-*a*	Bio	*L*	*V*	*l*	D_L	*z*	D_V
Chl-*a*	1							
Bio	0.23	1						
L	−0.45	−0.83*	1					
V	−0.19	−0.66	0.87*	1				
L	−0.40	−0.83*	1.0*	0.90*	1			
D_L	−0.21	0.80*	0.57	0.30	0.57	1		
Z	−0.40	0.66	−0.40	−0.26	−0.40	−0.90*	1	
D_V	−0.25	0.61	−0.33	−0.28	−0.33	−0.64	0.66	1

1999), and volcanic lakes (Arredondo-Figueroa et al., 1983, Alcocer & Escobar, 1996). We found both ellipsoid and perfectly circular systems, all of them apparently with a similar origin, but different development (see Herrera-Silveira & Comín, 2000). These are the first bathymetric maps for sinkholes in the Yucatan Peninsula, with exception of X-pooc, a system located in the ring of cenotes, near Mérida city (see Flores-Nava et al., 1989).

Water transparency measured with a Secchi disk was high compared with lakes, dams, and ponds of central and southern Mexico, but it was similar to volcanic and other karstic systems (Arredondo & Figueroa, 1983; Banderas-Tarabay et al., 1991; Armengol & Miracle, 1999). Transparency is an important factor in aquatic systems; among other effects, it influences thermal structure (Mazumder & Havens, 1998). In our survey all the non-stratified systems showed consistently high Secchi values. Low Secchi transparency values could involve higher concentrations of suspended inorganic particles, a common feature in karstic systems (Armengol & Miracle, 1999; Díaz-Arce et al., 2000); this would reduce the light input in the lake. Commonly, a correlation between chlorophyll *a* and Secchi depth is expected (Brylinsky & Mann, 1973; Fee, 1979); however, this relationship has not been well established in tropical systems, and was not confirmed in this study. Similar results were obtained by Armengol & Miracle (1999) in Spanish doline lakes; the main reasons explaining this are: (1) the presence of high concentrations of suspended mineral matter, rather than phytoplankton (Navarro-Mendoza, 1987; Armengol & Miracle, 1999); (2) maximum values of chlorophyll *a* are distributed in the metalimnion, not in the upper layer (see Fig. 5A).

Table 5. Morphometrically-conditioned productivity (MCP) scores and productivity-associated morphometric parameters (PAMP) found in eight cenotes in Quintana Roo, Mexico (abbreviations as in Table 1)

PAMP	Esp	Gal	k 170	Don	k 157	Min	Pad	Noh
L	4	3	1	8	3	1	3	5
L	5	3	1	8	5	1	4	7
D_L	1	2	2	8	1	1	1	3
A	4	2	1	8	4	1	3	7
V	4	8	8	4	5	8	6	1
D_V	8	3	8	2	6	3	6	1
Z	4	8	5	8	4	1	5	8
MCP	30	29	26	46	28	16	28	32

Navarro-Mendoza (1987) stated that depth has a more important role for conductivity than does distance from the coast. This is supported by the positive correlation between depth and conductivity found here (see Table 3). However, the high conductivity found in Noh ts' onot appears to be related to intense mineral input during the rainy season, because this system is located in a wetland area connected to the sea on the surface. It is probable that both depth and geographic location (coastal sink-holes in wetlands), are important factors which determine conductivity patterns in karstic systems of the Yucatan Peninsula.

All the systems studied are entirely freshwater, except Noh ts' onot, which is subsaline (Hammer, 1986). On average, pH values were similar in all systems, which were alkaline (Reid & Wood. 1976; Alcocer & Escobar, 1996).

Nutrient turnover rates were high because concentrations of dissolved forms (fractions) of organic nutrients were low. This is a common feature in tropical and oligotrophic systems; the low nutrient concentration has been related to low rainfall rates (Conde & Sommaruga, 1999). The nutrient peak observed in all systems in March was associated with limited rainfall in that month (CNA, 2001). Rain favors increased mineral transport to the systems (Conde & Sommaruga, 1999). The low phosphorus concentrations found in this study were related to a reaction with Ca and mg with soluble phosphates to form insoluble salts, which are subsequently precipitated on the sediment. This reaction is usual in this karstic systems (Navarro-Mendoza, 1987; Flores-Nava et al., 1989). The high N/P ratio revealed orthophosphates as the limiting factor in all systems (N/P > 10) (Mazumder & Havens, 1998).

Usually, the MCP indicates the potential productivity of a system (Alcocer & Escobar, 1993). In the systems surveyed, zooplankton biomass was inversely correlated with MCP, perimeter, and maximum length (Tables 3, 4). In systems with a different origin such as continental and coastal lagoons, these variables have been related to high fish biomass (Alcocer & Escobar, *op cit.*). The importance of this index as a tool for the evaluation of zooplankton production is evident. However, it is necessary to find the contribution of other factors than morphometry affecting secondary production, such as maturity, effect of predation, thermal stratification, or even the geographic location in this kind of system. The relevance of some of these factors has been analyzed for different systems (Contreras-Espinosa et al., 1994; Mazumder & Havens, 1998; Armengol & Miracle, 1999).

Zooplankton biomass in the sinkholes was low compared with temperate lakes (see Shuter & Ing, 1997). A low overall production of zooplankton and chlorophyll *a* in these tropical environments is a well-known fact, probably because of the relatively smaller size of tropical zooplankters (Mazumder & Havens, 1998; Gillooly & Dodson, 2000), the reduced numbers of true plankters from high predation rates, or other factors such as nutrient limitation, experimentally tested in daphniids (Plath & Boersma, 2001).

The thermoclines found in some of these systems probably favor higher concentrations of both chlorophyll *a* and zooplankton biomass below the metalimnion. The existence of an oxygen peak at 6 m in El Padre supports this explanation, at least for primary producers (Fig. 5A). This kind of positive heterograde curves in the metalimnion can be explained by the effect of stratification, which promotes the formation of a deep chlorophyll maximum (Armengol & Miracle, 1999). Note that all zooplankton samplings were made during daylight, so diurnal vertical migration could possibly have affected these results. Zooplankton biomass appears to be independent of chlorophyll *a* concentration; probably the predatory pressure on zooplankton is more important to determine its variation than is chlorophyll availability (Barbieri et al., 1999). The range of chlorophyll *a* concentrations allowed us to classify all the systems as oligotrophic (Contreras-Espinoza et al., 1994).

The MCP depends on factors directly related to production (l, L, D_L, A and D_V) (Alcocer & Escobar, 1993); however, it was not possible to find such a relationship. Our results are contrary to other reports from reservoirs and lagoons in Mexico (Alcocer & Escobar, *op cit.*). Estimations of biomass in the relatively well-known temperate regions are still under discussion (Shuter & Ing, 1997); clearly, there is a long road ahead to have a complete biological and limnological characterization of these tropical karstic systems.

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