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Temporal variation of phytoplankton from the tropical reservoir Valle de Bravo, Mexico

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Abstract

Valle de Bravo reservoir is used for aquatic, fishing and as a source of drinking water to Mexico City. Annual data on composition, abundances, species richness and diversity of the phytoplankton surface community and some physical-chemical parameters variations were discussed. Results showed a spatial homogeneity for environmental descriptors and phytoplankton samples but a temporal significant difference between months. Pulses of high algal densities corresponded to late stratification (October, 103 x10^3 cell ml^{-1}), early stratification (April, 107 x10^3 cell ml^{-1}) and plenty stratification (June, 69 x10^3 cell ml^{-1}). Taxa that reached higher densities were: Microcystis spp., Snowella septentrionalis, Anabaena spp., Aphanizomenon yezoense and Fragilaria crotonensis. Contribution of each taxon to the total phytoplankton density showed that majorities were rare (41%) or dominants (40%). Frequent alternation between pulses and low densities and diversity of phytoplankton as well as a relative high number of taxa found (68), could be explained by daily strong winds, unstable epilimnion thickness and incorporation and extraction of substantial volumes of water occurred in the reservoir. Dominances of cyanobacteria and some chlorococcal species and a high temporal fluctuated Shannon-Wiener diversity index (0.45- 2.35 bits) pointing to eutrophic and perturbed conditions.

Key words

Phytoplankton composition, Temporal variation, Tropical lakes-reservoirs, Valle de Bravo reservoir, Mexico

Introduction

Numerous studies have been carried out on the seasonal succession of phytoplankton in temperate regions (Reynolds, 1984; 1997). Lately, phytoplankton studies in tropical regions have been increasing (Lewis, 1987; Schiemer and Boland 1996), nevertheless more information is required (Crisman *et al.*, 2003).

The amplitude of seasonal variations in temperature and solar radiation is smaller in the tropics than in the temperate zone. In most tropical lakes, conspicuous temporal fluctuations in rainfall, runoff and/or vertical mixing imply some annual variations patterns which are reflected on species composition and abundance of phytoplankton (Wetzel, 2001). Furthermore, processes like sudden storm and periods of strong wind contribute to the mixing of the upper water layers increasing the phytoplankton diversity. These processes have been interpreted as intermediate perturbations (Padisak, 1994; Hambrigth and Zohary, 2000).

Mexican reservoirs are systems that have not received extensive limnological, ecological nor taxonomical studies. Multi-use demands on reservoirs for municipal drinking water, industrial water supply, irrigation, navigation, hydroelectric power generation, recreation, and aesthetics, dictate that scientific community could devote more attention to this kind of water bodies, both for a better understanding of functioning and for sound ecological management. Reservoirs occupy an intermediate position between rivers and natural lakes regarding to morphologic and hydrologic characteristics, relative importance of external nutrient inputs and internal nutrient cycling and the significance of allochthonous vs. autochthonous sources of organic matter to the food web (Thornton *et al.*, 1990).

Valle de Bravo reservoir (State of Mexico) is an important tourist destination where water sports and fishing are practiced. This reservoir is part of the Cutzamala System dams (Olvera-Viascan *et al.,* 1998; Tortajada and Castelan, 2003), which supply drinking water for a human population of 6 million inhabitants in Mexico City (Ramirez *et al.*, 2004). It is the most important reservoir because of its large storage capacity of 418.25 x 10^6 m^3 (National Commission of Water, 2005).

There are some previous works published about Valle de Bravo reservoir. Deguchi *et al.* (1980) applied a phytoplankton index and classified the water body as oligotrophic at that time. Olvera (1992) pointed out that the water quality had being deteriorated far ahead, changing from oligotrophic to eutrophic condition. Ramirez *et al.* (2002) reported zooplankton and phytoplankton temporal variability. They found that during the wet season (June–September 1998), when the reservoir is stably stratified, large blooms of cyanobacteria (some of them with toxic species, specially *Microcystis* ssp. and *Anabaena* spp.) occurred.

A combined observational-modeling study was conducted to investigate turbulence mixing, and the relation to surface forcing, in the surface boundary layer (Anis and Singhal, 2006). Coinciding with our sampling times, Merino *et al.*, 2008 pointed out that the reservoir is daily swept by strong diurnal winds causing vertical displacements of the thermocline and boundary mixing, enhancing the productivity during the stratification period. Jimenez Contreras *et al.* (2009) studied the zooplankton community composition at different depths. They found that the rotifer genera *Keratella*, *Polyarthra* and *Trichocerca*, constituted nearly 80% of the total numerical abundances.

Nevertheless, there is no in-depth analysis of the structure and dynamic of the phytoplankton community in Valle de Bravo, which is fundamental as primary producers for the management and the assessment of the trophic state system. In addition, the appearance of blooms of some potentially toxic cyanobacteria species represents a serious risk for human beings.

The aims of the present study were to determine the phytoplankton taxonomic composition, abundances and diversity, to delineate its temporal pattern and, to reference their basic ecological frame during an annual cycle in Valle de Bravo.

Materials and Methods

Study area: Valle de Bravo is a tropical high altitude reservoir located west of Toluca City, in the State of Mexico, at 19º11’50" N and l00º09’13" W, and at an altitude of 1780 m asl (Fig. 1). It is part of the Cutzamala System located in the high basin of the Balsas River that belongs to the Hydrologic Region 18 (RH-18). The reservoir is classified as warm monomictic, stratified for nine months with anoxic hypolimnion (March to October) and, complete mixing in December (Olvera-Viascán *et al.*, 1998 and Merino et al. 2008). It has a surface area of about 19 km^2 and represents a 3.5% of the drainage basin. The mean depth (Z) is about 20 m and the maximum depth (Zmax) is 35 m (Olvera-Viascán *et al.* loc. cit.). The basin has a sub-humid temperate climate with a rainy season during the summer (June to October), especially in July-September. Rainfall less than 5% of that of the annual total occur during the winter (García, 1990).

The territory is characterized by hills with plains, predominantly orthic acrisol soil and humic andosols (López-Garcia *et al.*,1990). The structural base of the dam is lime/calcareous, but on the surface volcanic materials prevail. The vegetation is a mixed pine-oak forest with deciduous low secondary forest that induced pastures and seasonal agriculture (Rzedowski and Reyna-Trujillo, 1990).

Sampling: Monthly samples were taken at the surface (0.5 m depth) with a Van Dorn sampler (2 L) from July 2000 to July 2001 (except February) at five stations: Yacht Club, Carrizal, Centre, the Dam wall and Amanalco (Fig. 1). The physical and chemical parameters measured *in situ* were: temperature, specific conductivity standardized to 25°C (K_{25}), pH, dissolved oxygen (DO) and transparency as Secchi disk depth (Z_{SD}). Euphotic depth (Z_{EU}) was calculated multiplying Z_{SD} by a factor 1.7 (Esteves, 1988). From the water sample were determined: Chemical Oxygen Demand (COD), ammonia (N-NH_4^+), nitrites (N-NO_2^-), nitrates (N-NO_3^-), orthophosphates (P-PO_4^{3-}) and phytoplankton according to standard methods (APHA, 1985). Lugol´s iodine solution was used as preservative for quantitative and qualitative phytoplankton analysis.

Phytoplankton cells count was done following sedimentation with an inverted light microscope D-Carl Zeiss using the Utermöhl method (APHA, 1985). Taxa were determined at species level wherever possible. *Microcystis* spp. and spirally-coiled *Anabaena* spp. could not be distinguished as separated species for abundance calculations. Filamentous species were quantified by their number of cells per filaments.

Prescott (1975), Huber-Pestalozzi (1962, 1968), Komárek and Fott (1983), Tell and Conforti (1986), Komarek and Anagnostidis (1999), Popovsky and Pfiester (1990), Round *et al.* (1990), Comas (1996) and Hakansson (2002) were consulted for species identification.

In order to determine the temporal species contribution pattern (dominant, temporal, constant and rare species) a diagram frequency (%) *versus* density (log n+1) were analyzed as suggested by Garcia de Leon (1988). The algal frequency was calculated adding the number of months in which each taxon were present, and expressed as an annual percentage. Density was expressed as the logarithm of the mean of the total number of individuals (n) + 1 per taxon from the 5 sampled stations.

Statgraphics Plus (2001) was used to analyze the data obtained. Analysis of variance (ANOVA) was carried out to determine if there were differences in the pattern of environmental and biological variables between the five sample stations per month (spatial analysis), as well as throughout the study period between months (temporal analysis). The multiple range test was used to determine significance in variation. The method currently being used to discriminate among the means was Fisher’s least significant difference (LSD) procedure.

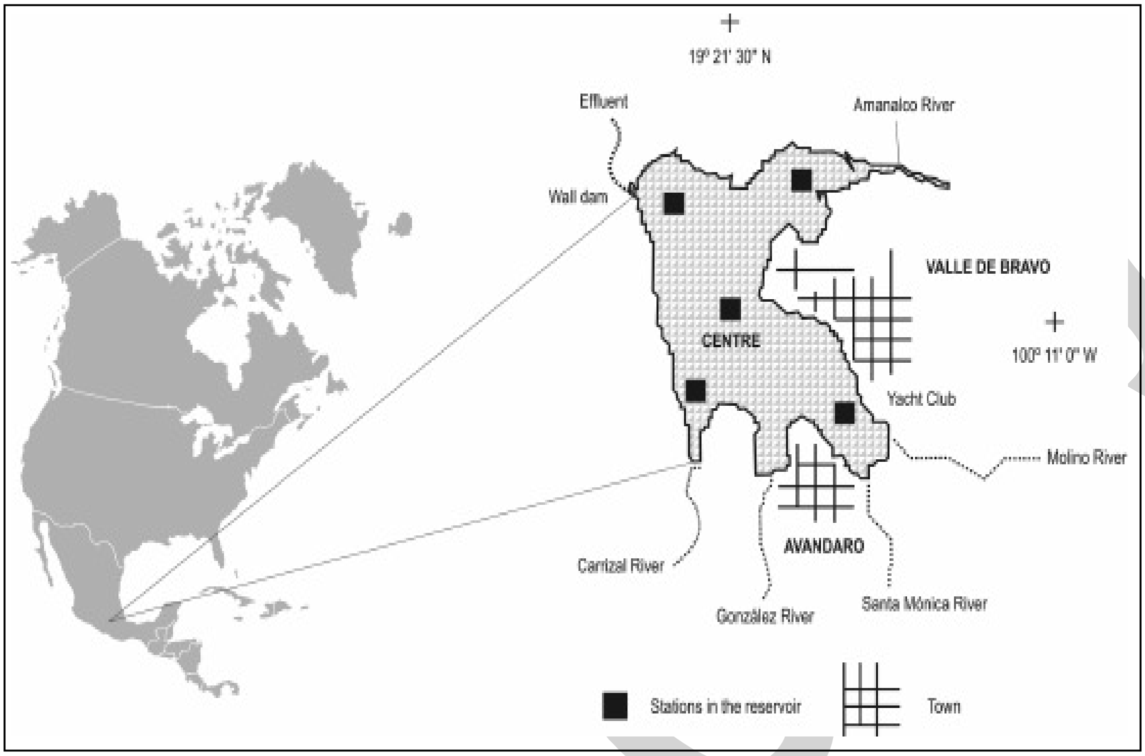

Fig. 1: Sampling sites in Valle de Bravo reservoir, Estado de Mexico, Mexico

To calculate species diversity, quantitative data of the phytoplankton were analyzed by the Shannon-Wiener (S-W) index ($H' = - ÓP_i \ln P_i$) from the abundance data (bits ind^{-1}) and Pielou's evenness ($J' = H'/\log(S)$) where: P_i = the proportion of individuals found in the *i*th species and S= total species found in each samples. These indices were analyzed by Plymouth Routines in Multivariate Ecological Research (2001).

Results and Discussion

Environmental conditions: Statistical analysis (data not presented here) showed a homogeneous spatial pattern between the surface sampling sites for physical and chemical parameters each month ($p>0.05$, n=5), but temporal significant differences ($p<0.05$, n=11) between months. Monthly averages, maximum and minimum of the 5 sampling sites represent the temporal variations of the main environmental variables during the study period (Fig. 2A-F).

Water temperature ranged from 18.0°C, January and April 2001 to 23.7°C in July 2000 (Fig. 2A). The decrease in air temperature from November to January allows well mixing of the water column. This result matched with Olvera-Viascan (1998) and Merino *et al.*, 2008 who pointed out that based on the thermal classification, the reservoir exhibits a warm-monomictic pattern with stratification period from February to October. This pattern has been reported also in some relatively high altitude and deep Mexican lakes Atexcac (Macek *et al.*, 1994), Alchichica (Alcocer *et al.*, 2000) and Zirahuen (Martinez-Almeida and Tavera, 2005).

Fig. 2B shows that the concentration of D.O. fluctuated between 2.4 (December) and 8.2 mg l^{-1} (August). Relatively low concentrations of D.O. detected in October and December must be linked to the late-stratification stage and overturn, when the mixing layer goes deeper to anoxic areas. Thus, the oxygen is redistributed in a greater volume of water which provokes an abrupt deficit in the upper layers of the column. Merino *et al.*, 2008 reported hypolimnetic anoxia during stratification, while the whole water column remained under-saturated (60%) during mixing period.

The pH ranged from neutral (7.0 to 7.2) during the mixing, November to December, to alkaline (> 7.8) during the other months, with a maximum value of 9.4 in September 2000, May and July 2001 (Fig. 2C). The reduced buffering capacity of this system (total alkalinity 1.40±0.06 meq l^{-1}) allows strong changes in pH (Merino *et al.*, 2008). High and low values of D.O. and pH were associated with pulses and decrements of phytoplankton, respectively (see Phytoplankton section).

Secchi disk depth varied from 0.3 to 2.5 m, with the highest transparency in January and May (Fig. 2D). Euphotic depth (Z_{EU}) corresponding to these Z_{SD} was 0.5 to 4.3 m. The highest transperancy occurred in January and May and the minimum one during the advanced rainy period, especially at October when a pulse of phytoplankton abundance also appeared (see Phytoplankton section).

Specific conductivity (K_{25}) ranged between 91 to 148 µS cm^{-1} (Fig. 2E). These ionic concentrations can be regarded as

Table - 1: Temporal phytoplankton species densities and their annual contribution pattern (frequency vs density) in Valle de Bravo Reservoir. July 2000 to July 2001

Species	Density												Frequency *vs.* Density
	J	A	S	O	N	D	J	M	A	M	J	J	
Chlorophyceae													
1 - *Ankyra judayi* (G.M. Smith) Fott	1	1	1	1	1	1	1	1	1	1	1	1	D
2 - *Botryococcus braunii* Kützing								1					R
3 - *Carteria* sp	1	1	1	1	1	1					1	1	R
4 - *Chlamydomonas* sp		1			1		1		1				R
5 - *Chodatella ciliata* (Lagerheim) Lemmermann	1	1	1					1	1	1	1	1	R
6 - *Closterium acutum* Brebisson ex Ralfs	1	1	1	1	1	1			1	1	1	1	D
7 - *C. aciculare* T. West	1	1	1	1		1	1	1	1			1	R
8 - *Coelastrum microporum* Nageli.	1	1	1	2	2	1	1	2	2	2	1	1	D
9 - *C. reticulatum* (Dangeard) Seen var. *cubanum* Kom		1	1	1	1							1	R
10 - *Cosmarium punctulatum* Brébisson	1	1	1	1	1	1			1	1	1	1	R
11 - *Cosmarium* sp	1												R
12 - *Dyctiosphaerium pulchellum* H.C. Wood	1												R
13 - *Eudorina elegans* Ehrenberg				1					1				R
14 - *Monoraphidium dybouskii* (Wolosz.) Hind et Kom- Legn	2	2	1	2	2	1							D
15 - *Mougeotia* sp	3	4	3	4	3	3	1	1	3	2	2	3	D
16 - *Neochloris* sp	1	1		1	1		1	1	1	1	1	1	D
17 - *Nephrocytium* aff. *agardhianum* Nägeli			1	1	1		1	2	1	1		1	T
18 - *Oocystis marssonii* Lemmermann	2	2	1	2	1	1	1	2	2	2	2	2	D
19 - *Quadrigula lacustris* (Chodat) G.M. Smith	1	1	1	1	1	1	1	2	1	2	2	1	D
20 - *Paulschulzia tenera* (Korschikoff) Lund	1	1	1	1	1	1		1	1	1			T
21 - *Radiococcus* sp	1	1					1	3	2	3	2	2	T
22 - *Scenedesmus denticulatus* Lagerheim	2	2	2	2	2	2				2	1	1	D
23 - *Schroederia setigera* (Schröder) Lemmermann			1	1	1	1	1		1		1	1	R
24 - *Staurastrum anatinum* Cooke et Wills	1	1	1	1	1	1							R
25 - *S. gladiosum* W.B. Turner					1						1	1	R
26 - *S. gracile* Ralfs				1	2	2							T
27 - *S. muticum* Brébisson ex Ralfs	1	1		1				1	1	1		1	R
28 - *S. paradoxum* Meyen ex Ralfs	1	1	1	1	1	1	1	1	1	1	1	1	D
29 - *Staurodesmus cuspidatus* (Brébisson ex Ralfs) Teiling			1	1	1	1							R
30 - *Tetraedron minimum* var. *scrobiculatum* Lagerheim	2	1	1	2	2	2		1	1	1	1	1	D
Bacillariophyceae													
31 - *Achnanthes* sp		1			1	1							R
32 - *Amphora* sp		1											R
33 - *Aulacoseira granulata* (Ehrenberg) Simonsen	1	1	1		1	1	1	1				1	R
34 - *Cyclotella ocellata* Pantocsek	2	1	1	2	3	3	1		1		1	2	D
35 - *Fragilaria crotonensis* Kitton	2	2	2	2	2	3	3	3	3	2	2	2	D
36 - *Gomphonema* sp		1											R
37 - *Navicula* sp	1	1			1								R
38 - *Nitszchia* sp				1									R
39 - *Ulnaria ulna* (Nitzsch) P. Compère	2	2	1	2	1	1							T
40 - *Urosolenia eriensis* (H. L. Smith) Round & Crawford				1	1	2							T
Cyanobacteria													
41 - *Anabaena* sp	2	3	2	3	3	2			3	3		2	D
42* *Anabaena* aff. *spiroides* Lemmermann & *A. crassa* Cronberg	3	3	2	3	2	2	1	4	2	3		2	D
43 - *Aphanizomenon yezoense* Watanabe	3	2	2	3	1		1	3	2	2	2	2	D
44 - *Snowella septentrionalis* Komárek & Hindák	2	2	2		1			4	4	3	4		T
45** *Microcystis botrys*, *M. flos-aquae* & *M. wesenbergi*	3	3	4	4	3	3	3	4	3	3	2	3	D
46 - *Woronichinia naegeliana* (Unger) Elenkin	2	1	2	3	3	3		3	3	3	3	2	D
47 - *Lyngbya birgei* G.M. Smith	3	3	2	3	2	2		2	2	2	1		D
48 - *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek			2	2	3	2							T
49 - *Merismopedia trollerii* Bachman	1	2	2	2	3	4							T

Dinophyceae													
50 - *Ceratium hirundinella* Dujardin	1	1	1		1	1		1	1	1	1	1	R
51 - *Gymnodinium* aff. *paradoxum* Schilling	1	1	1	1	1	1	1	1	1	1	1	2	D
52 - *Gymnodinium* sp	1	1	1	1			1	1			1	1	R
53 - *Peridinium aciculiferum* Lemmermann	1	1	1	1	1	1			1				R
54 - *Peridiniopsis elpatiewskyi* (Ostenfeld) Bourrelly	2	1	1		1	1	1			1			T
55 - *P. polonicum* (Woloszyñska) Bourrelly	1		1	1	1	1							R
Euglenophyceae													
56 - *Trachelomonas hispida* (Perty) Stein	1	1	1		1	1							R
57 - *T. volvocina* Ehrenberg	1	1	1	1	1	1	1	1	1	1	2	1	D
58 - *Euglena* sp	1										1		R
Chryptophyceae													
59 - *Cryptomonas curvata* Ehrenberg	1	1	1	1	1	2	2	2	1	1	1	1	D
60 - *C. marssonii* Skuja	2	1	2	1	2	1	1	2	1	2	2	2	D
61 - *Chroomonas acuta* Utermöhl	2	2	2	2	2	2	1	2	1	2	2	1	T
62 - *Chroomonas* sp	2	2	1	2	2	3							D
Chrysophyceae													
63 - *Dinobryon divergens* O.E. Imhof	1	1	1	1	1	2	1	1	1	1	1	1	R
64- *Mallomonas tonsurata* Teiling						1							T
65 - *Chrysochromulina* aff. *parva* Lackey	3	3	3	2	3	2							T

Considering * as 2 species and ** as 3 species Total: 68 species

Legends:

Densities (cells ml^{-1})

1	1- 99
2	100- 999
3	1000- 10000
4	10000- 100000

Frequency vs Density

D- Dominants
T- Temporals
R- Rares

Table - 2: Species richness reported in some Mexican freshwater bodies

Class	Zempoala[1]	Zirahuén[2]	Lago de Guadalupe[3]	Valle de Bravo[4]
Chlorophyceae (Chlor)	8	35	30	30
Cyanobacteria (Cyan)	1	3	4	12
Bacillariophyceae (Bacill)	9	11	10	10
Dinophyceae (Dino)	2	5	0	6
Euglenophyceae (Eugle)	2	2	9	3
Chryptophyceae (Cryp)	0	0	3	4
Chrysophyceae (Chrys)	0	3	4	3
Total taxa	22	59	60	68

[1]Garcia and Tavera, 2002; [2]Martínez and Tavera, 2005; [3] Lugo *et al.*, 1998; [4] Present study

being intermediate. According to Talling and Talling classification (1965) it belongs to body water of Class I (< 600 µS cm^{-1}). COD values were from 2-27 mg O_2 l^{-1} with minima values during mixing (Fig. 2F). It coincided with a period of low phytoplankton densities (see Phytoplankton section).

Nitrites were detected in low concentrations (< 0.1 µM l^{-1}) during stratification with a minimum value in March (0.022 µM l^{-1}) and reaching a maximum in overturn (0.436 µM l^{-1}). Lowest values of ammonia were measured during the stratification period (July 2000, 0.059 µM l^{-1}) and the highest one after mixing (March, 38.511 µM l^{-1}). Nitrates reached high concentrations during the mixing (3.271-4.774 µM l^{-1}) and lowest values in the stratification period (June, 0.016 µM l^{-1}). Orthophosphates were highest after mixing period (March, 0.418 µM l^{-1}) and lowest values during stratification (July, 0.105 µM l^{-1}). Total dissolved inorganic nitrogen and soluble reactive phosphorus ratio (DIN: SRP) < 16 occurred in October and May to July 2001. Merino et al. 2008 pointed out strong difference between the mixing and stratification periods in Valle de Bravo. During mixing, the ratio pointing to phosphorous limitations but during stratification, the epilimnion showed lower ratios indicating that nitrogen was the limiting nutrient. The magnitude of P and N values in Valle de Bravo indicates a disturbed environment that receives a nutrient overload of anthropogenic origin. Based on P concentrations it could be classified as mesoeutrophic water body (Monbet and McKelvie, 2007).

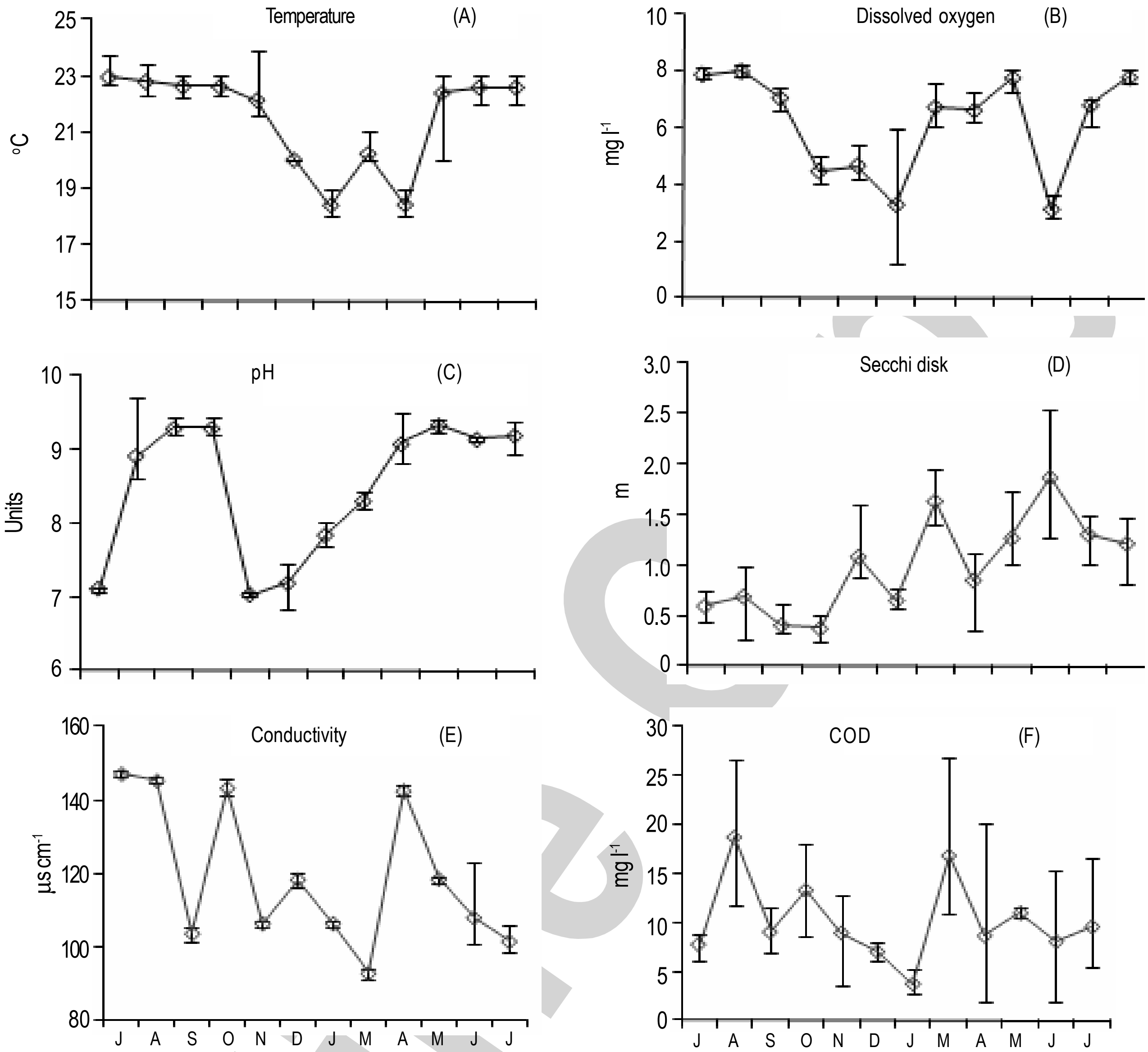

Fig. 2: Mean temporal variation of physico-chemical data from water surface samples in Valle de Bravo Reservoir, July 2000 to July 2001. Bars indicate maximum and minimum values of the 5 samplings stations. A- Temperature, B- Dissolved Oxygen, C- pH, D- Secchi disk transparency, E- Conductivity at 25°C and F- Chemical Oxygen Demand

Phytoplankton: Table 1 shows the record of 68 taxa in Valle de Bravo reservoir: 30 Chlorophyceae (44%), 12 Cyanobacteria (18%), 10 Bacillariophyceae (15%), 6 Dinophyceae (9%), 4 Chryptophyceae (6%), 3 Euglenophyceae (4%) and 3 Chrysophyceae (4%). The contribution of each taxon to the total phytoplankton density showed that the majority of them were rare (41%) or dominants (40%), and only 19% were temporals. There were not constant species, with high frequency and low density (Table 1 and Fig. 3). Chlorophycean richness (mainly Chlorococcales) was the highest in all categories; species of Cyanobacteria were mainly dominants and diatoms, rare (Fig. 4). The higher richness of Chlorophyceae and the number of Bacillariophyceae taxa are similar to the observed pattern for other Mexican water bodies such as Lago de Guadalupe (Lugo *et al.*, 1998) and Lake Zirahuen (Martinez-Almeida and Tavera, 2005). Although it could be considered that phytoplanktonic species richness of Valle de Bravo was moderate (68 taxa) in comparison to some other tropical water bodies widely studied (Schiemer and Boland, 1996) its higher than those recorded from other Mexican ones in an annual cycle (Table 2). The number of taxa were relatively higher and constant, around 45 during the plenty and late stratification (July-November) but abruptly decreased in the overturn period (Fig. 5A).

Like physical and chemical results, with a homogeneous spatial pattern, the phytoplankton abundance showed a temporal

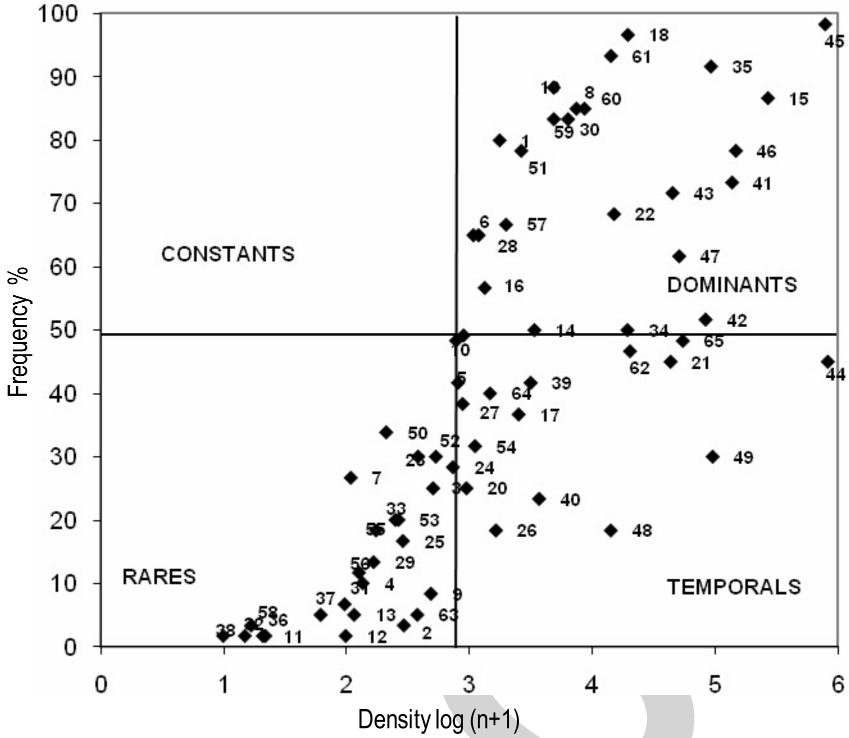

Fig. 3: Species distribution based on the frequency (number of months in which each taxon were present) *versus* density (mean of the total number of individuals (n) + 1, per taxon). There were no constant species, with high frequency and low density. Numbers correspond to species legend in Table 1

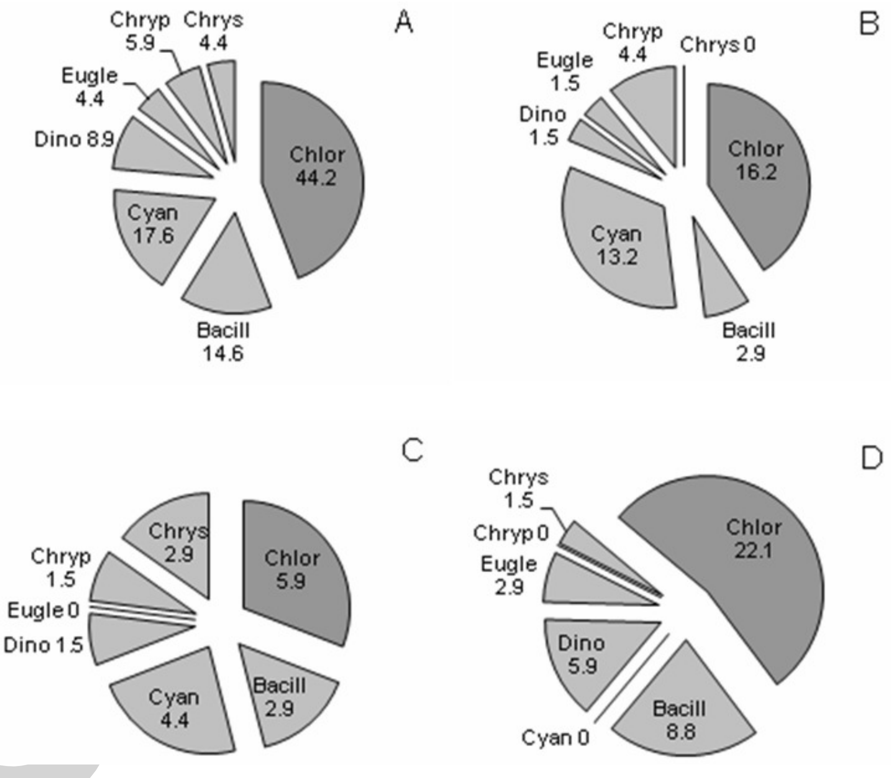

Fig. 4: Contribution percentage of each taxonomical group reported in Valle de Bravo reservoir. July 2000 to July 2001. (A) Number of total taxa, (B) Dominants, (C) Temporals (D) Rares. Chlorophyceae (Chlor), Cyanobacteria (Cyan), Bacillariophyceae (Bacill), Dinophyceae (Dino), Euglenophyceae (Eugle), Chryptophyceae (Chryp), Chrysophyceae (Chrys)

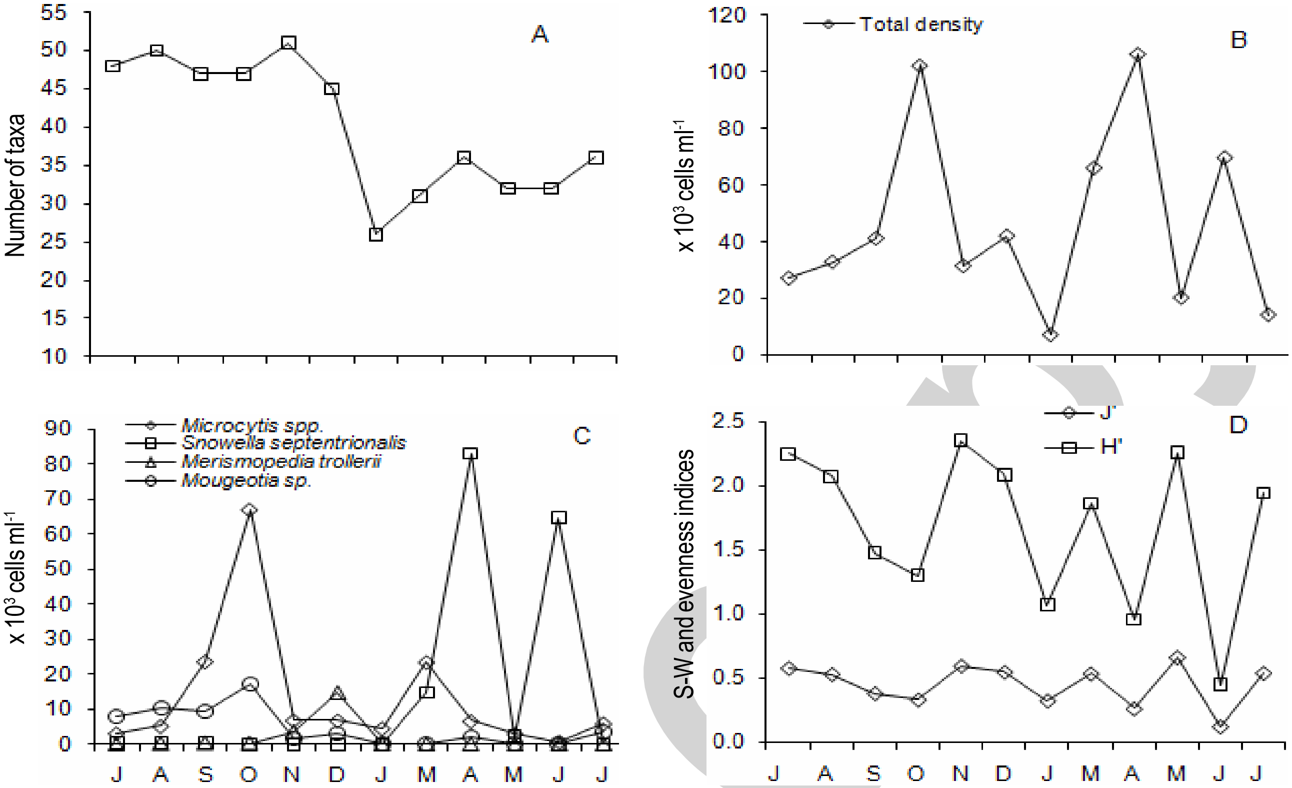

Fig. 5: Temporal variation of phytoplankton in Valle de Bravo Reservoir. July 2000 to July 2001, (A) Number of taxa, (B) Total density, (C) Main contribution species by abundance, (D) Shannon-Wiener index (H', based on ln) and Pielou's evenness (J')

significant difference between months ($p < 0.05$, n=11). High densities of organisms corresponded to late stratification (October, 103 x 10^3 cell ml^{-1}) and early stratification period (April, 107 x 10^3 cell ml^{-1}), whereas smaller density (< 40 x 10^3 cell ml^{-1}) occurred both during the plenty stratification and mixing period (Fig. 5B). *Microcystis botrys*, *M. flos-aquae*, *M. wesenbergii* and *Mougeotia* sp. were the highest contribution in October's peak, meanwhile, the cyanobacteria *Snowella septentrionalis* was dominant in April. The presence of an additional pulse of *S. septentrionalis* in June during the plenty stratification was also outlined (Fig. 5C). Some Nostocales (*Anabaena* ssp., *Aphanizomenon yezoense*) and *Microcystis* ssp., prevailed also during this period. These temporal pulses of cyanobacteria abundances coincided with N-limitated periods (N:P ratio < 16) in Valle de Bravo reservoir.

During the overturn, the water column mixing should be the main force to re-suspend the diatoms in Valle de Bravo, which were a dominant group during this period, especially *Cyclotella ocellata* and *Fragilaria crotonensis* (Table 1). It is pointed out that because of their higher weight, in comparison to other algal groups, diatoms require well-mixed conditions in order to remain suspended in the water column (Reynolds 1994). The chlorococcal *Nephrocytium* aff. *agardhianum* and *Radiococcus* sp., the cyanobacteria *Anabaena crassa, A.* aff. *spiroides, Microcystis botrys*, *M. flos-aquae.* and *M. wesenbergii* and, the diatom *Fragilaria crotonensis* characterized the early stratification.

It should be noted that even though chlorophycean presented highest richness, cyanobacteria reached the highest densities in Valle de Bravo reservoir (Table 1). Peaks that were dominated by *Microcystis* spp. and *Anabaena* ssp. regard special attention for their potential toxicity, especially when occurring in such drinking water and recreational reservoirs (Falconer, 2005). Under conditions of eutrophication, cyanobacteria are known to proliferate and form noxious blooms in freshwater environments (Whitton and Potts, 2002). The presence of cynobacterial blooms in the warm period has been pointed out in some Mexican water bodies, eg: *Nodularia spumigena* in Alchichica (Oliva *et al.*, 2001) and *Snowella septentrionalis* in Lake Zirahuen (Martinez-Almeida and Tavera 2005). These water bodies present common conditions: high insolation, a relatively high temperature, and a low N:P ratio at the beginning of the water column stability period.

The Shannon-Wiener diversity index ranged from 0.450 to 2.353 bits ind^{-1} and Pielou's evenness from 0.130 to 0.664. Both indices values showed a high temporal fluctuation (Fig. 5D) with a statistically significant difference between months ($p < 0.05$, n=11). It indicates conditions of intermittent surface disturbance where, temporally, certain phytoplankton taxa have better environmental conditions to reach higher individual numbers than others.

During the late stratification period, when the number of taxa were relatively higher and constant (Fig. 5A). The S-W index and

Pielou's evenness values decreased gradually from 2.25 to 1.30 bits ind^{-1} and 0.58 to 0.34, respectively (Fig. 5D). Pulses of phytoplankton abundance (Fig. 5B) matched with a low S-W index value. It means that the most unequal proportion of species occurred at this time with trend to the prevalence of some dominant taxa, such as *Microcystis* spp. and *Snowella septentrionalis* (Fig. 5C)

The highest number of taxa (51), S-W index and equitability values were achieved just before the overturn (November) when proportions of species in a simple sample were close to each other. Later on, during the overturn (December-January) there was a decreasing of species richness up to 26 as well as the S-W index (1.07 bits ind^{-1}) and total phytoplankton abundance (7.1 x 10^{3} cell ml^{-1}). The fact that the total phytoplankton abundance declined distinctly before and during the overturn must be connected with a redistribution of the number of individuals in an expanded water column as well as a lesser possibility to stay in the euphotic zone where normally appropriated photosynthesis occurs. Consequently, the low Zeu in the water column for this period, around 1.4 m (Fig. 2D), must be related with no biogenic factors.

Overviews: Stratification in tropical water bodies is not as stable as in temperate ones (Lewis, 1983). The epilimnion thickness could be altered by physical processes both in the day-night cycle and by eventual intermittent alterations that are relatively short, like: cold fronts, hurricanes, strong winds; or of longer duration (mixing). These processes may play an important role in aquatic ecosystem dynamics, and may modify or limit biological production. The turbulence mixing creates unstable conditions in the upper water layers responsible for the distribution and the supply of nutrients from the nutricline, which in many water bodies coincides with the thermocline, upward (Anis and Singhal, 2006). It allows an intermittent increasing of biomass densities during stratification as have been reported for tropical regions (Lewis, 1996). Jimenez Contreras *et al.* (2009) and Merino *et al.* (2008) found intermittent chlorophyll pulses in Valle de Bravo, with maximum values (> 12 µg l^{-1}) during stratification and a lowest ones (< 3 µg l^{-1}) in overturn.

Temporally, the alternation between high and low densities shows that phytoplankton in Valle de Bravo is related to hydrographic factors (circulation and structure of the water column, *sensu* Talling, 1986). This reservoir is daily swept by strong winds that blow mainly along the major axis (NW-SE). In the afternoon wind speeds can reach up to 7-8 m s^{-1} (Merino *et al.*, 2008). On the other hand there are incorporation and extraction of substantial volumes of water (Tortajada and Castelan, 2003). These two processes, could be provoking continuous and/or intermittent disturbance in the reservoir. As it has been pointed out, the environmental heterogeneity increases the number of species and diversity present in aquatic system (Hambright and Zohary, 2000). High numbers of dominant taxa in Valle de Bravo could be explained by disturbances of intermediate frequency or intensity that can act to maintain a continuous reset between phytoplankton composition, higher species richness and, a significantly fluctuated abundances, diversity and evenness in the upper water layers during stratification (Fig. 5A-D).

Furthermore, the fluctuating and insufficient sub-aquatic irradiance, given by the concentration of dissolved and particulate organic and inorganic matter could also be a restricted factor for the phytoplankton development. In Valle de Bravo, the euphotic zone reached a maximum annual depth of 4.3 m. In eutrophic water bodies the biogenic turbidity produced by algal populations is high. Thus, not only abiogenic particles but algae themselves reduced light penetration decreasing considerably the effective trophogenic zone. Since no analyses of suspended and soluble matter were made is difficult to discriminate which is the contribution of each part. However, low transparency observed in October could be corresponding to the pulse of phytoplankton abundance and advanced rainy season. On the other hand higher transparency occurred during stratification matches with no sediments contributions from the basin, characteristics of dry season (Figs. 2D). Elevated turbulence may also exposing phytoplankton upward to higher values of irradiances and lead to increased levels of biomass and, eventually, to large bloom coinciding with the stratification and the higher insolation period. That could be the case of Valle de Bravo with low transparency, but with a high unstable upper water layers responsible of nutrients supply from the nutricline.

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