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Typology of shallow lakes of the Salado River basin (Argentina), based on phytoplankton communities

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Abstract

The phytoplankton communities of eleven shallow lakes from Buenos Aires Province, Argentina, were studied seasonally from 1987 to 1989. Several physical and chemical properties were measured in each lake (pH, temperature, dissolved oxygen, transparency, nutrients), in order to interpret the structural and dynamic traits of the phytoplankton community.

Important differences between the lakes studied were put in evidence by means of multivariate techniques (Cluster Analysis and PCA). The shallow lakes densely populated by macrophytes hosted lowest phytoplanktonic densities, with average values ranging from 690 to 16500 algae ml^{-1}. High species diversities were observed in these lakes (4.0–4.8). Lakes less colonized by macrophytes had higher phytoplankton densities. In some of them important blooms of Cyanophyceae were recorded, with between 60000 and 179000 algae ml^{-1}, and concomitant low diversities.

The results of this investigation support the hypothesis that the phytoplankton community is strongly influenced by the macrophytes, by direct competition and/or by competition from periphytic algae associated with higher plants.

Introduction

While studies of the shallow lakes of the Salado River Basin (Buenos Aires Province, Argentina) are relatively numerous (Olivier, 1955; Tell, 1972; Dangavs, 1976; Conzonno *et al.*, 1991; Pastore & Tur, 1991), investigations of their phytoplankton are few. There is scarce floristic information (Guarrera *et al.*, 1968; Yacubson, 1965; Izaguirre *et al.*, 1991) and few surveys focusing on one particular lake (Boltovskoy *et al.*, 1990; Conzonno & Claverie, 1988).

These water bodies were classified by Ringuelet (1968) on the basis of various limnologic variables; the present work constitutes the first attempt at outlining an analogous classification based on their phytoplankton communities. These classifications are abundant from other geographic areas (Margalef *et al.*, 1976; Arvola, 1986; Eloranta, 1986; Earle *et al.*, 1987; Willén *et al.*, 1990; Lyche, 1990; Suykerbuyk, 1991). Recently, Izaguirre *et al.* (1990) and Moraes Huszar *et al.* (1990) presented phytoplankton-based typological schemes for Southamerican inland water bodies. In this paper we characterize the phytoplankton communities of 11 shallow lakes from the Salado

River Basin, determining their floristic compositions, species diversities and the densities of their phytoplankton populations. Seasonal changes and their relationships with the environmental factors are analyzed. Using classification and ordination techniques (Cluster Analysis and Principal Components Analysis), and on the basis of phytoplankton data, we propose a typology of the lakes analyzed.

Study area

The lakes are located in the Salado River floodplain, Buenos Aires Province, Argentina (35° 10′ to 36°00′ S; 57°40′ to 60° 10′ W). The Salado River flows through this area along a NE-SW axis. The total length of the river is approximately 700 km, and its catchment area is about 80 000 km^2 (Ringuelet, 1962).

According to Ringuelet (1962), this system is oligohaline to mesohaline, with high levels of chloride and sulphate ions.

The study area is encompassed by the Subtropical Region. The mean annual precipitation is about 1000 mm (FAA, 1980) with marked seasonal differences between a wet and a dry period. During the rainy season the rivers can flood flat lands, while during the dry one some of the shallowest lakes can dry out completely.

Maximum depths of the lakes studied never exceed 2 m. Their basins were probably formed by a combination of river and wind action (Ringuelet, 1962; Tricart, 1973). Their sediments are muddy and contain high levels of organic matter. Because of their small size, they are strongly influenced by wind, and are therefore polymictic.

The lakes Culú-Culú, Colis, Adela, Chis-Chis, La Tablilla and Las Barrancas are densely populated by macrophytes. The submersed species *Ceratophyllum demersum* and *Myriophyllum quitense* cover almost all the bottom of these lakes, while *Scirpus californicus* constitutes the main emergent macrophyte, covering more than 60% of the surface in each lake. In the remainder lakes, where the vegetation is removed periodically for recreation purposes, the macrophytes are restricted to the margins. The 11 lakes surveyed present different degrees of connection with the Salado River. Five of them are enclosed in a chain-system of several lakes (Fig. 1). The main morphometric features are shown in Table 1. For some of them there is a lack of morphologic information because they have never been studied before.

Materials and methods

Samples were collected seasonally from November 1987 to February 1989. Each lake was sampled 6 times except La Salada, which was dry in summer 1989. Two sampling stations were established in lakes with large differences between a littoral and a pelagial zone, but only one in those densely populated by macrophytes.

At each lake, samples for qualitative and quantitative analyses were taken. As a complement to taxonomic analyses, and in order to obtain adequate number of the scarcest organisms, additional samples were obtained with a net of 15 μm mesh size. Cell counts were based on 500 ml samples preserved with Lugol's solution (1%).

The following physical and chemical variables were measured: transparency (with a Secchi disk); water temperature, pH, dissolved oxygen and conductivity (with Luftman P-300 and C-400 combined electronic meters). Water samples were taken for later analyses of total phosphorus and total nitrogen concentrations.

Phytoplankton samples were examined under a light microscope at 100× magnification. Most taxa were identified to the species and/or subspecies levels. Counts were performed with an inverted microscope following the Utermöhl method (1958). Two, 5, 10 and 25 ml chambers were used, depending on phytoplankton concentrations. Replicate chambers were counted for each sample. Counting error was estimated according to Venrick (1978) in a number of random fields; a maximum error of approximately 20% was set for the more abundant species. In all cases individuals were counted, and for colonial or filamentous algae the size and/or number

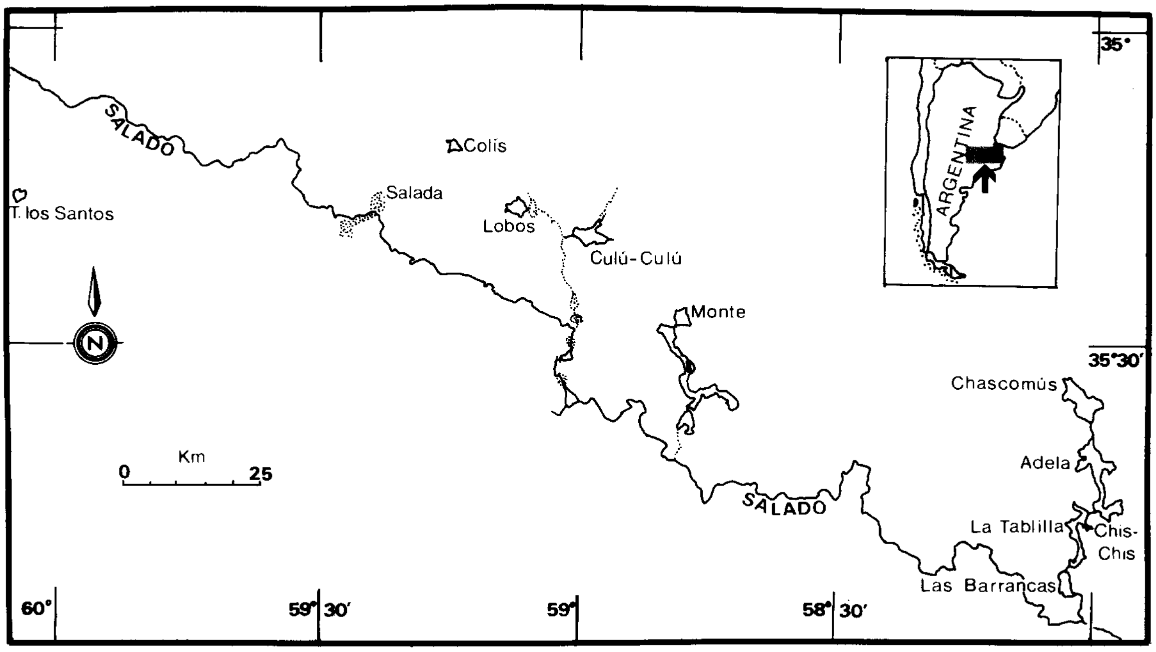

Fig. 1. Location of the shallow lakes studied.

of cells corresponding to a standard individual was established.

Chemical analyses of nutrients were performed following techniques detailed in Mackereth *et al.* (1978).

Numerical analysis

Phytoplanktonic species diversity for each sample was estimated using the index of Shannon & Weaver (1949).

The non parametric Wilcoxon test (Daniel, 1978) was used to test significance in differences between littoral and pelagial zones of each lake.

A Cluster Analysis was performed using Pearson's correlation index and UPGMA linkage procedure (Sneath & Sokal, 1973). The classification of lakes was based on a logarithmically transformated and reduced matrix of 140 species. The rare species were removed (occurring in less than 3 samples, at low densities) because they are not reliable for the typology of the environments,

Table 1. Morphometric parameters of the lakes studied according to Quirós *et al.* (1983).

	Chascomús	Adela	Chis-Chis	La Tablilla	Las Barrancas	Lobos	S. M. Monte	Culú-Culú
Surface area (km^2)	28.7	21.0	14.7	15.9	8.5	7.5	6.4	12.0
Max. length (km)	10.0	10.4	6.5	14.0	5.0	4.0	3.5	6.5
Max. width (km)	5.0	7.9	3.5	2.5	1.5	3.0	2.5	4.5
Shoreline length (km)	30.0	37.8	24.0	40.0	15.0	12.5	12.5	27.0
Max. depth (m)	1.9	1.7	1.5	1.5	1.5	1.46*	1.7**	–
Mean depth (m)	1.5	1.2	1.1	1.1	1.1	1.07*	0.69**	
Volume (km^3)	0.047	0.026	0.016	0.016	0.011	0.008*	0.009**	–

* Data from Boltovskoy *et al.* (1983).
** Data from Guarrera (1962).

since their appearance is aleatory (Allen & Koonce, 1973).

A Principal Component Analysis (Orlocci, 1966) was carried out on the basis of a correlation matrix between phytoplankton data (richness, diversity, total density and density of the principal algal classes), and abiotic data (temperature, pH, conductivity and nutrients).

Results and discussion

Physical and chemical properties

Table 2 shows the values of the physical and chemical variables measured.

In all lakes waters are relatively alkaline, with pH values ranging from 8 to 10.2. High alkalinity is mainly due to the calcium carbonate-rich mother rock of the Salado River Basin (OEA, 1971; CODESA, 1984). In addition, the active photosynthesis of macrophytes and algae also increases the pH, which accounts for the fact that maximum pH values were recorded in the growing season.

Although the amount of dissolved oxygen was rather fluctuating, in all cases it increases towards the winter. The values ranged from 5.6 mg l^{-1} to supersaturation, but most of them are relatively high because of high primary productivity levels.

Water temperature followed ambient temperature closely. Extreme values were 31.4 °C (summer) and 8.9 °C (fall).

Transparency ranged from 14 cm to 160 cm; in general terms, clearest waters were associated with macrophyte-rich lakes (Fig. 2).

The relatively high conductivity values recorded are mainly due to the composition of surrounding soils and the mother rock. Most of the records are within the 1,000-2,000 μS cm^{-1} range. La Salada Lake, directly connected with the Salado River, showed the highest values. O'Farrell (pers. comm.) reported high conductivity values for this river. Peaks in conductivity were recorded in summer in coincidence with the dry season. These results agree with the observations of Boltovskoy *et al.* (1990) in Lobos Lake.

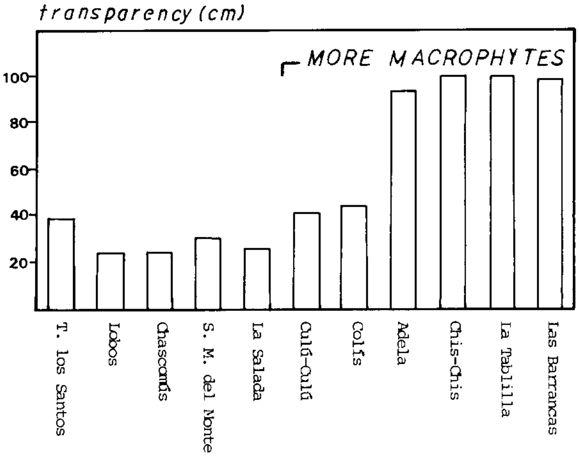

Fig. 2. Mean transparency for each lake (November 1987-February 1989).

Total phosphorus concentrations varied between 0.02 and 0.61 mg l^{-1}, but were generally rather constant. A slight increase in this nutrient was observed in Spring 1988 and in Summer 1989. Nitrogen concentrations ranged from 1.67 to 6.8 mg l^{-1}, and the lowest values occurred during winter, when algal densities were lowest. Phosphorus and nitrogen concentrations are within the ranges reported for eutrophic and hypereutrophic lakes (Lambou *et al.*, 1983; Quirós & Cuch, 1985) and, in particular, total P values coincided with those found previously in these shallow lakes (Quirós, 1989).

Phytoplankton structure and dynamics

A total of 517 phytoplanktonic taxa were identified in the 11 lakes. Table 3 shows the floristic list of the 139 species which were used in the Cluster Analysis.

According to Wilcoxon's test, in 62% of the cases examined, differences between littoral and pelagial samples are not significant. Moreover, we think that most of the statistically significant dissimilarities were governed by chance because higher algal densities at either coastal or central stations would shift swiftly with short-term changes in environmental conditions. Because of their small size these lakes are readily influenced

Table 2. Values of the physical and chemical variables measured in the lakes studied. 1: spring 1987; 2: summer 1988; 3: fall 1988; 4: winter 1988; 5: spring 1988; 6: summer 1989; ***a***: average.

Lake		Sample code	Temperature (°C)	pH	Conductivity (μS cm^{-1})	Dissolved oxygen (mg l^{-1})	Transparency (cm)	Total P (mg l^{-1})	Total N (mg l^{-1})
Todos los Santos	1	31	20.5	9.2	1762	6.6	34	0.21	5.11
	2	32	29.9	10.0	2200	10.5	48	0.12	2.53
	3	33	12.7	9.4	1599	11.6	35	0.14	3.09
	4	34	11.7	9.4	1705	12.9	43	0.25	5.80
	5	35	22.8	9.3	1940	10.8	36	0.48	–
	6	36	29.4	9.7	280	–	32	0.58	–
	a						38	0.30	4.13
Colís	1	42	22.9	9.0	824	9.4	25	0.33	1.67
	2	43	26.4	8.4	2060	8.0	46	0.38	2.76
	3	44	12.3	9.2	950	12.8	50	0.20	4.39
	4	45	14.0	9.4	–	supersat.	50	0.33	4.60
	5	46	25.5	9.9	2740	10.2	–	0.48	–
	6	47	29.6	8.9	3370	–	–	0.21	–
	a						43	0.32	3.36
La Salada	1	37	21.8	8.3	3020	5.7	32	0.40	4.13
	2	38	31.4	9.3	6600	13.0	24	0.59	3.34
	3	39	12.5	8.7	2300	10.3	30	0.20	4.49
	4	40	12.4	9.0	4860	11.2	14	0.51	6.20
	5	41	29.3	8.8	8000	11.8	–	0.56	–
	a						25	0.45	4.54
Lobos	1	48	19.5	8.1	1305	8.4	25	0.28	3.73
	2	49	26.5	9.3	1920	11.8	14	0.22	4.24
	3	50	11.0	8.8	930	11.5	30	0.15	4.33
	4	51	9.2	9.4	1886	16.0	29	0.30	6.40
	5	52	23.0	9.2	3300	supersat.	30	0.49	–
	6	53	25.0	9.1	4940	–	15	0.38	–
	a						24	0.30	4.67
Culú-Culú	1	54	22.1	7.6	862	5.6	25	0.18	5.53
	2	55	31.0	8.9	1980	–	–	0.30	4.58
	3	56	12.6	8.4	1180	9.1	71	0.12	5.13
	4	57	14.8	8.2	1615	11.3	45	0.24	5.80
	5	58	26.9	9.2	3530	supersat.	18	0.61	–
	6	59	25.1	9.3	5500	–	–	0.49	–
	a						40	0.32	5.26
S. M. del Monte	1	60	22.2	8.2	938	8.0	25	0.22	4.76
	2	61	22.8	8.5	1458	7.9	17	0.24	2.12
	3	62	12.0	8.0	405	7.0	31	0.19	3.25
	4	63	12.2	8.5	814	11.0	22	0.30	6.50
	5	64	27.0	8.6	1527	10.4	46	0.27	–
	6	65	25.7	9.4	1910	–	37	0.20	–
	a						30	0.24	4.16
Chascomús	1	1	23.6	8.9	1220	9.3	15	0.04	4.07
	2	2	22.0	8.8	1385	7.6	45	0.10	3.07
	3	3	11.0	8.3	610	10.3	20	0.22	4.58
	4	4	9.5	8.7	669	11.6	15	0.20	6.70
	5	5	23.8	8.7	996	9.3	21	0.26	5.92

Table 2. (Continued)

Lake		Sample code	Temperature (°C)	pH	Conductivity (μS cm^{-1})	Dissolved oxygen (mg l^{-1})	Transparency (cm)	Total P (mg l^{-1})	Total N (mg l^{-1})
	6	6	24.5	8.6	1450	–	27	0.19	4.96
	a						24	0.17	4.88
Adela	1	7	29.6	9.6	1762	10.4	67	0.07	4.99
	2	8	27.7	8.8	1842	7.3	100	0.06	2.50
	3	9	10.1	8.4	1087	10.3	110	0.07	4.13
	4	10	13.8	8.9	1121	15.5	78	0.10	5.90
	5	11	25.2	10.2	3740	12.0	105	0.21	3.59
	6	12	25.0	8.0	7030	–	100	0.26	3.79
	a						93	0.13	4.15
Chis-Chis	1	13	25.7	9.9	1500	supersat.	110	0.15	5.34
	2	14	28.3	9.4	1721	14.0	60	0.05	3.11
	3	15	8.9	8.5	1026	12.1	100	0.10	3.96
	4	16	15.0	9.0	1190	15.6	108	0.25	4.70
	5	17	24.0	9.9	1870	13.5	110	0.27	4.85
	6	18	23.5	9.3	1940	–	112	0.18	4.62
	a						100	0.17	4.43
La Tablilla	1	19	26.4	10.0	1517	9.3	60	0.06	3.26
	2	20	29.9	9.7	1890	12.0	117	0.02	3.52
	3	21	12.2	9.0	1050	9.7	122	0.10	4.02
	4	22	13.8	9.3	1505	14.9	–	0.20	5.20
	5	23	22.3	9.9	1925	10.0	117	0.23	5.42
	6	24	28.5	9.5	3090	–	82	0.20	6.80
	a						100	0.13	4.70
Las Barrancas	1	25	23.5	9.5	1670	7.8	67	0.09	4.05
	2	26	28.5	9.0	1580	11.0	160	0.02	2.80
	3	27	10.8	8.2	1147	8.5	75	0.09	3.19
	4	28	15.6	8.2	2350	14.1	150	0.20	6.10
	5	29	24.0	9.3	1670	supersat.	117	0.25	5.41
	6	30	29.5	9.4	4140	–	18	0.19	3.89
	a						98	0.14	4.24

by transient factors, such as wind-force and direction. Table 4 summarizes average phytoplankton densities, richness and species diversities for each lake.

The number of phytoplankton taxa varied between 11 and 132. Las Barrancas Lake showed highest richness, probably due to its vicinity with the Salado River. During periods of high water discharge this river can contribute significantly to the specific inventory of associated lakes.

Although all these lakes host phytoplankton communities typical of eutrophic and mesotrophic systems (Table 3), there are some important differences among them. Comparison of their phytoplankton densities (Fig. 3), clearly shows that Todos los Santos, Lobos and Chacomús Lakes exhibit highest values, reaching a peak of 179000 algae ml^{-1} (Todos los Santos, Summer). These lakes are dominated by Cyanophyceae with densities characteristic of algal blooms. In addition, low species diversities were recorded in these three lakes (Table 4). These results indicate that Todos los Santos, Lobos and Chascomús are typically eutrophic. Dominance of blue-green algae and bloom formations in eutrophic lakes have been reported repeatedly (Coveney, 1977;

Table 3. List of phytoplankton species used in the cluster analysis. Characterization: M: mesotrophic; M-E: meso-eutrophic; E: eutrophic; D: distrophic; P: polluted waters; A: alkaline; B: brackish

CHLOROPHYCEAE

Actinastrum hantzschii var. *subtile* Wolosz.	E
Bothryococcus braunii Kütz.	M
Coelastrum astroideum De-Not.	
Coelastrum microporum Näg.	E
Coelastrum pulchrum Schmidle	
Crucigenia quadrata Morr.	E
Dictyosphaerium pulchellum Wood	E
Didymocystis bicellularis (Chod.) Kom.	E
Kirchneriella contorta var. *elegans* (Playf.) Kom.	
Lobocystis neodichotoma Izaguirre	M-E A
Monoraphidium arcuatum (Kors.) Hind.	
Monoraphidium caribeum Hind.	
Monoraphidium circinale (Nyg.) Nyg.	E
Monoraphidium contortum (Thur.) Kom.-Legn.	E
Monoraphidium komarkovae Nyg.	M D
Monoraphidium minutum (Näg.) Kom.-Legn.	
Monoraphidium tortile (W. *et* G. S. West) Kom.-Legn.	M-E
Oocystis lacustris Chod.	E
Oocystis parva W. *et* G. S. West	
Oocystis solitaria Wittr.	
Oocystis solitaria f. *major* Wille	
Pediastrum boryanum (Turp.) Menegh.	E P
Pediastrum musterii Tell *et* Mataloni	M
Pediastrum tetras (Ehr.) Ralfs	
Planctonema lauterbornii Schmidle	
Scenedesmus acuminatus (Lagerh.) Chod.	E
Scenedesmus acuminatus f. *tortuosus* (Skuja) Kors.	
Scenedesmus armatus Chod.	E
Scenedesmus balatonicus Hortob.	
Scenedesmus brasiliensis Bohl.	M-E
Scenedesmus ecornis (Ehr.) Chod.	E
Scenedesmus linearis Kom.	
Scenedesmus longispina Chod.	
Scenedesmus manus Chod.	
Scenedesmus oahuensis (Lemm.) G. M. Smith	
Scenedesmus opoliensis Richt.	
Scenedesmus ovalternus Chod.	
Scenedesmus pecsensis Wherk.	
Scenedesmus quadricauda (Turp.) Bréb.	M-E P
Scenedesmus sempervirens Chod.	E
Scenedesmus spinosus Chod.	
Sphaerocystis schroeteri Chod.	E
Tetraedron minimum (A. Br.) Hansg.	E
Tetraedron triangulare Kors.	
Tetrastrum glabrum (Roll) Allstr. and Tiff.	E
Tetrastrum hortobagyi Hajdu	
Etrastrum komarekii Hind.	E
Tetrastrum staurogeniaeforme (Schröd.) Lemm.	
Tetrastrum triangulare (Chod.) Kom.	E
Treubaria triappendiculata Bern.	

CYANOPHYCEAE

Anabaena aphanizomenoides Forti	
Anabaena spiroides Kleb.	

ZYGOPHYCEAE

Closterium aciculare West	E
Closterium acutum var. *variabile* (Lemm.) W. Krieg.	
Closterium dianae var. *arcuatum* (Bréb.) Rabenh.	
Cosmarium abbreviatum Raciborski	
Cosmarium granatum Bréb.	D A
Cosmarium laeve var. *laeve* Rabenh.	
Cosmarium laeve var. *westii* Krieg. *et* Gerloff	
Cosmarium margaritiferum Menegh.	M-E
Cosmarium praecisum var. *suecicum* Borge	
Cosmarium staurastroides var. *amazonense* Först.	
Euastrum crassicolle Lund.	
Staurastrum crenulatum (Näg.) Del.	
Staurastrum hexacerum (Ehr.) Wittr.	
Staurastrum paradoxum Meyen	E

BACILLARIOPHYCEAE

Achnantes exigua Grun.	M A
Amphora libyca Ehr.	E A
Amphora pediculus (Kütz.) Grun.	
Amphora veneta Kütz.	E A
Anomoeoneis sphaerophora var. *sphaerophora* (Ehr.) Pfitzer	E A
Aulacoseira granulata (Ehr.) Sim.	M-E A
Cocconeis placentula var. *euglypta* (Ehr.) Cleve	M-E A P
Cocconeis placentula var. *lineata* (Ehr.) V.H.	A
Cyclotella atomus Hust.	
Cyclotella meneghiniana Kütz.	E A B
Cymbella minuta Hilse	P
Cymbella muelleri Hust.	A
Epithemia adnata var. *proboscidea* (Kütz.) Patr.	
Epithemia sorex Kütz.	M A
Eunotia pectinalis var. *rostrata* Germain	
Fragilaria construens var. *construens* (Ehr.) Grun.	M-E A
Fragilaria construens var. *subsalina* Hust.	
Fragilaria construens var. *venter* (Ehr.) Grun.	M-E A
Fragilaria inflata (Heiden) Hust.	
Gomphonema lanceolatum Agardh	
Gomphonema parvulum Kütz.	P
Gomphonema subclavatum Grun.	
Navicula cuspidata (Kütz.) Kütz.	M-E A
Navicula halophila (Grun.) Cleve	
Navicula laevissima Kütz.	
Navicula peregrina (Ehr.) Kütz.	
Nitzschia amphibia Grun.	E A
Nitzschia hantzschiana Rabenh.	A
Nitzschia hungarica Grun.	A
Nitzschia palea var. *tenuirostris* Grun.	E P
Nitzschia romana Grun.	
Nitzschia tryblionella var. *subsalina* (O'Meara) Grun.	
Synedra acus Kütz.	M A
Synedra ulna var. *amphirynchus* (Ehr.) Grun.	

EUGLENOPHYCEAE

Table 3. (Continued)

Anabaena sp.			*Euglena agilis* Carter	E
Anabaenopsis arnoldii Aptek.			*Euglena allorgei* Defl.	E
Anabaenopsis circularis (G. S. West) Wol. *et* Miller			*Euglena gracilis* Klebs	E
Anabaenopsis elenkini V. Miller			*Lepocinclis fusiformis* (Carter) Lemm	E.
Anabaenopsis tanganyikae (G. S. West) Wol. *et* Miller			*Trachelomonas intermedia* Dang.	E
Aphanocapsa delicatissima W. West *et* G. S. West			*Trachelomonas volvocinopsis* Swir.	E
Aphanocapsa koordersi Strom				
Aphanocapsa pulchra (Kütz.) Rabenh.				
Aphanocapsa roeseana de Bary			TRIBOPHYCEAE	
Aphanothece caldariorum Richter				
Chroococcus minor (Kütz.) Näg.			*Goniochloris mutica* (A. Brawn) Fott	E
Chroococcus minutus (Kütz.) Näg.				
Coelosphaerium palidum Lemm.				
Coelosphaerium pusillum Van Goor			DINOPHYCEAE	
Eucapsis alpina Clements *et* Shantz				
Lyngbya contorta Lemm.			*Gymnodinium* sp.	
Lyngbya limnetica Lemm.			*Peridinium lomnickii* Wolosz.	
Merismopedia minima Beck			*Peridinium* spp.	
Merismopedia punctata Meyen	E			
Microcystis aeruginosa Kütz.	E	P		
Microcystis pulverea var. *incerta* (Lemm.) Crow				
Microcystis robusta (Clark) Nygaard				
Oscillatoria annae Van Goor				
Oscillatoria chlorina Kütz.	E			
Oscillatoria tenuis Ag.				
Pseudoanabaena catenata Lauterb.				
Raphidiopsis curvata Fritsch *et* Rich				
Raphidiopsis mediterranea Skuja				
Spirulina maior Kütz.	E			

Cronberg, 1982; Cabeçadas *et al.*, 1986; Olive & Deshon, 1986; Berg *et al.*, 1987; Cowell *et al.*, 1987. Dawes *et al.*, 1987). There are several hypotheses to explain dominance of blue-greens in these conditions (Tilzer, 1987; Shapiro, 1990); low availability of CO_2 and/or high pH, and reduced transparency seem to be the most important factors that account for Cyanophyceae being especially competitive in these shallow and nutrients rich lakes.

Table 4. Average phytoplankton densities (algae ml^{-1}), diversities and richness for each lake.

	Cyanophyceae	Chlorophyceae	Bacillariophyceae	Total phytoplanktonic density	Species diversity (Shannon-Weaver)	Richness (species number)
Todos los Santos	92320	7541	121	100710	2.08	53
Colís	263	3140	345	3993	4.63	61
La Salada	4833	6928	2001	14042	4.12	70
Lobos	43785	3099	661	47794	2.25	60
Culú-Culú	592	3688	11192	16506	4.19	59
S. M. del Monte	2437	1310	944	4833	3.74	59
Chascomús	5378	1344	5951	13576	3.04	63
Adela	252	641	473	1814	4.85	75
Chis-Chis	266	315	37	693	4.42	57
La Tablilla	165	266	405	1039	4.27	70
Las Barrancas	8750	846	695	10942	4.05	103

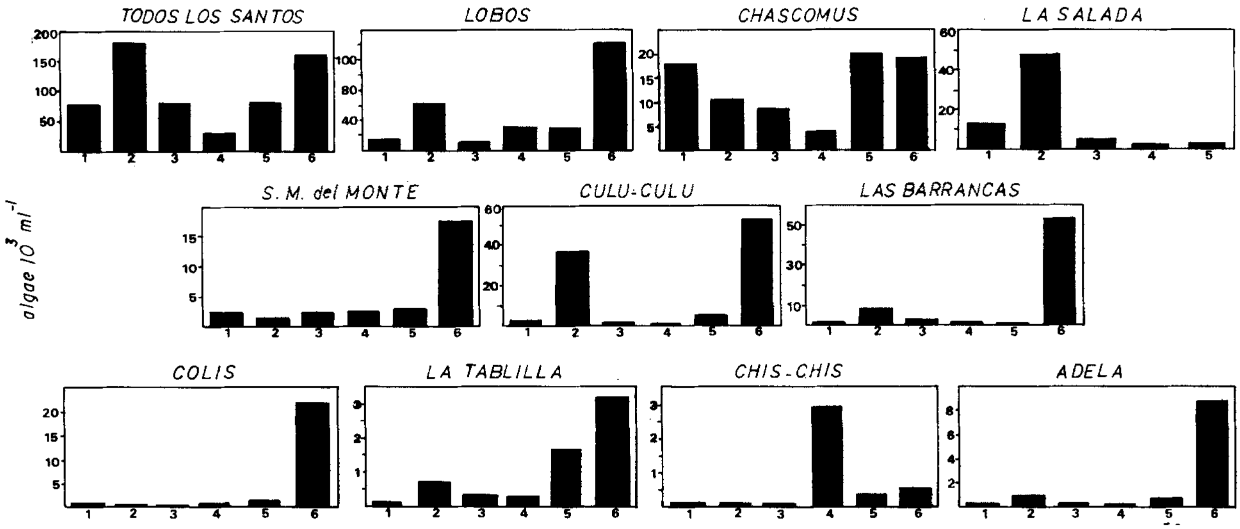

Fig. 3. Seasonal changes of phytoplankton densities for each lake. 1: spring 1987; 2: summer 1988; 3: fall 1988; 4: winter 1988; 5: spring 1988; 6: summer 1989.

The lakes completely colonized by macrophytes (Colís, Culú-Culú, Adela, Chis-Chis, La Tablilla and Las Barrancas) showed lowest algal densities, with average values ranging from 690 to 16500 algae ml^{-1}. On the other hand, their species diversities were higher than those observed in lakes less densely populated by higher plants, varying, on the average between 4.05 and 4.85. These communities comprise many tychoplanktonic species, usually associated with periphytic and benthic habitats. In these lakes algal blooms have never been recorded during the present study.

Monte and La Salada Lakes showed intermediate density and diversity values.

The highest phytoplankton densities recorded

Table 5. Summary of the principal characteristics of the phytoplankton communities of the two lake types defined in this work. Data are average values based on samples collected between 1987 and 1989 in the 11 studied lakes.

	Shallow lakes completely colonized by macrophytes	Shallow lakes with less development of macrophytes
Phytoplanktonic richness	71	61
Species diversity (Shannon-Weaver)	4.40	3.05
Phytoplankton density (algae ml^{-1})	5,831	36,191
Algae blooms	No	Yes
Dominant group of algae	None	Cyanophyceae, Chlorophyceae
Dominant species	Without dominant species. Frequency of species of *Monoraphidium*, *Tetraedron*, *Didymocystis*, *Fragilaria*, and *Nitzschia* genus. Abundant tycoplanktonic species.	*Aphanocapsa delicatissima*, *Lyngbya contorta*, *Lyngbya limnetica*, *Oscillatoria tenuis*, *Anabaena* spp., *Aulacoseira granulata*, *Cyclotella meneghiniana*, *Fragilaria construens*

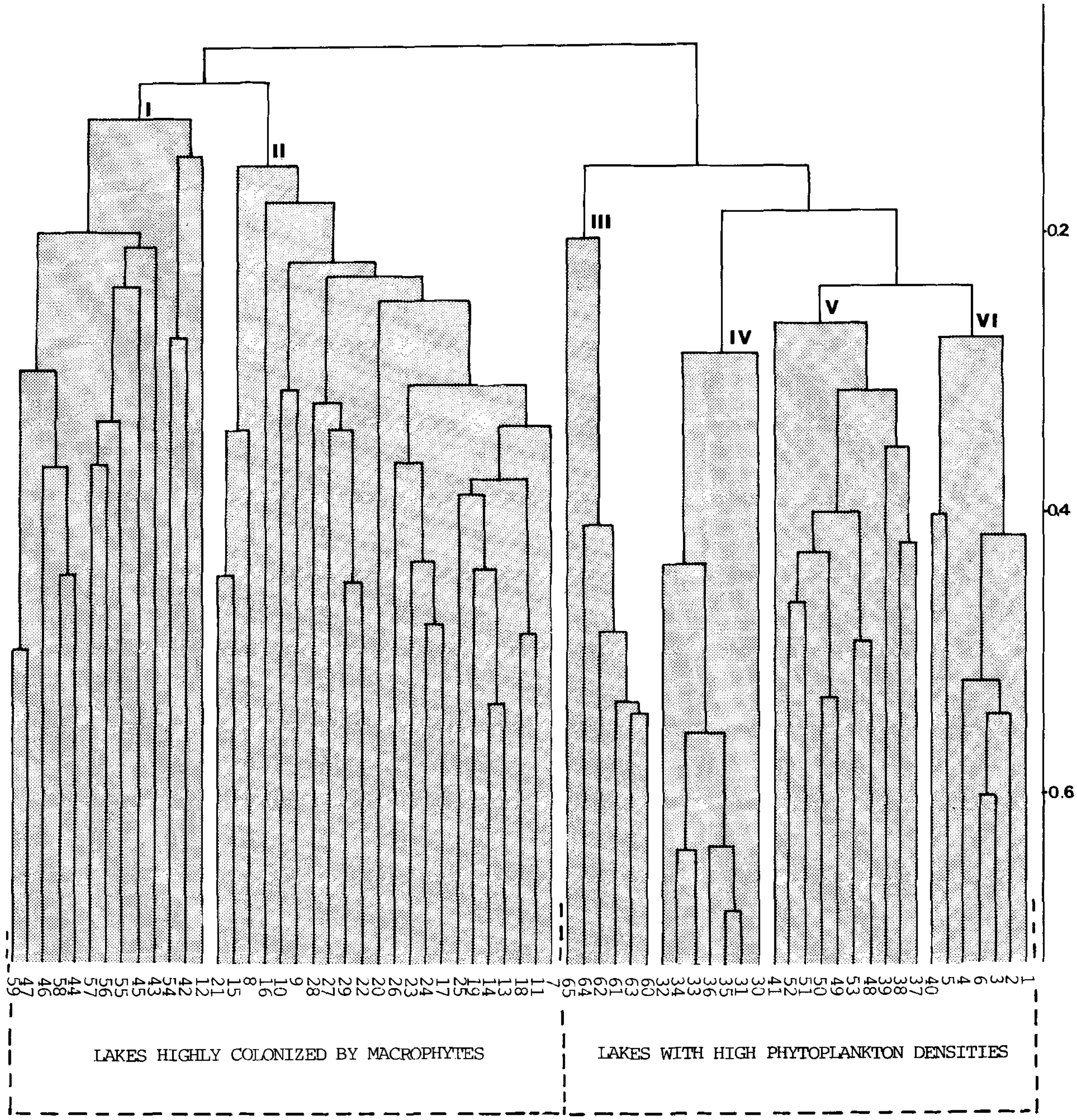

Fig. 4. Results of the Cluster Analysis based on phytoplankton composition. Sample codes are indicated in Table 2.

in summer 1989 in most of the lakes were due to a concentration effect during this dry period. In particular, La Salada Lake dried out completely in this season (Fig. 3).

Our results suggest that the phytoplankton community is strongly influenced by the macrophytes, directly as well as indirectly. In lakes where macrophytes are abundant, the waters are more clear and phytoplankton is typically scarce and more diverse. Engel (1988), studying a shallow Wisconsin lake, concluded that submerged macrophytes delayed blooms of blue-green algae

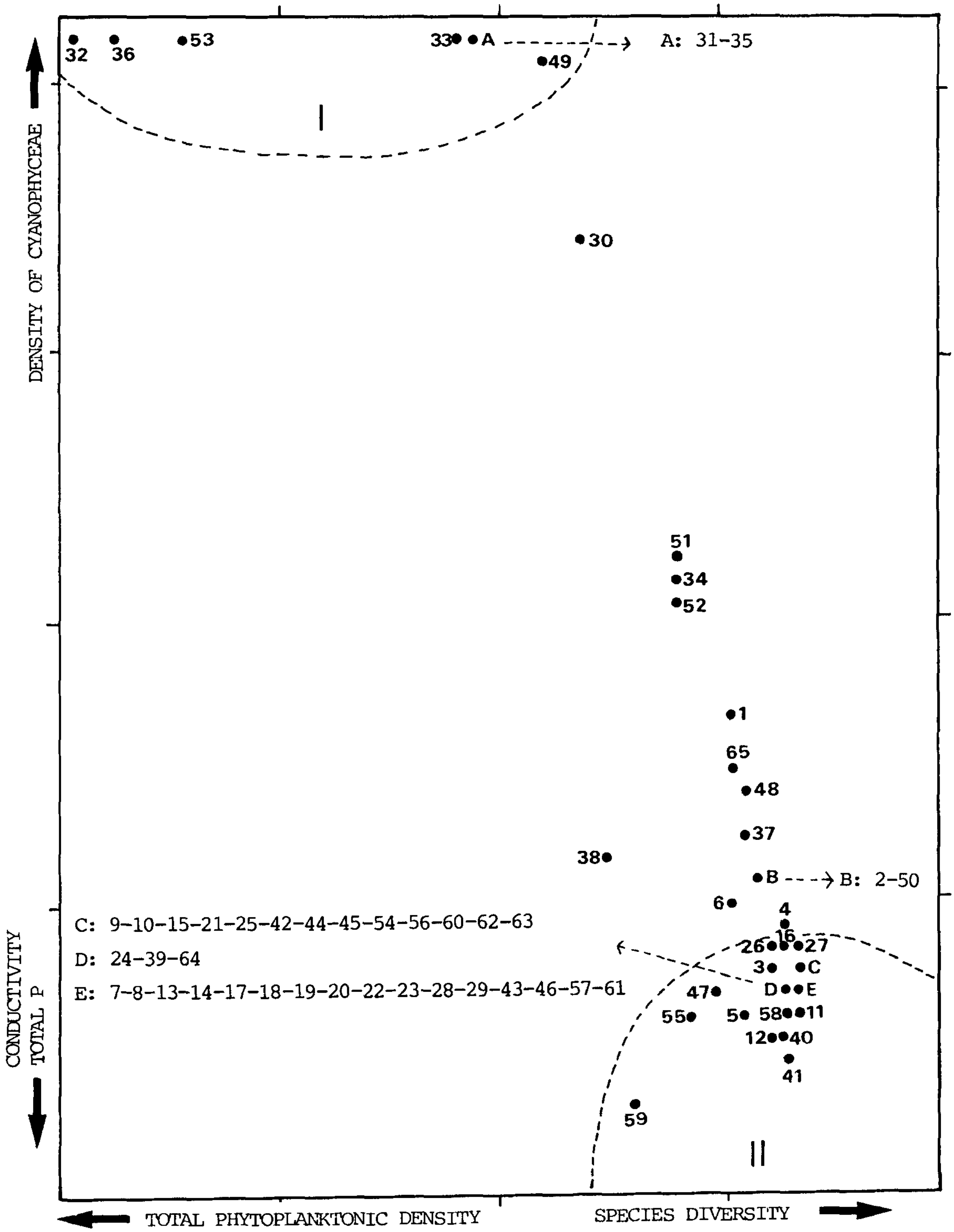

Fig. 5. Representation of the first and second component of the PCA performed with phytoplanktonic and abiotic data. Cumulative variance in both axis I and II: 47.52%. Sample codes are indicated in Table 2.

through storage of nutrients and interception of land runoff. Complementarily, low phytoplanktonic densities could respond to high competition from periphytic algae. In lakes where the macrophytes are abundant, periphytic algae are abundant too. According to Hansson (1988), periphyton covering the sediment surface depresses growth of planktonic algae by reducing the outflow of dissolved nutrients from the mineralization zone. This mechanism may be important, especially in shallow lakes.

All the differences between the lakes surveyed are summarized in Table 5. We characterize the structure of the phytoplankton communities defining their main attributes.

Cluster analysis and PCA

Results of the numerical analyses reflect the differences discussed above.

The classification of the lakes yielded two large groups (Fig. 4). One of them includes lakes highly colonized by macrophytes. The second group includes the lakes with higher densities of phytoplankton, and in general, those which have less development of macrophytes. Within the second group the planktonic communities are more heterogeneous. Thus, subgroups formed by particular lakes can be observed in the dendrogram. These results agree with the observations of Lyche (1990), who found that the phytoplankton of different eutrophic lakes are very dissimilar, probably due to the dominance of a single species, which often differs from one lake to another.

The first four factors of the PCA account for 70% of the total variance. The first principal component is directly correlated with species diversity and inversely with total phytoplanktonic density and with the abundance of Cyanophyceae and Chlorophyceae. The second factor has a strong loading on density of Cyanophyceae and is inversely correlated with conductivity and total P. Figure 5 shows the ordination of the samples in the space defined by the first two axes. One corner (upper left) host principally the summer samples from the two lakes dominated by Cyanophyceae, Todos los Santos and Lobos (encircled in I). The opposite corner (lower-right) is occupied by the samples from the shallow lakes with high macrophytic densities (encircled in II). Although Chascomús belongs to a chained lake-system, it is isolated from the rest because of its higher phytoplankton density, as noticed in the Cluster Analysis.

The PCA reveals that, in spite of the extreme differences discussed above, there is a transition between lake. types. This fact may be due, among other factors, to seasonal fluctuations. This work constitutes a first attempt to simplify the variability of these aquatic environments, but the classification obtained can be modified if other variables are taken into account.

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