

## Coccal green algae (Chlorophyta) in shallow ponds in Veracruz, México

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With 126 figures and 2 tables

**Abstract:** A taxonomical and ecological characterization of some unicellular and coenobial species of green algae from few shallow water bodies of the Mexican Gulf coastal plateau is presented. Sixty-nine taxa were registered including a new form: *Coelastrum pulchrum* f. *taverae* nov. forma. The majority of species in the studied environments have a wide geographical distribution (85.5 %); a small percentage of them is exclusively tropical, 5.8 %, exclusively temperate (4.4 %) or known in warm waters from the temperate zone (4.3 %). The importance of shallow water bodies in the distribution and dispersion of species to other environments within the area is discussed, considering particularly the composition of species and the size of the algae involved.

**Key words:** Chlorococcales, Chlorophyta, ponds, tropics, geographical distribution, México.

### Introduction

In the last years, phylogenetic trees based on 18S rRNA gene sequence analysis have provided new insights into the systematics of the coccoid green algae (HANAGATA 1998, HEGEWALD & HANAGATA 2000, among others). The molecular genetic investigations offer quite new criteria to clarify the relationship into a group or among the different algal groups; however, in practical terms, the morphological classification remains until now as a worldwide resource for limnological and ecological studies. For this reason, in this work a detailed discussion on supraspecific systematic was not included.

Chlorococcalean are actually recognized as a heterogeneous group of algae whose phylogenetic relationships must be clarified; nevertheless, from the ecological point of view they are widely accepted as a more or less consistent entity, exhibiting similar adaptive responses like sensitivity to concentration of nutrients

and light. The reference to Chlorococcales in eutrophic water bodies is traditional in literature, especially in shallow waters (ROUND 1981). If we consider these algae as an ecological group, they are valuable to interpret survival strategies in phytoplankton and to characterize communities. Many chlorococcalean algae have a short life cycle and fast growth (REYNOLDS 1984) and many species are able to grow up in sprays (LUTY & HOSHAW 1967, MROSIŃSKA 1990, NEUSTUPA 2004) what confers them a high capacity of dispersion and colonization. In the short time, chlorococcalean algae may form important populations in phytoplankton (HAPPEY-WOOD 1988) and as a function of their rapid response to environmental conditions, are a good element for identifying and typifying limits and directions of environmental changes in aquatic ecosystems.

The classification of phytoplankton established by REYNOLDS and his co-workers (2002) refers the conspicuous presence of green algae as characteristic elements in their assemblages; frequently, species of chlorococcalean are abundant in such assemblages. In lotic as well as lentic-environments with low current velocity (comparable to lakes with brief retention times), Chlorophyta and specially chlorococcalean s.l. are an important phytoplanktic element, commonly as the dominant group or co-dominant with diatoms (HAPPEY-WOOD 1988). Although, planktic chlorococcaleans are generally temporal populations in deep lakes (SOMMER et al. 1986, LAMPERT & SOMMER 1997), part of their life cycle may occur in benthic or shallow conditions. HAPPEY-WOOD (1988) mentions the interchange of active growth species may be ecologically significant only in shallow or well-mixed water bodies, though the populations growing in very shallow environments may act as inocula of larger water bodies within the basin.

The established patterns for high latitudes do not have a counterpart in the low latitudes (HAPPEY-WOOD 1988). We consider that in the Tropics the ecological role of the shallow water bodies as floristic reservoirs can be only preliminary established or related to the geographical distribution of species. In this context, the taxonomical characterization of chlorococcalean algae gets relevant for the Tropics to find environmental latitudinal profiles (LEWIS 1996).

In the quite different climatic zones of the large Mexican territory, there are many water bodies of different ecology that facilitate comparative and valuable studies about biodiversity of algal communities. From the State of Veracruz, only 17 species of Chlorococcales s.l. have been recorded (MARGAIN-HERNÁNDEZ 1981, 1989, ORTEGA 1984, TAVERA 1996); in spite of it is one of the richest States in permanent and temporal water bodies, especially in pluvial and fluvial types.

The principal aim in this study is to present an illustrated account of the distribution, life form and affinity to trophic conditions of the unicellular and coenobial green chlorophytes formerly belonging to Chlorococcales s.l., and to assess richness of the group in shallow water bodies in a tropical region, as elements to analyze the floristic potential of algae in Veracruz.

## Study Area

Numerous shallow water bodies exist between rivers, streams and lakes in the coastal plateau in the State of Veracruz-Llave. Many of them are permanent, like those included in this work. The studied sites were Paso del Toro ( $19^{\circ}01'19''$  N and  $96^{\circ}08'01''$  W), La Piedra ( $18^{\circ}58'08''$  N and  $96^{\circ}05'13''$  W) and Cerro Gordo ( $19^{\circ}00'13''$  N and  $96^{\circ}06'36''$  W) (Fig. 1). These are rainwater ponds without a

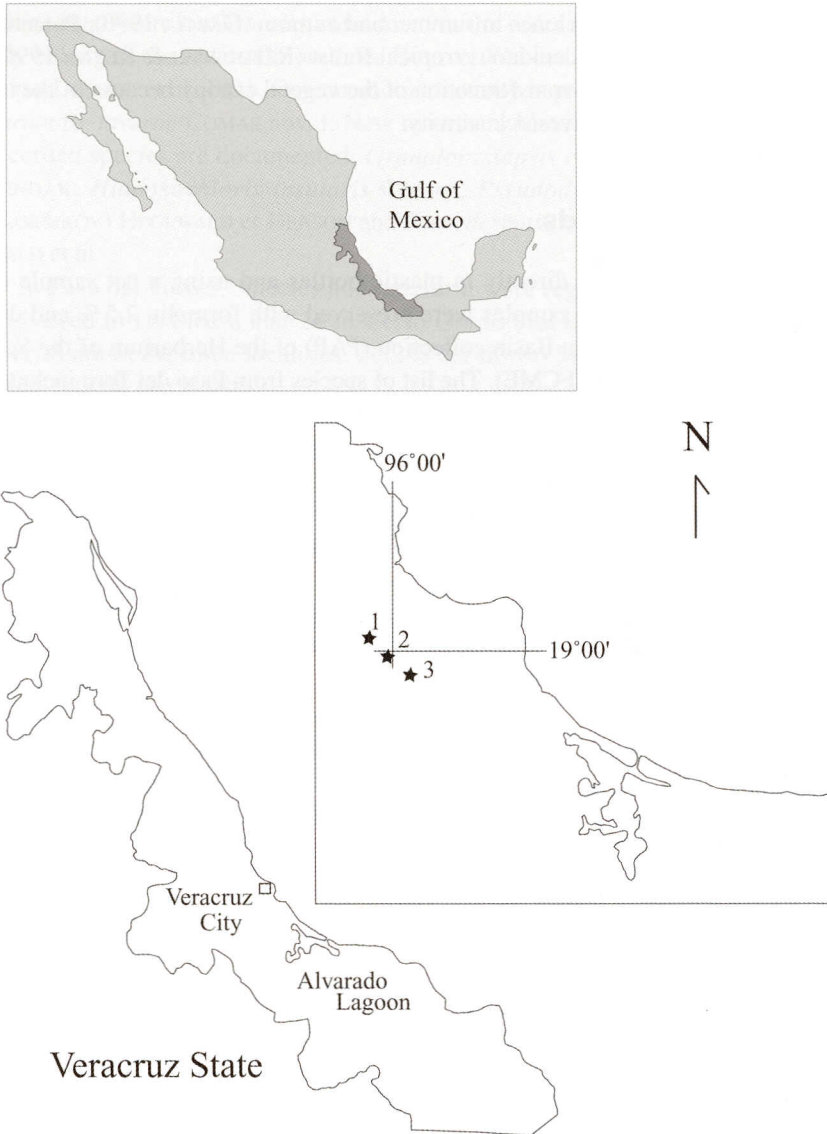


Fig. 1. Location of collecting sites. 1 = Paso del Toro; 2 = Cerro Gordo; 3 = La Piedra. State of Veracruz-Llave, México.

specific use, though sometimes the cattle drink water there. They are located at 18–25 meters above sea level in an area of low fluvial plateaus with alluvial-accumulative costal deposits formed in the Quaternary (LUGO-HUBP & CÓRDOVA 1990, CSERNA 1990). The soils in this region have a constant humidity regime with gravel, sand and silt (MAPLES-VERMEERSCH 1990, MARÍN et al. 1990). The mean annual temperature is higher than 26 °C, with a mean annual precipitation of 1500–2000 mm and 50 to 100 annual cloudy days (VIDAL-ZEPEDA 1990). The weather according to KÖPPEN, modified by GARCÍA is warm-subhumid with summer rains and tropical cyclones in summer and autumn (GARCÍA 1990). Potential vegetation in the area is deciduous tropical forest (RZEDOWSKI & REYNA 1990), but with a high degree of transformation of the vegetal canopy because of the intensive agricultural and livestock activity.

## Material and Methods

Samples were collected directly in plastic bottles and using a net sample of 10 µm mesh. Reference samples were preserved with formalin 2.5 % and deposited in the Papaloapan Basin collection (PAP) of the Herbarium of the Sciences School at UNAM (FCME). The list of species from Paso del Toro includes material from a collection realized in 1994 and kindly provided by Dr. Jiří KOMÁREK. Samples were observed in a Nikon Optiphot (Japan) microscope with DIC; documentation of species was performed with Ektachrome Tungsten-professional 64 and Agfa APX100. Registration of pH, conductivity and temperature was made with field equipment probes Conductronic (México). Transparency was measured by Secchi depth.

The richness analysis used jackknife (KREBS 1998), based on presence of species; the sites were considered as quadrats sampled in an area. Jackknife estimator is calculated by the formula:

$$\hat{S} = s + \left( \frac{n-1}{n} \right) k$$

where  $\hat{S}$  is the jackknife estimate of species richness;  $s$  is the observed total number of species present in the  $n$  quadrats;  $n$  is the total number of quadrat samples and  $k$  is the number of unique species. The variance measures the confidence limits for the jackknife estimator:

$$\text{var}(\hat{S}) = \left( \frac{n-1}{n} \right) \left[ \sum_{j=1}^n (j^2 f_j) - \frac{k^2}{n} \right]$$

where  $\text{var}(\hat{S})$  is variance of  $\hat{S}$  from the jackknife estimate equation;  $f_j$  is the number of quadrats containing  $j$  unique species ( $j = 1, 2, 3, \dots, s$ );  $k$  is the number of unique species and  $n$  is the total number of quadrat samples.

## Results

The studied water bodies are shallow and small, completely open. In spite of differences in size among them, water temperature is similar; the color of water is slightly green and not turbid. Conductivity is moderate and pH is circumneutral to alkaline (Table 1).

Sixty-nine taxa of unicellular and coenobial chlorophytes were determined; those species without a previous record to México are described and illustrated. These algae were traditionally considered in the order Chlorococcales and actually belong to the orders Chlorellales BOLD et WYNNE 1978 and Sphaeropleales *sensu* DEASON et al. 1991. One taxonomic novelty is presented, *Coelastrum pulchrum* fo. *tavaerae* COMAS nov. f. New records to México as well as some rarely recorded species are documented: *Granulocystopsis coronata* (LEMMERMANN) HINDÁK, *Hindakochloris insularis* COMAS, *Pseudodydimocystis planctonica* (KORŠIKOV) HEGEWALD et DEASON and *Scenedesmus indicus* PHILIPOSE ex HEGEWALD et al.

In Paso del Toro 53 species and one form were registered; 30 species were registered in La Piedra and 24 in Cerro Gordo (Table 2). Only 10.2% of the species are in the three localities, 36.2% are in two localities and 53.6% were found only in one locality.

Most of the species have a wide distribution (85.5%); the 5.8% have a tropical distribution; some (4.4%) have been registered only as temperate in distribution and some (4.3%) are present in warm waters from the temperate zone (Table 2).

The species registered have a planktic and/or periphytic life form but *Botryococcus braunii* KÜTZING can also live in the benthos (Table 2). Only four of the determined species have been registered as exclusively from oligotrophic environments, the others grow in meso- to eutrophic environments and may have a wide tolerance to the trophic level. Even if for some of the species the type of environment where they grow is not defined, most are recorded from stagnant waters, while 18.6% are known from running water.

Almost half of the species (47%) are smaller than 20  $\mu\text{m}$ , whereas the remaining taxa are larger.

The richness estimation ( $\hat{S}$ ) indicated that we might expect a total diversity value of 94.6 species considering the three sampling sites. At  $n-1$  degrees of free-

Table 1. Values of some parameters in the water bodies studied. Figures correspond to 2001.

	surface	highest	Secchi	Conductivity	Temperature	pH
	(m <sup>2</sup> )	depth	depth	$\mu\text{S cm}^{-1}$	(° C)	(units)
		(m)	(m)			
Paso del Toro	80	0.9	0.45	460	27	7.8
La Piedra	2695	1.15	0.60	330	23	7.2
Cerro Gordo	437	2.05	0.55	378	25	8

Table 2. Localities: **1** = Paso del Toro; **2** = Cerro Gordo; **3** = La Piedra. Geography (Geogr.): **c** = cosmopolitan; **t** = temperate; **ww** = warm water in the temperate zone; **tr** = tropical. Life Form (L.F.): **pl** = planktic; **pe** = periphytic; **b** = benthic. Environment (Env.): **0** = every type; **1** = large lakes; **2** = small lakes; **3** = lagoons; **4** = ponds; **5** = rivers; **6** = streams; **7** = reservoirs; **8** = stagnant water, not specified; **9** = running water, not specified. Trophic Level (T.L.): **o** = oligotrophic; **m** = mesotrophic; **e** = eutrophic; **w** = wide range. New record to México = N.R. – = Not specified. Source for columns 3–7 from cited literature.

Species	Locality	Geogr.	L. F.	Env.	T. L.	N. R.
<i>Ankistrodesmus falcatus</i>	3	c	pl	–	m	
<i>Botryococcus braunii</i>	3	c	pl, b	–	–	
<i>B. terribilis</i>	1, 3	c	pl	–	o, m	+
<i>Closteriopsis acicularis</i>	3	c	pl	8, 9	m	
<i>Coelastrum indicum</i>	1, 2, 3	ww	pl	2	eu	+
<i>C. microporum</i>	1, 2, 3	c, t	pl	–	eu	
<i>C. pseudomicroporum</i>	1, 2, 3	t	pl	2, 4	eu	+
<i>C. pulchrum</i>	1	ww	pl	2	–	+
<i>C. pulchrum</i> f. <i>taverae</i>	1	tr	pl	4	eu	+
<i>Coenococcus tetrasporus</i>	3	tr	–	4	eu-m	+
<i>Crucigenia mucronata</i>	1	c	pl	–	eu	+
<i>Crucigeniella apiculata</i>	1, 2, 3	c	pl	1, 4	eu	+
<i>Desmodesmus abundans</i>	1	c	pl	4	eu	
<i>D. armatus</i> var. <i>armatus</i>	2	c	pl	–	w	
<i>D. armatus</i> var. <i>spinosus</i>	1	c, common in t	pl	1, 7	–	
<i>D. denticulatus</i>	1	c, common in t	pl	1, 7	–	
<i>D. lefevrei</i>	1	c	pl	0	eu	+
<i>D. maximus</i>	1, 2	c	pl	1, 4, 7	–	
<i>D. opoliensis</i>	1, 2	c	pl	0	eu	
<i>D. serratus</i>	1, 3	c	pl	2	–	
<i>D. spinulatus</i>	1	c	–	1, 2	–	+
<i>Desmodesmus</i> sp.	1					
<i>Dictyosphaerium ehren-</i> <i>bergianum</i>	1, 2, 3	c	pl	1, 4, 5	eu	
<i>D. pulchellum</i>	1, 3	ww	pl, pe	8, 9	o	
<i>Granulocystopsis coronata</i>	3	c	pl	2, 4, 5	–	+
<i>Gregiochloris lacustris</i>	1, 3	c	pl	1, 4,	o	
<i>Hindakochloris insularis</i>	3	c	pl, d	4	eu	+
<i>Kirchneriella aperta</i>	1, 3	c	pl, pe	4	eu	+
<i>K. hindakiana</i>	1	t	–	–	–	+
<i>K. irregularis</i> var. <i>irregularis</i>	1, 2	c	Pe	4	eu	+
<i>K. irregularis</i> var. <i>spiralis</i>	3	c, >tr	pl, pe	–	–	+
<i>K. lunaris</i>	1	c	pl	4	m-eu	
<i>K. obesa</i>	1, 2	c	pl, pe	4	eu	
<i>Korshikoviella limnetica</i>	1, 3	c	pl	–	–	+
<i>Monoraphidium contortum</i>	1, 2, 3	c	pl	4, 5	o-m-eu	
<i>Nephrocitium lunatum</i>	3	t, tr (c)	pl	8	–	
<i>Oocystis borgei</i>	1, 2	c	pl	2	m	
<i>O. lacustris</i>	1, 3	c, rare in tr	pl	–	o-eu	
<i>Pediastrum boryanum</i>	1, 2	c	pl, pe	0	w	
<i>P. duplex</i> var. <i>duplex</i>	3	c	pl	4	eu	
<i>P. duplex</i> var. <i>gracillimum</i>	1	c, >t, <tr	pl, pe	1, 2	–	+
<i>P. subgranulatum</i>	1	c	pl	4	eu	
<i>P. tetras</i>	1	c	pl	0	o-eu	
<i>Pseudodidymocystis planctonica</i>	2	c	pl	–	eu	+
<i>Raphidocelis arcuata</i>	1, 3	tr	pl	1	o	+

Table 2. (continued)

<i>R. contorta</i>	1, 3	c	pl	4	eu	+
<i>Raphidocelis</i> sp.	1					
<i>Scenedesmus acuminatus</i>	1, 2	c	pl	0	w	
<i>S. arcuatus</i> var. <i>platydiscus</i>	1	c	pl	5	–	
<i>S. indicus</i>	1	c	pl	4	m-eu	+
<i>S. obliquus</i> var. <i>dimorphus</i>	1, 2	c	pl	4	eu	
<i>S. obtusus</i>	2	c	pl	5	–	
<i>S. verrucosus</i>	1, 3	c	pl, pe	4	eu	
<i>Schroederia setigera</i>	1	tr	pl	1, 7	eu	
<i>Selenastrum bibrainum</i>	1, 2	c	pl, pe	–	–	+
<i>S. gracile</i>	1, 2, 3	c	pl	4	eu	
<i>Siderocelis ornata</i>	1, 3	c	pl	2, 4, 6	–	+
<i>Sorastrum americanum</i>	1, 3	c	pl	4	o	
<i>Tetrachlorella alternans</i>	1, 2	t	pl	–	eu	+
<i>Tetraedron caudatum</i>	1	c	pl	4	eu	
<i>T. minimum</i>	1, 2	c	pl, pe	0	w	
<i>Tetralantos lagerheimii</i>	1	c	pl	2, 4	eu	+
<i>Tetrastrum elegans</i>	2	c	pl	–	eu	+
<i>T. heteracanthum</i>	1	c	pl	–	eu	
<i>T. homoiacanthum</i>	1	c	–	3	o	+
<i>T. komarekii</i>	2, 3	c	pl	4	eu	+
<i>T. triangulare</i>	1	c	pl	4	eu	+
<i>Treubaria triappendiculata</i>	3	c	pl	1, 4, 5	eu	
<i>Westella botryodes</i>	1, 2	c	pl	4	eu	

dom and 95% confidence interval, the variance of this value fluctuates between 78 and 110 species.

## Description of taxa

*Ankistrodesmus falcatus* (CORDA) RALFS (Figs 2, 72)  
Cells: 40–50 x 1.6–2 µm.

*Botryococcus braunii* KÜTZING (Figs 3, 73)  
Cells: 12–14 x 5.6–6 µm. Colonies have a maximum diameter of 152 µm.  
The ovoid cells cover up to half of their length with a mucilaginous envelope. This species has long autospores and cells with a less denser arrangement than *B. terribilis* KOMÁREK et MARVAN 1992.

*B. terribilis* KOMÁREK et MARVAN (Figs 4, 74)  
Colonies are irregular to near spherical, with brownish mucilage. Cells are obovate with a parietal chloroplast and one pyrenoid, densely joined in a radial disposition and covered by the mucilage in more than half of their length. The connecting tubules are short and occasionally not visible. Colonies: 83.2 µm in diameter as maximum; cells: 8–10 x 5 µm.

New record to México.

*Botryococcus terribilis* has typical mucous ramifications at the colony borders. In the Paso del Toro population, our exemplars lack these ramifications; however, we identified them as *B. terribilis* because of their dimension, the obovate cells densely disposed in colonies and mostly covered by the colonial sheath.

*Closteriopsis acicularis* (G.M. SMITH) BELCHER et SWALE (Figs 5, 75)

Cells: 44–52 x 2.4–3 µm.

This species was recorded previously in México (TAVERA et al. 2000). The Veracruzuan population is not typical; it presents straight as well as slightly curved cells with abruptly pointed ends.

*Coelastrum indicum* TURNER (Figs 6, 76)

Spherical coenobia have 8 to 16 cells, which are spherical in lateral view, bearing 5 to 6 short and wide joining projections and a slight thickening in the apical cell wall. Protoplast is circular to polyhedral in polar view. Cells: 5.6–13.2 µm in diameter. Diameter of 6-celled coenobia: 23.6–24.8 µm.

New record to México.

*C. microporum* NÄGELI in A. BRAUN (Figs 7, 77)

Spherical coenobia have 8 to 16 cells, which are spherical in lateral view, without joining projections between them and without apical thickenings. Cells: 4–5.6 µm in diameter. Coenobia: 12.5–24 µm.

The Veracruzuan exemplars are smaller than those recorded from Cuba (COMAS 1996).

*C. pseudomicroporum* KORŠIKOV (Figs 8, 78)

Spherical coenobia have 8 to 16 cells, which are oval to cuneiform in lateral view, with 5 to 6 short and cylindrical joining projections between cells, and apical thickenings in the cell walls. In polar view, the protoplast is circular. Cells: 5.6–13.6 µm in diameter and 6.4–8 µm high. Coenobia: 17–32 µm in diameter.

New record to México.

The populations from Paso del Toro have bigger dimensions than in the species diagnosis.

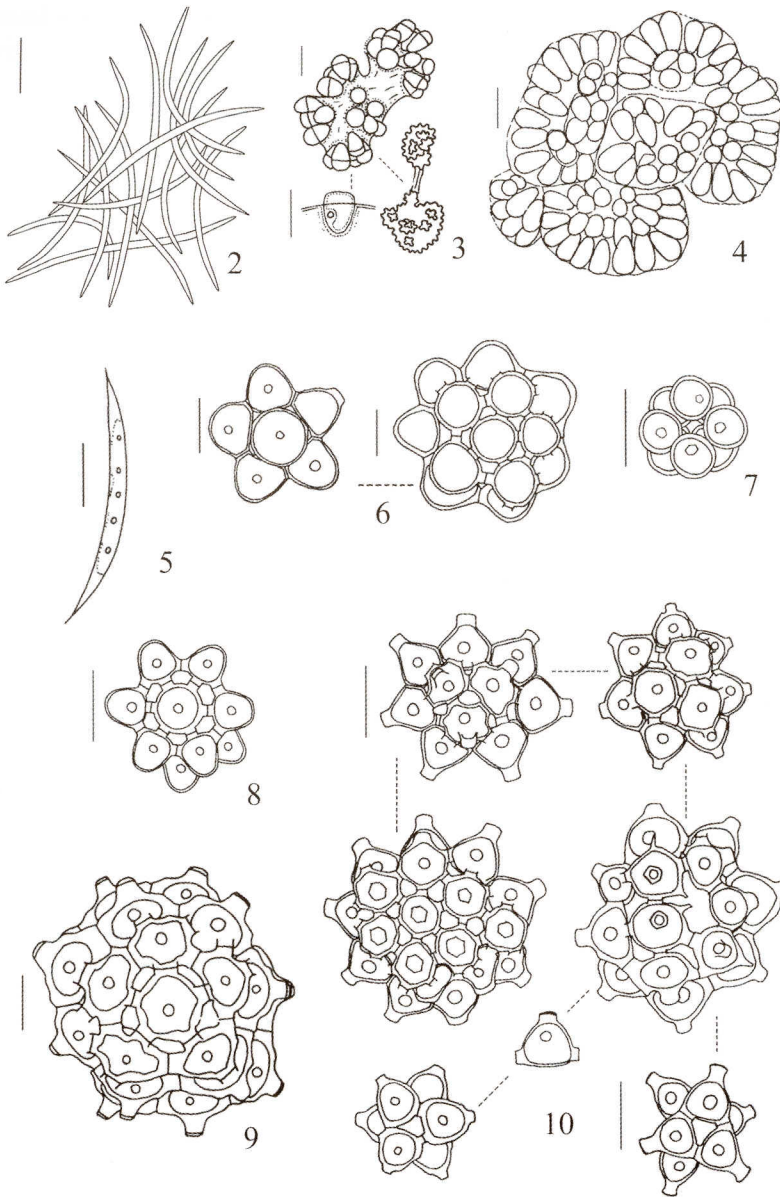
*C. pulchrum* SCHMIDLE (Figs 9, 79)

This species is mainly characterized by its nearly polygonal cells in lateral view; their apical ends have a free, cylindrical process of variable length depending on the specimen age. In the spherical coenobia, the cells join by more or less conical connecting processes, which are 5–6 according to the number of neighbouring cells, but always an appendix is present between two close cells. Coenobia have irregular intercellular spaces.

New record to México.

In the populations of this species, two different morphotypes are clearly distinguishable: One whose features correspond with SCHMIDLE's description





Figs 2-10. 2 - *Ankistrodesmus falcatus*; 3 - *Botryococcus braunii*; 4 - *B. terribilis*; 5 - *Closteriopsis acicularis*; 6 - *Coelastrum indicum*; 7 - *C. microporum*; 8 - *C. pseudomicroporum*; 9 - *C. pulchrum*; 10 - *C. pulchrum* f. *taverae* nov. f. Bars = 10  $\mu$ m.

(1892), but the adult individuals additionally have a tiny depression in lateral view, to both sides of the bases of the apical processes. These depressions give the appearance of "shoulders" to the superior margin of the cells. The second morphotype (see COMAS 1989) corresponds to individuals with triangular cells in lateral view, with convergent superior margins in juvenile stages and especially in adults; these margins are more or less rounded and lineal up to the apex. Moreover, at the base of the free processes, these individuals have a lateral narrowing which does not reach the interior of the cell. Both morphological types are also different in some quantitative features. In the typical *C. pulchrum* (Figs 9, 79), the cells are 9.6–22  $\mu\text{m}$  in diameter with the apical appendix 1.8–6.4 in length; in the other morphological type, cells are 4–11.2  $\mu\text{m}$  in diameter, with the apical appendix 1.6–2.8  $\mu\text{m}$  in length.

In Paso del Toro, the second morphological type is more abundant. We have considered this population as an independent taxon at the taxonomical rank of forma and its description is the following:

*C. pulchrum* f. *taverae* COMAS nov. f. (Figs 10, 80a–c)

Diagnosis: A typo cellulis praecipue plus minusve triangularis differt.

Holotypus: Figura nostra 10.

Etymologia: Forma ad honorem Rosaluz Tavera nominata.

Spherical coenobia composed by 8–16 cells, joined to each other by 5–6 cylindrical to conical, appendices; always an appendix between two neighbouring cells. Spaces between cells are triangular or irregularly circular. In lateral view, cells are triangular with the superior margins converging straightly toward the apex (in young stages), or with round outlines (adult stages); in the apical region a free process, protruded, more or less cylindrical in its 2/3 part, then widening toward the truncate-rounded pole (Fig. 80c). At the basis, these free appendices present a lateral narrowing. In polar view, cells are polyhedral. Chloroplasts are ovate to ovate-triangular in lateral view, compressed in the basal part; in polar view, they appear polyhedral to near spherical. Cells: 4–11.2  $\mu\text{m}$  in diameter; apical appendix: 1.6–2.8  $\mu\text{m}$  in length. Coenobia: 22.4–34  $\mu\text{m}$  in diameter.

*C. pulchrum* f. *taverae* nov. f. could be considered close to *C. proboscideum* BOHLIN in WITTRÖCK et al. 1896, but this species does not form free appendices properly; instead the external layers of the cells wall fold to form a proboscoid or trunk (COMAS & KRIENITZ 1997), the cells are triangular and their protoplasts are also triangular in polar view. In addition, the cells are joined directly by their cell walls and the coenobia are more or less cubical (see COMAS 1992a).

In *C. pulchrum* two infraspecific taxa are known: var. *collifer* (KAMMERER) KOMÁREK 1983 and var. *cruciatum* (KAMMERER) KOMÁREK 1983. The first one with three apical appendices is perhaps closely related to *C. stuhlmannii* SCHMIDLE 1900, the second one was considered as an independent species (*C. bohlianum* COMAS 1982).

*Coenococcus tetrasporus* (KOMÁREK) HINDÁK (Figs 11, 81a–b)

Globose, spherical or amorphous colonies formed by multiple families of 4 to 16 cells tetrahedrally ordered. The mucilaginous envelope is diffluent, continuous, without defined stratification between families, and just slightly visible in some cells or around recently divided autospores. Cells are spherical with a cup-shaped chloroplast with one pyrenoid. Autospores disposed tetrahedrally inside sporangium. Cells: 2.4–4 µm in diameter.

New record to México.

This species was originally described from Cuba as *Eutetramorus tetrasporus* KOMÁREK 1983 and until now, it had only been recorded in that country. We accept the suggestion by HINDÁK (1977, 1984), followed also by JOHN & TSARENKO (2002), to use *Coenococcus* instead of *Eutetramorus* WALTON because it has an incomplete description based on *E. globosus* WALTON, which has spherical, parallelly arranged cells.

*Crucigenia mucronata* (G.M. SMITH) KOMÁREK (Figs 12, 82)

Cells are trapezoid with external sides slightly concave in the middle portion; they end up with a warty thickening or a wide spine in the cell wall. Cells partially joined by their sides to form very irregular tetrads. Chloroplast is parietal with one pyrenoid. In the studied populations, coenobia with 16 or more cells are more frequent. Cells: 4–8.8 x 2.4–5 µm. Coenobia of 16 cells: 12.4–24 x 8–16 µm.

New record to México.

*Crucigeniella apiculata* (LEMMERMANN) KOMÁREK (Figs 13, 83)

Coenobia are elongate, with the cell plane-division in an angle larger than 45°, which produce an irregular syncoenobia, not quadrate. Elongated cells have a visible thickening in the distal part of the cell wall, and have another one, not so evident, in the proximal part. Cells join only in a short part of their length. In each vertex of minor coenobia remainings of mother cells walls are present. Cells have one parietal chloroplast with a pyrenoid. Cells: 4–4.8 x 2.4–3.2 µm. Coenobia of 8 cells: 12–14 x 10–12.4 µm.

New record to México.

*Desmodesmus* (CHODAT) AN, FRIEDL et HEGEWALD

The species of *Scenedesmus*, subgenus *Desmodesmus* were transferred by HEGEWALD (2000) to the genus *Desmodesmus* based on the sequencing results of their ITS-2 rDNA (Internal transcribed spacer of ribosomal DNA) (AN et al. 1999). We include the synonyms to emphasize the morphological characteristics used for their identification.

*D. abundans* (KIRCHNER) HEGEWALD (Figs 14, 84)

(= *Sc. abundans* (KIRCHNER) CHODAT 1913)

Coenobia have two or four aligned cells, which are ellipsoidal with rounded to slightly conical poles. External cells are slightly curved with free sides biondulated or straight and poles slightly elongated. All cells have polar spines in one or

both poles; spines of external cells have an asymmetrical curvature. In the free side of external cells, there are one or two relatively long spines, but shorter than the polar ones. Cells: 8–9.6 x 1.6–4 µm. External spines: 6.6–10 µm, polar spines: 2.3–4.6 µm.

Recorded from México as *Sc. abundans* by MARGAIN-HERNÁNDEZ (1989), without a description or illustration.

*D. armatus* (CHODAT) HEGEWALD var. *armatus* (Fig. 15)  
(= *Sc. armatus* (CHODAT) CHODAT 1913)  
Cells: 8–12 x 3.2–4.8 µm. Spines: 5.8–6.7 µm.

*D. armatus* var. *spinus* (FRITSCH et RICH) HEGEWALD (Figs 16, 85)  
(= *Sc. praetervisus* CHODAT 1926)  
Cells: 11.8–14.4 x 3.2–5 µm. Spines: 3–5.7 µm.

The exemplars have the same characteristics as those described by KOMÁREK & FOTT (1983) for *Sc. praetervisus*, although the cells from our localities have more elongated poles and the polar teeth in the external cells form short spines, one of them evidently longer and diagonally symmetrical.

*D. denticulatus* (LAGERHEIM) AN, FRIEDL et HEGEWALD (Fig. 17)  
(= *Sc. denticulatus* LAGERHEIM 1882)  
Coenobia formed by four alternated ovoid cells. All with similar outline, and one or two short spines at poles. We observed only one population. Cells: 6.4–7.2 x 4–4.2 µm.

For México exists one record (PÉREZ MENDOZA 2003) without description or illustration and as *Sc. denticulatus*.

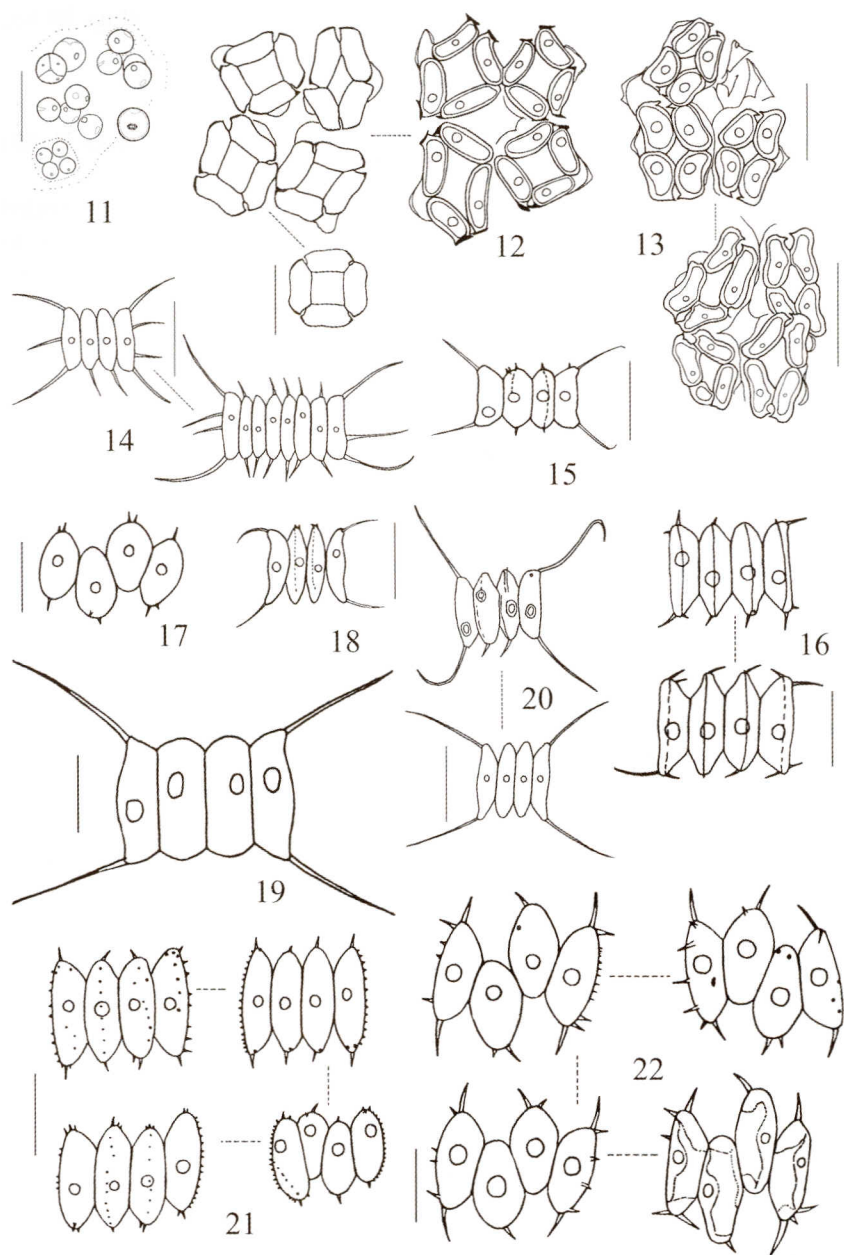
*D. lefevrei* (DEFLANDRE) AN, FRIEDL et HEGEWALD (Figs 18, 86)  
(= *Sc. carinatus* var. *aculeatus* (HORTOBÁGYI) PANKOW 1986).  
Coenobia with 2–4 parallelly arranged cells, which are fusiform with slightly protruded poles. Our exemplars rarely form two-celled coenobia. The external cells have curved ends and a thickening at the pole, the free sides are swollen at the middle. Long asymmetrical spines are disposed subapically at the pole of external cells. Internal cells with a longitudinal line of teeth and two divergent short spines at one of the poles. Cells: 11–12.8 x 4.8–5.2 µm. Spines: 4.8–5.1 µm.

New record to México.

The taxon is close to *Sc. opoliensis* var. *aculeatus* HORTOBÁGYI, synonym of *Sc. carinatus* var. *aculeatus* according to HEGEWALD & SILVA (1988). KOMÁREK & FOTT (1983) considered the former as a valid variety but with doubts about coenobia formation by two cells as described by HORTOBÁGYI (1960).

*D. maximus* (W. et G.S. WEST) HEGEWALD (Figs 19, 87a–b)  
(= *Sc. westii* (G.M. SMITH) CHODAT 1926)  
Cells: 8–14 x 4–6.2 µm. Spines: 16–17.8 µm long.

In the samples from Paso del Toro syncoenobia were frequently observed (Fig. 87b).



Figs 11–22. 11 – *Coenococcus tetrasporus*; 12 – *Crucigenia mucronata*; 13 – *Crucigeniella apiculata*; 14 – *Desmodesmus abundans*; 15 – *D. armatus* var. *armatus*; 16 – *D. armatus* var. *spinosus*; 17 – *D. denticulatus*; 18 – *D. lefevrei*; 19 – *D. maximus*; 20 – *D. opoliensis*; 21 – *D. serratus*; 22 – *D. spinulatus*. Bars = 10  $\mu$ m.

*D. opoliensis* (RICHTER) HEGEWALD (Figs 20, 88)

(= *S. opoliensis* RICHTER 1895)

Cells: 10–21.8 x 2.4–4 µm, spines up to 20 µm long.

*D. serratus* (CORDA) AN, FRIEDL et HEGEWALD (Figs 21, 89)

(= *Sc. serratus* (CORDA) BOHLIN 1901)

Coenobia formed by four aligned cells in the same plane, sometimes surrounded by a thin mucilaginous layer. Cells are ellipsoidal to cylindrical, with conic to rounded poles. In each pole, 1 to 4 short spines. The internal cells have one line of short spines. The external cells are straight, not clearly different from internal ones and with a marginal line of short spines. Cells: 10.42–16 x 3.2–6.4 µm. Spines up to 2 µm long.

PÉREZ MENDOZA (2003) recorded *Sc. serratus* without description.

*D. spinulatus* (BISWAS) HEGEWALD (Figs 22, 90)

(= *Sc. polydenticulatus* HORTOBÁGYI 1969)

Cells are ovate markedly alternate and with a distinctive pattern of spines. At the poles of marginal cells there are 1–3 short spines, 1–2 are disposed perpendicularly to the cell axis. The other one is vigorous and evidently longer and it is oriented along the longitudinal axis of cells. At one of the poles of the internal cells, appear 1–2 short spines of which one is also longer than the other, but without the orientation of the external cells. The presence of short spines in the free sides of the external cells is remarkable; occasionally they are reduced to denticular, very small structures, which are irregular and variable in number. Cells: 12–14.4 x 3.7–8 µm. Spines: 2–5 µm long.

New record to México.

Among the species now included in *Desmodesmus spinulatus*, in our opinion, *Scenedesmus polydenticulatus* has the most similar morphology although it lacks the vigorous spines in the free sides of marginal cells present in our material. On the other side, *S. spinulatus* BISWAS, according to the iconotype, has more or less aligned cells with very strong spines on the cell poles, but also lacks spines in the lateral sides of marginal cells.

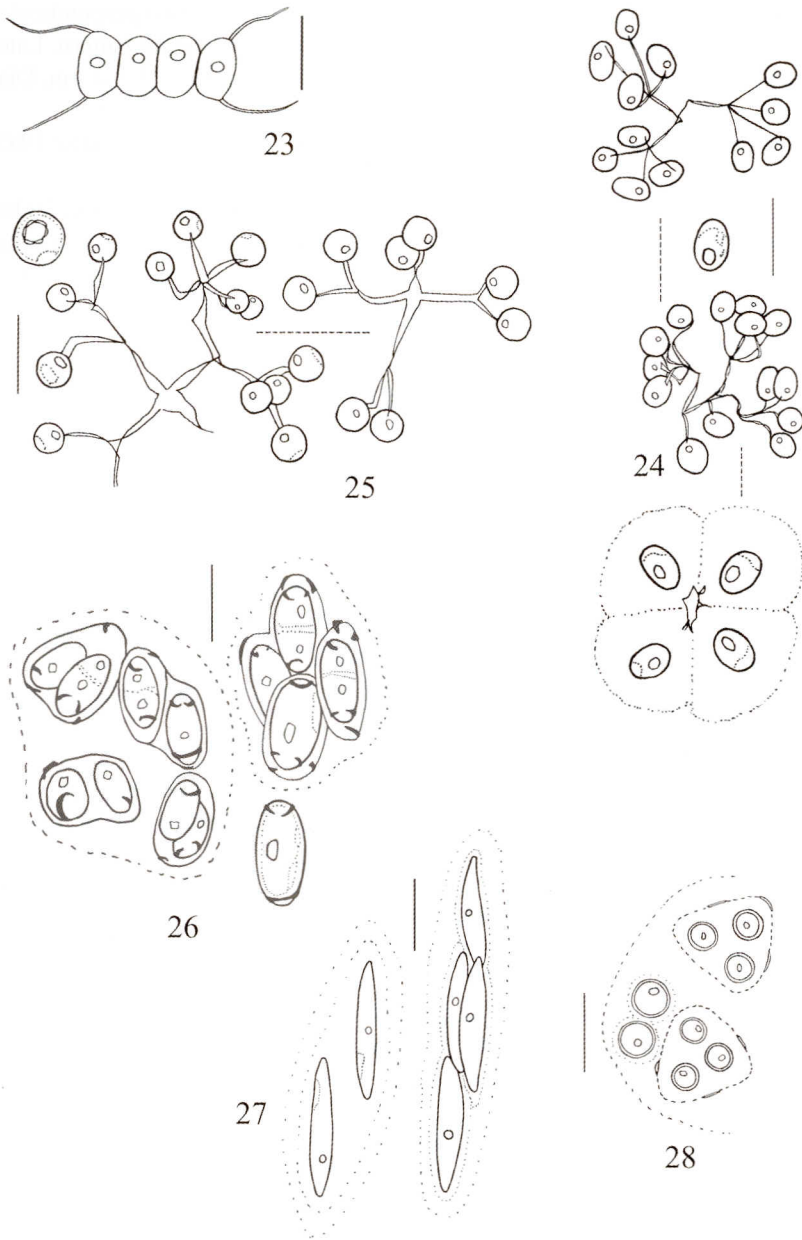
*Desmodesmus* sp. (Figs 23, 91)

Coenobia formed by 4–8 alineated cells. Cells are cylindrical, broadly rounded at the poles; especially in the external cells, with long asymmetrical spines, curved and apically disposed. Cells: 8–9.6 x 4–4.5 µm. Spines: 19.6–23.9 µm long.

This population resembles *Sc. magnus* MEYEN sensu KOMÁREK & FOTT (1983), but it would be necessary to find more material to evaluate their affinities with the described species in the *Desmodesmus* group.

*Dictyosphaerium ehrenbergianum* NÄGELI (Figs 24, 92)

Colonies irregularly formed by 4–24 oval to ellipsoidal cells, disposed in groups of two or four cells, connected by mucilaginous remnants of mother cell walls. Cells have a laminar, basal, parietal chloroplast with one pyrenoid. After forma-



Figs 23–28. **23** – *Desmodemus* sp.; **24** – *Dictyosphaerium ehrenbergianum*; **25** – *D. pulchellum*; **26** – *Granulocystopsis coronata*; **27** – *Gregiochloris lacustris*; **28** – *Hindakochloris insularis*. Bars = 10  $\mu$ m.

tion of autospores, a clear separation of daughter cells in two perpendicular planes between them occurs, this division results in a rectangular pattern. Later this pattern changes into an almost radial colony. Cells: 4–6.4 x 3.2–4 µm. Diameter of colonies: up to 60 µm.

Previously recorded from México (ORTEGA 1984, MENDOZA-GONZÁLEZ 1985, PÉREZ MENDOZA 2003), without description or illustration.

According to KOMÁREK & FOTT (1983) tropical populations of this species belong probably to a different taxon, but the organisms from Veracruz are similar to those found in Brazil by BICUDO & VENTRICE (1968), corresponding well to *D. ehrenbergianum* by their morphology and way of separation of autospores.

*D. pulchellum* WOOD (Figs 25, 93a-b)  
Cells: 4–4.8 µm in diameter. Colonies up to 40 µm in diameter.

The dimensions of our exemplars are similar to var. *minutum* DEFLANDRE 1926 but the colonies have more cells than this variety. Thus we assume that both taxa may be the same.

*Granulocystopsis coronata* (LEMMERMANN) HINDÁK (Figs 26, 94)  
Colonies composed by 2–8 cells, with a wide, stratified, mucilaginous envelope. Cells are ellipsoidal with one or two elongated warts at the poles, arranged in a ring-like structure. One or two parietal chloroplasts are present, each one with one pyrenoid. Two autospores remain joined by the expanded and gelatinized mother cell wall. Cells: 7.0–9.6 x 4.8–5.2 µm.

New record to México.

KOMÁREK & FOTT (1983) mention that this species has 2–8 isolated and elongated polar warts, but in our material, the polar warts are mostly joined forming ring-like structures.

*Gregiochloris lacustris* MARVAN, KOMÁREK et COMAS (Figs 27, 95)  
Cells: 13.6–14 x 3–3.2 µm. Colonies up to 45 x 15 µm. Some exemplars have individual envelopes around each cell.

This is the third record of the species from eutrophic water bodies in Mexico (GARCÍA-RODRÍGUEZ & TAVERA 1998, TAVERA et al. 2000).

*Hindakochloris insularis* COMAS (Figs 28, 96)  
Spherical to irregular colonies formed by 4-celled families disposed tetrahedrally in a mucilaginous envelope. Remnants of mother cell walls are observed at margins of the four-cell groups. Cells are spherical with a cup-shaped chloroplast with a pyrenoid; cell wall is thin. Cells: 3.2–5.6 µm in diameter. 4-celled coenobia: up to 20 µm. Colonies: up to 60 µm in diameter.

New record to México.

Until now, this species was known only from Cuba. Veracruzean populations are smaller than Cuban ones, but the rest of morphological and ecological characteristics is similar.

The genus *Hindakochloris* was established by COMAS (1992b) for those



species of *Thorakochloris* with reproduction exclusively by autospores. In the latter genus only the type species *T. tetras* PASCHER remains, which reproduces by hemiautospores (non-motile cells having stigmata and contractile vacuoles).

In a recent revision of Radiococcaceae, KOSTIKOV et al. (2002) do not recognize *Hindakochloris*. However, they use also morphological characteristics as unstable and variable in a phylogenetic line (PRÖSCHOLD et al. 2001, KRIENITZ et al. 2001, WOLF et al. 2002). We maintain the taxonomic validity of *Hindakochloris* until new genetic and ultrastructural studies show another evidence.

*Kirchneriella* SCHMIDLE

This is one of the most represented genera in the collected samples. The populations show a wide morphological variation even in those characters considered of diagnostic value.

*K. aperta* TEILING (Fig. 29)

Coenobia ovoid to irregularly shaped, with 2–32 cells irregularly disposed. Our populations are very variable in morphology, especially in the form and extension of sinus between cell poles, which appears from typical wide V to U-shaped. Cells: 7.8–12 x 2.5–6.6  $\mu\text{m}$ .

New record to México.

The Veracruzean exemplars present conspicuous pyrenoids like the Cuban populations studied by the first author (COMAS 1996). However, presence of pyrenoids had been questioned (KOMÁREK & FOTT 1983). This species, in its typical form, is more frequent in temperate countries.

*K. hindakiana* MARVAN, KOMÁREK et COMAS (Fig. 30)

Groups of cells form irregular colonies. Cells are distant between each other and inside a wide mucilaginous envelope. Cells are variable in shape with slightly convergent-ends; poles are slightly acute to round. The external sides of cells are convex at the larger side and sometimes cells are somewhat angular as in *Selenoderma malmaeana* BOHLIN, but without the typical macroscopic colonies formed by this benthic alga. Cells: 7–10 x 3.5–5.2  $\mu\text{m}$ .

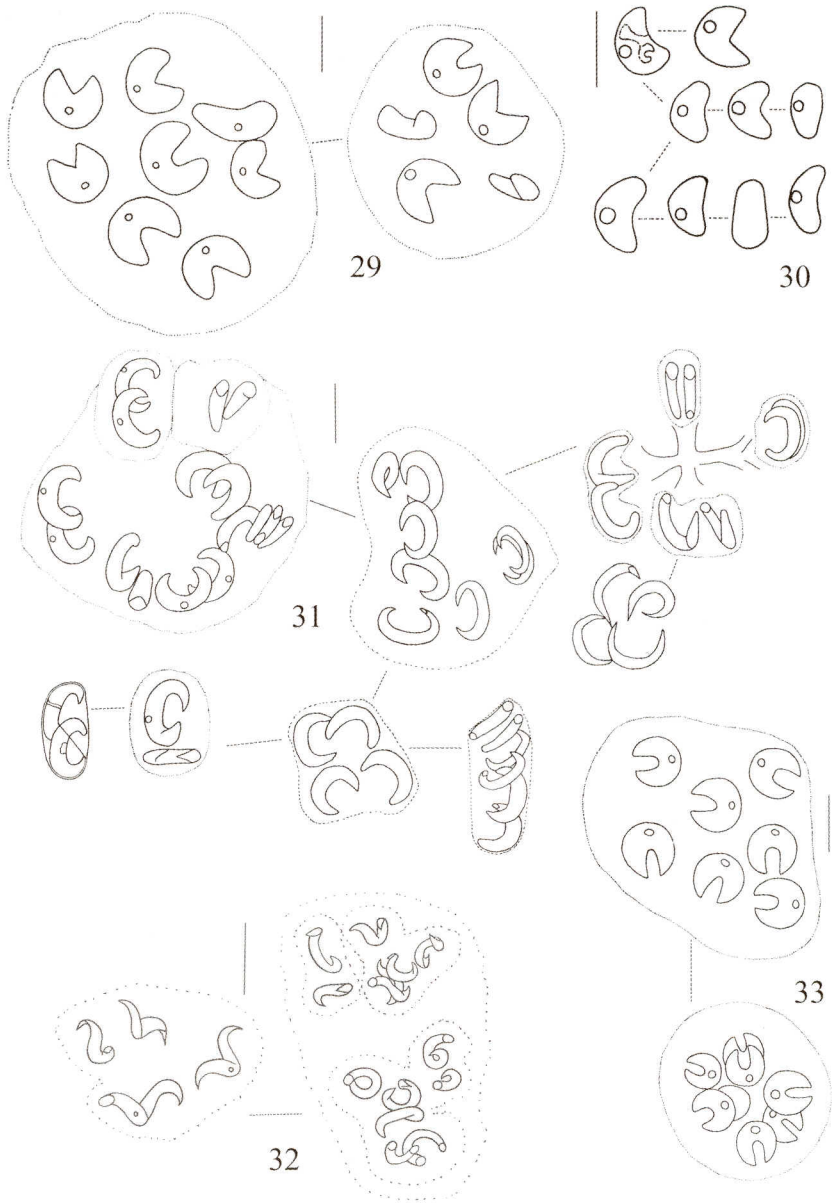
New record to México.

*K. irregularis* (G.M. SMITH) KORŠIKOV var. *irregularis* (Figs 31, 97a–b)

In spite of its wide variability, the cell morphology corresponds well with that of the species. The colonial mucilage is narrow and inconspicuous. The cells in the colony are irregularly disposed, although a tendency to the orientation of the convex sides towards the colony borders is visible. In the center, it is possible to observe remains of mother cell walls. In some individuals a pyrenoid was observed in each cell; cell apices always with different curve ratio; poles are slightly blunted to sharply acute. Cells: 8.3–10 x 1.6–4  $\mu\text{m}$ .

New record to México.

This is a cosmopolitan species, frequent in meso- to eutrophic environments in the tropical zone.



Figs 29–33. 29 – *Kirchneriella aperta*; 30 – *K. hindakiana*; 31 – *K. irregularis* var. *irregularis*; 32 – *K. irregularis* var. *spiralis*; 33 – *K. lunaris*. Bars = 10  $\mu$ m.

The presence of pyrenoids in some cells confirms its inclusion in the genus *Kirchneriella* as correct (KORŠIKOV 1953, KOMÁREK & FOTT 1983, MARVAN et al. 1984) and not in *Pseudokirchneriella* HINDÁK (HINDÁK 1990). It seems that under *K. irregularis* there are two very similar morphological groups, and the unique difference between them is the presence or absence of a pyrenoid. The real absence of a pyrenoid must be confirmed by electron microscopy.

*K. irregularis* var. *spiralis* KORŠIKOV (Figs 32, 98)

This variety is distinguished by the torsion grade of cells, from 1 to 1.5 turns. Pyrenoid only present in some adult cells. Cells: 12–16 x 2–2.4  $\mu\text{m}$ .

New record to México.

The Veracruzean populations form dense colonies adherent to detritus.

*K. lunaris* (KIRCHNER) MÖBIUS (Figs 33, 99)

Cells have the tendency to set down with their convex sides towards the colony center, which is a specific characteristic, but they differ from the typical *K. lunaris* in the presence of a pyrenoid and in having lesser rounded outlines and longer cell apices, with the opening between them forming a U- or wide V-shape. Cells: 4.8–8.6 x 2.4–4  $\mu\text{m}$ .

The described variation was observed in Cuba (COMAS 1996) and in the wetlands of Península of Yucatán (México), but in both cases without pyrenoids. We believe that the morphology for all these populations should be considered as a tropical variation of *K. lunaris*.

*K. obesa* (W. WEST) SCHMIDLE (Figs 34, 100a-b)

Cells: 7.8–12 x 3.3–6  $\mu\text{m}$ . Autospores: 6 x 2  $\mu\text{m}$ .

The studied population corresponds well with the description of the species, but its cells have less rounded outlines, the incisions between apices are much wider and deeper and the cell poles are more acute than in the typical form. This is another case of variation in the Tropics with respect to the temperate zone populations.

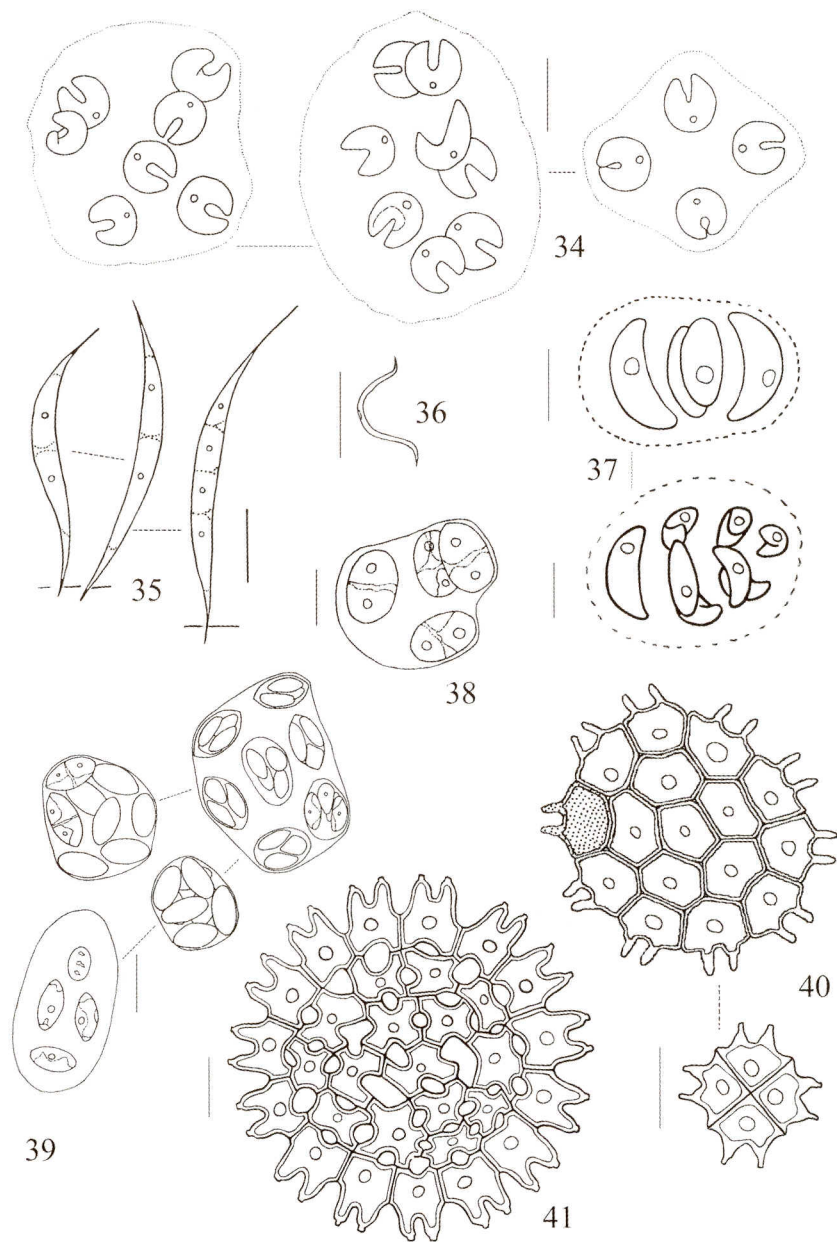
*Korshikoviella limnetica* (LEMMERMAN) SILVA (Figs 35, 101)

Cells are always fixed to substratum, especially over remains of arthropods. Shape of cells is straight or curved-fusiform, with elongated poles. Their basal part is slightly wider than the apical one and with a long projection. The basal end without differentiation anchor- or disc-shaped. Young cells with one parietal chloroplast, adult ones with many and with one pyrenoid not clearly visible in each one. Cells: 26.4–56 x 2.4–6  $\mu\text{m}$ . Apical projection up to 8  $\mu\text{m}$ .

New record to México.

*Monoraphidium contortum* (THURET) KOMÁRKOVÁ-LEGNEROVÁ (Fig. 36)

Cells: 13.2–22 x 1.2–1.6  $\mu\text{m}$ .



Figs 34–41. 34 – *Kirchneriella obesa*; 35 – *Korshikoviella limnetica*; 36 – *Monoraphidium contortum*; 37 – *Nephrocystium lunatum*; 38 – *Oocystis borgei*; 39 – *O. lacustris*; 40 – *Pediastrum boryanum*; 41 – *P. duplex* var. *duplex*. Bars = 10  $\mu$ m.

*Nephrocytium lunatum* W. WEST (Figs 37, 102)

Cells: 14–16 x 5–8  $\mu\text{m}$ . 4-celled coenobia: 40 x 30  $\mu\text{m}$ .

*O. borgei* SNOW (Figs 38, 103)

Cells: 12.8–21 x 9.6–13.7  $\mu\text{m}$ . Colonies: 25.6–29.6  $\mu\text{m}$  in diameter.

*Oocystis lacustris* CHODAT (Figs 39, 104)

Cells: 7.2–10.4 x 3–6.4  $\mu\text{m}$ . Colonies: 16.8–25  $\mu\text{m}$  in diameter.

*Pediastrum boryanum* (TURPIN) MENENGHINI (Fig. 40)

Cells: 9–10 x 9–10  $\mu\text{m}$ . Processes length: 2  $\mu\text{m}$ . Opening between processes: 3  $\mu\text{m}$ . Coenobia: 18–22  $\mu\text{m}$ .

In our samples the four-celled coenobia are common.

*P. duplex* MEYEN var. *duplex* (Fig. 41)

Internal cells: 7.2–8 x 10–12  $\mu\text{m}$ . External cells: 9.6–10.4 x 8–8.8  $\mu\text{m}$ . Processes length: 4  $\mu\text{m}$ . Coenobia diameter: 56–72  $\mu\text{m}$ .

*P. duplex* var. *gracillimum* W. et G.S. WEST (Figs 42, 105)

This variety is characterized by its intercellular holes wider than cell diameters. Processes are long and cylindrical. The cell wall is smooth. Internal cells: 12 x 10.4  $\mu\text{m}$ . External cells: 8–13.2 x 16–18.6  $\mu\text{m}$ . Processes length: 9.6  $\mu\text{m}$ . Opening between processes: 6.4–9.6  $\mu\text{m}$ . Coenobia: 44–48  $\mu\text{m}$  in diameter.

New record to México.

*P. subgranulatum* (RACIBORSKI) KOMÁREK et JANKOVSKÁ (Figs 43, 106)

Internal cells: 10.4–12 x 8–9.6  $\mu\text{m}$ . Processes length: 4–5.6  $\mu\text{m}$ . Opening between processes: 7.2–8  $\mu\text{m}$ . External cells: 10.4–11.2 x 10.8–13.3  $\mu\text{m}$ . Coenobia: 36–40  $\mu\text{m}$ . Cell wall finely ornamented.

Some authors considered this species as a variety of *P. duplex*; the latter species was recorded previously from México.

*P. tetras* (EHRENBERG) RALFS (Figs 44, 107)

Internal cells: 8–8.2 x 7.2–7.6  $\mu\text{m}$ . External cells: 9.6–9.8 x 9.4–9.6  $\mu\text{m}$ . Coenobia: 33.6–40  $\mu\text{m}$ .

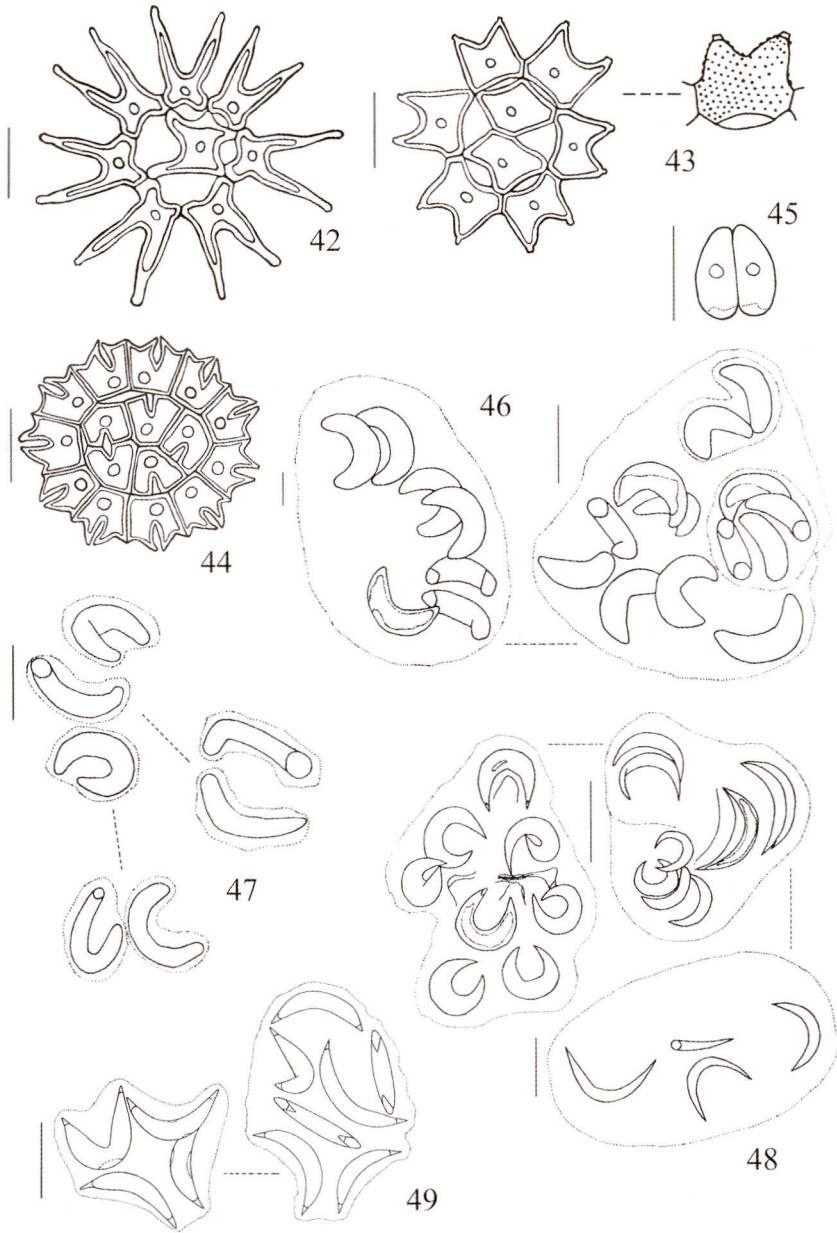
*Pseudodidymocystis planctonica* (KORŠIKOV) HEGEWALD et DEASON

(Figs 45, 108)

Coenobia formed always by two cells. Wide ovate cells with rounded poles without thickenings, joined all along their longitudinal axes. Smooth cell wall. Cells have one parietal chloroplast with a pyrenoid. Autospores are always in groups of two (never four) cells. Cells: 10–11.4 x 5–5.6  $\mu\text{m}$ .

New record to México.

The distinction between *Pseudodidymocystis* and *Didymocystis* is based mainly on the presence of sporopollenine in the cell wall. The distinction be-



Figs 42–49. 42 – *Pediastrum duplex* var. *gracillimum*; 43 – *P. subgranulatum*; 44 – *P. tetras*; 45 – *Pseudodidymocystis planctonica*; 46 – *Raphidocelis arcuata*; 47 – *R. contorta*; 48 – *Raphidocelis* sp.; 49 – *R. cfr. mucosa* (Cuba). Bars = 10  $\mu$ m.

tween the two species of *Pseudodidymocystis* is based on morphological characteristics (HEGEWALD & DEASON 1989), but these are not so clear in natural materials (not cultivated). However, measurements and general appearance of our material are closer to *P. planctonica* than to *P. fina* (KOMÁREK) HEGEWALD et DEASON.

*Rhaphidocelis arcuata* (G.M. SMITH) MARVAN, KOMÁREK et COMAS (Fig. 46)  
Colonies are round or slightly irregular with 4 to 16 isolated cells, irregularly distributed, curved, crescent-shaped and with apices distinctly truncated. Chloroplasts are ribbon-shaped without pyrenoids, situated in the convex and wider portion of the cell. Reproduction is by four autospores. Occasionally, cells surrounded by their own mucilage envelope inside the colony. Cells: 11.2–13.2 x 4.4–5 µm.

New record to México.

KOMÁREK & FOTT (1983) pointed out that this is a clean-water species distributed in the Northern temperate zones. The Veracruzean exemplars correspond precisely to the morphology of the typical species. Organisms belonging to this species were also described from Xochimilco (TAVERA et al. 2000). These tropical populations seem to grow well in waters rich in organic matter.

*R. contorta* (SCHMIDLE) MARVAN, KOMÁREK et COMAS (Fig. 47)  
Colonies are spherical. Cells are cylindrical, curved and sometimes irregularly twisted, more or less rounded at poles, surrounded by a fine mucilaginous envelope. The chloroplast is parietal, without pyrenoid. Cells: 10–15 x 3.3 µm.

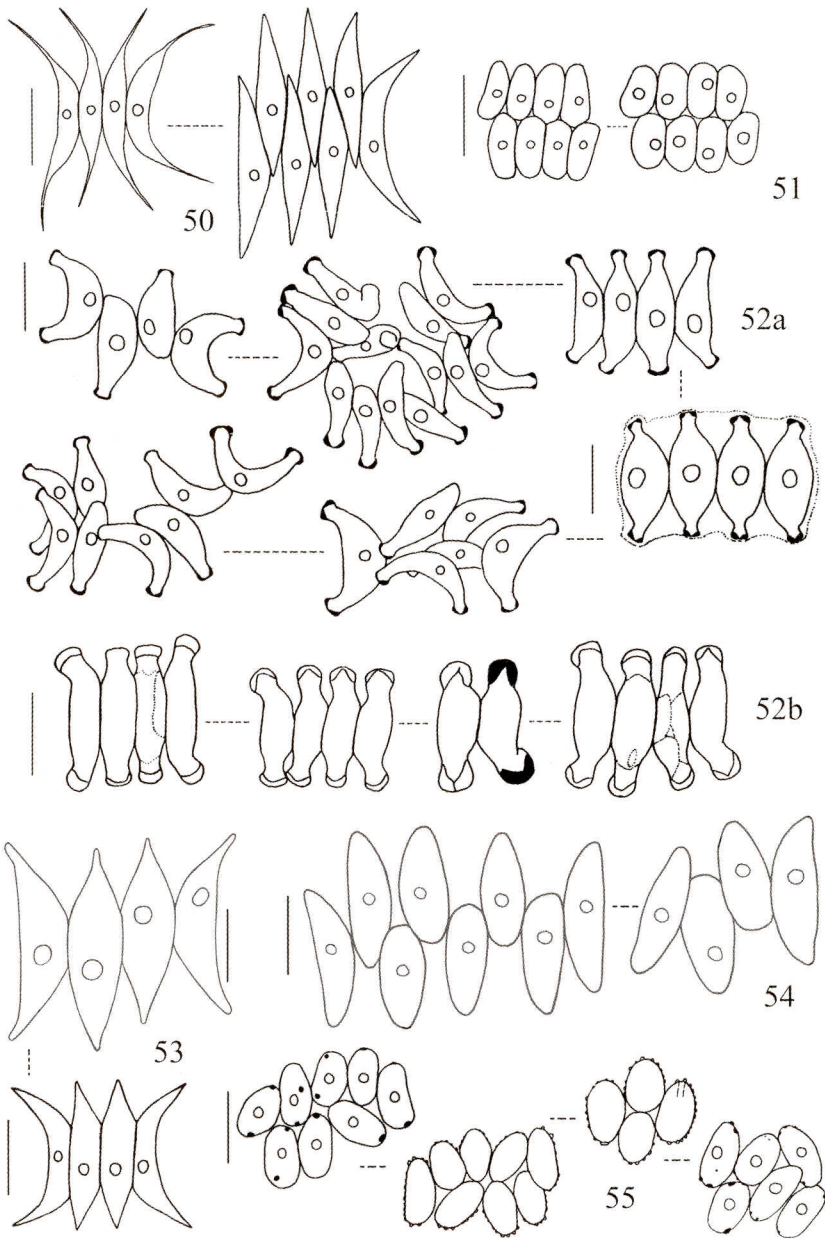
New record to México.

*Rhaphidocelis* sp. (Figs 48, 109)  
Colonies are amorphous, mucilaginous; cells are fusiform, slightly curved to arcuate, gradually attenuated to the ends; poles are acute; the parietal chloroplast has no pyrenoid. Reproduction is by 2–4 autospores arranged in series inside the mother cell wall. Cells: 7.5–11.8 x 1.5–3.3 µm.

Our population is more related to *R. mucosa* (KORŠIKOV) MARVAN et al., but the cells are more arcuate, smaller (in the typical *R. mucosa* the cells are 14–15 µm long), irregularly disposed inside the colony and not closely associated with remnants of mother cell walls. In addition, *R. mucosa* is known only from Central Europe (KOMÁREK & FOTT 1983). Similar organisms (Fig. 49) were found in an extremely eutrophic Cuban pool (Prov. Camagüey) (COMAS unpubl.). A precise taxonomical definition of this alga needs further studies.

*Scenedesmus acuminatus* (LAGERHEIM) CHODAT (Figs 50, 110)  
Cells: 12–26.4 x 2.4–4 µm. 4-celled coenobia: 12–18 µm.

*S. arcuatus* var. *platydiscus* G.M.SMITH (Figs 51, 111)  
Cells: 6.4–10 x 4–5 µm. 8-celled coenobia: 12–14.45 x 20.6–22.35 µm.



Figs 50–55. **50** – *Scenedesmus acuminatus*; **51** – *S. arcuatus* var. *platydiscus*; **52a** – *S. indicus*; **52b** – *S. bacillaris* (Cuba); **53** – *S. obliquus* var. *dimorphus*; **54** – *S. obtusus*; **55** – *S. verrucosus*. Bars = 10  $\mu$ m.



*S. indicus* PHILIPOSE ex HEGEWALD, ENGELBERG et PASCHMA (Figs 52a, 112a–b) Coenobia formed by 4–16 aligned to markedly alternated cells, forming irregular syncoenobia; cells are cylindrical-fusiform with flat capitate poles, curved in the same direction for the internal cells and in different directions in the external ones, joined in a third of their length; cell wall is smooth, thick at cell poles, especially at the corners. Cells: 8.3–17.6 x 3.3–8.8  $\mu\text{m}$ . Coenobia: up to 25  $\mu\text{m}$  high.

New record to México.

*S. bacillaris* GUTWINSKI 1890 (= *S. producto-capitatus* SCHMULA 1909) and *S. indicus* are very close. They differ mainly by the arrangement of cells in the coenobium: cells are aligned or slightly alternated in the former and markedly alternated (in zigzag) in the latter. Composed coenobia (syncoenobia) are frequently formed in *S. indicus*. This species was described by PHILIPOSE (1967) without type designation, hence invalid. HEGEWALD (1976) included it as a variety of *S. producto-capitatus*, but its basionym was based in the same invalid name. HEGEWALD et al. (1988) validated the name proposed by PHILIPOSE (1967) with a designated lectotype; however, they did not refer to the Latin diagnosis (PHILIPOSE 1967, pages 258–259) or to a previous one. In spite of this omission, the validation of the name could be accepted according to ICBN rules.

In the population of Paso del Toro the arrangement of cells in the coenobium is highly variable from aligned cells as in *S. bacillaris* to cells disposed in zigzag similar to those of *S. indicus*; however, transient individuals also occur. Syncoenobia are frequently present. The population, altogether, could be identified as *S. indicus* (Fig. 52a).

The first author found in Cuba some populations identical to *S. bacillaris*; that means, only coenobia with cells aligned or slightly alternated (never in zigzag) were observed; composed coenobia were absent in these collections (Fig. 52b). Therefore, it is possible to find populations corresponding to one or to another morphological type but taking into account that the cells' arrangement in the coenobium is highly variable and that transient individuals may occur, *S. bacillaris* and *S. indicus* belong probably to the same species, but separated in two different infraspecific taxa.

*S. obliquus* var. *dimorphus* (TURPIN) HANSRIG (Figs 53, 113)  
Cells: 18.2–26.4 x 3.3–5.6  $\mu\text{m}$ . Coenobia: 21.6  $\mu\text{m}$  as the maximum.

*S. obtusus* MEYEN (Figs 54, 114)  
Cells: 13.6–18.4 x 6.4–7.2  $\mu\text{m}$ . 4-celled coenobia: 24.8–28.8  $\mu\text{m}$

This is a very variable species, including many described taxa (HEGEWALD et al. 1988) and its taxonomy is rather complicated. Following this broad species concept, we found in our samples organisms with ovoid cells with a blunt apex and wide basis or slightly ellipsoidal cells, in which the marginal ones have straight or slightly convex sides, arranged mostly in alternated coenobia. In the population from Cerro Gordo, the cells are morphologically similar to *S. baculi-*

*formis* CHODAT but not forming characteristic zigzag coenobia also, the cells sometimes resemble *S. antillarum* COMAS, but without the lamellated polar thickening in the cell wall. Moreover, our exemplars are similar to *S. ovalternus* CHODAT (nomen nudum, sine typo) and especially to *S. ovalternus* var. *graevenitzii* (BERNARD) CHODAT (= *Steinedesmus graevenitzii* (BERNARD) KOFOID), but not forming composed coenobia. All these mentioned species were included in *S. obtusus* by HEGEWALD et al. (1988), but later, HEGEWALD & HANAGATA (2000) considered *S. ovalternus* as a separate species, based on gene sequence analysis.

*S. verrucosus* ROLL (Figs 55, 115)

Coenobia mostly 8-celled composed by two rows of cells densely joined, compact, disc-shaped, without holes between cells; cells are basically ovoid, the marginal ones ellipsoidal, sometimes with concave free sides; cell wall with delicate or thick warts (especially at poles) forming irregular rows. Cells: 4–5.6 x 3.2–3.4  $\mu\text{m}$ . Coenobia: 12–12.6 x 15.6–16  $\mu\text{m}$ .

For México exists a previous record by TAVERA (1996), but without description or illustration.

*Schroederia setigera* (SCHRÖDER) LEMMERMANN (Figs 56, 116)

Cells: 50.4–60 x 2.4–4.8  $\mu\text{m}$ . Apical spine: 8–12  $\mu\text{m}$  long.

*Selenastrum bibraianum* REINSCH (Figs 57, 117)

Colonies fascicled formed by 4–16 cells joined in fours by their convex sides, cruciform in section; cells are fusiform, more or less arcuate to crescent-shaped up to almost semicircular, gradually pointed; chloroplast parietal without pyrenoid. Cells: 6.4–14 x 2–4.4  $\mu\text{m}$ .

New record to México.

In the studied populations, the cells are smaller than in the species description; however, other features correspond very well (cells joined by their convex sides forming more or less regularly fascicled colonies). The species is very rare in the Tropics, but it is frequent in the plankton of clear to eutrophic pools and ponds in the temperate zone.

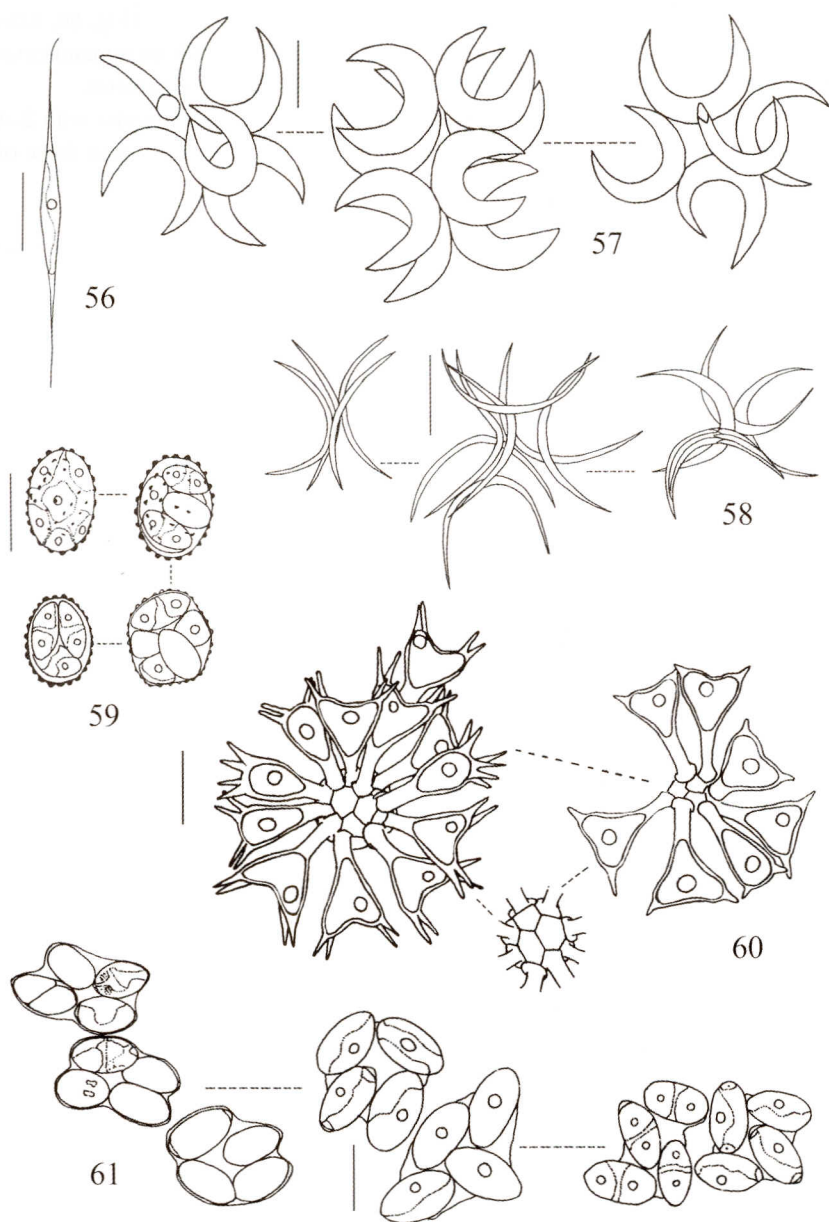
*S. gracile* REINSCH (Figs 58, 118a–b)

Cells: 17–40 x 1.6–3.2  $\mu\text{m}$ .

*Siderocelis ornata* (FOTT) FOTT (Figs 59, 119a–b)

Cells are solitary or joined in four-celled groups inside the mother walls. Cells ellipsoidal or oval with rounded poles, with a hyaline to slightly brownish cell wall and ornamented with irregularly disposed warts. In the Paso del Toro population, some solitary cells with six chloroplasts, each with a visible pyrenoid, appear. Colonies with 4–8 cells are more frequent. Ellipsoidal autospores, having two parietal chloroplasts, each with one pyrenoid. Cells: 8–18.8 x 3.3–13.6  $\mu\text{m}$ .

New record to México.



Figs 56–61. **56** – *Schroederia setigera*; **57** – *Selenastrum bibrainum*; **58** – *S. gracile*; **59** – *Siderocelis ornata*; **60** – *Sorastrum americanum*; **61** – *Tetrachlorella alternans*. Bars = 10  $\mu$ m.

*Sorastrum americanum* (BOHLIN) SCHMIDLE (Fig. 60, 120)  
Coenobia with 16 and 32 cells: up to 40 µm in diameter (without appendices); pedicels from 1/2 to the cell diameter long. Cells: 8.3–16 µm in diameter.

In the Veracruzean populations, the cells are more or less triangular with 2–4 appendices in their external angles, pedicels are thinner and longer than those of typical *S. americanum*.

*Tetrachlorella alternans* (G.M. SMITH) KORŠIKOV (Figs 61, 121)  
Coenobia with 4 cells markedly alternating joined by a mucilaginous envelope, colorless, diffluent, not dilated, very often forming syncoenobia of up to 16 cells. Cells are ellipsoidal with rounded or slightly acute poles. External cells are parallel between them and arranged at angle to the internal ones. Cell wall is smooth. Each cell has 1–2 parietal cup-shaped or plate-shaped chloroplasts with pyrenoids. Cells: 6.4–12 x 3.2–7 µm.

New record to México.

*Tetraedron caudatum* (CORDA) HANSGIRG (Fig. 62)  
Cells: 11.2 µm in diameter. Spines: up to 8 µm long.

*T. minimum* (A. BRAUN) HANSGIRG (Figs 63, 122)  
Cells: 6.4–7.4 µm in diameter.

*Tetrallantos lagerheimii* TEILING (Fig. 64)  
Very irregular coenobia; cells are frequently joined by their walls or by mucilage. Wide mucilage covers the resulting groups. Cells are crescent-shaped, curved, with rounded to attenuated poles. Chloroplast is parietal with one indistinct pyrenoid. Cells: 12–17.6 x 3.3–5 µm.

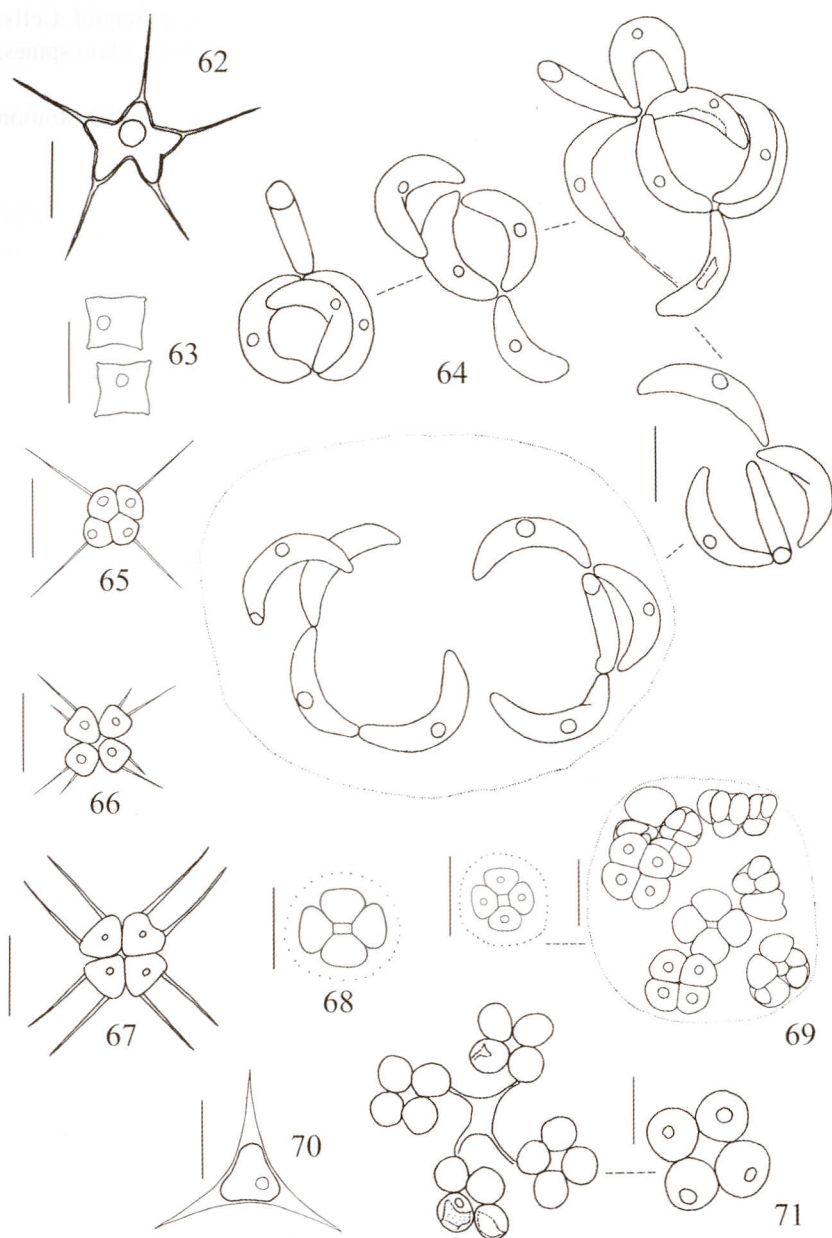
New record to México.

This population fits with the species description (KOMÁREK & FOTT 1983); however, when comparing with TEILING's illustration (1916), some morphological differences are noticeable: cells are cylindrical, slightly arcuate and sometimes twisted to the ends. The characteristics of Veracruzean populations were observed also in Cuba, identified as *T. cf. lagerheimii* (COMAS 1991).

*Tetrastrum elegans* PLAYFAIR (Fig. 65)  
Coenobia slightly rectangular to elliptical with cells disposed in cross, with their external sides rounded and without central hole. Each cell with one spine symmetrically disposed. Parietal chloroplast with one pyrenoid. Cells: 3.2–4.8 µm. Coenobia: 8.8–9.6 µm. Spines: 6.4–8 µm long.

New record to México.

*T. heteracanthum* (NORDSTEDT) CHODAT (Figs 66, 123a–b)  
Coenobia elongated to one direction, with a hole more or less rectangular in the center. Cells are triangular with concave to flat external sides and with two diag-



Figs 62–71. 62 – *Tetraedron caudatum*; 63 – *T. minimum*; 64 – *Tetrallantos lagerheimii*; 65 – *Tetrastrum elegans*; 66 – *T. heteracanthum*; 67 – *T. homoiacanthum*; 68 – *T. komarekii*; 69 – *T. triangulare*; 70 – *Treubaria triappendiculata*; 71 – *Westella botryoides*. Bars = 10  $\mu$ m.

onal symmetric, unequal spines. Parietal chloroplast has one pyrenoid. Cells: 4–4.8  $\mu\text{m}$ . Coenobia: 8.5–9 x 9.2–12  $\mu\text{m}$ . Long spines: 12  $\mu\text{m}$  long. Short spines: 5–5.8  $\mu\text{m}$  long.

For México exists only a previous record without description or illustration (PÉREZ MENDOZA 2003).

*T. homoiacanthum* (HUBER-PESTALOZZI) COMAS (Figs 67, 124)

Coenobia are more or less rectangular with a quadrate central hole. Cells are triangular with their external sides flattened or slightly concave and two spines of equal length. Parietal chloroplast has one pyrenoid. Cells: 4–7  $\mu\text{m}$  in diameter. Coenobia, without spines: 12–19  $\mu\text{m}$  in diameter. Spines: 5–12  $\mu\text{m}$  long.

The taxon was described by HUBER-PESTALOZZI (1929) as a variety of *T. heteracanthum*, but was considered as a separate species by COMAS (1984) and HINDÁK (1984), thus the priority of this taxonomical level should be established.

New record to México.

*T. komarekii* HINDÁK (Fig. 68)

Coenobia are rectangular, frequently surrounded by a fine mucilaginous layer and has a small rectangular hole in the center. Cells are triangular to trapezoidal; the external sides of cells are convex. Smooth cell wall has no spines or warts. Chloroplast is parietal without pyrenoid. Cells: 2.4–3.2  $\mu\text{m}$ . Coenobia: 5–6  $\mu\text{m}$ .

New record to México.

The species differs from *T. triangulare* mainly by the absence of pyrenoids; therefore, its existence should be clarified in the future.

*T. triangulare* (CHODAT) KOMÁREK (Figs 69, 125)

Coenobia are rectangular, with a small rectangular hole. A diffluent mucilage is common to the coenobium. Cells are triangular with their external side convex and forming a regular cross. Cell wall is smooth, without spines or warts. Chloroplast is parietal with one pyrenoid. Cells: 4.8–6.4  $\mu\text{m}$ . Coenobia: 9.2–10.4  $\mu\text{m}$ .

New record to México.

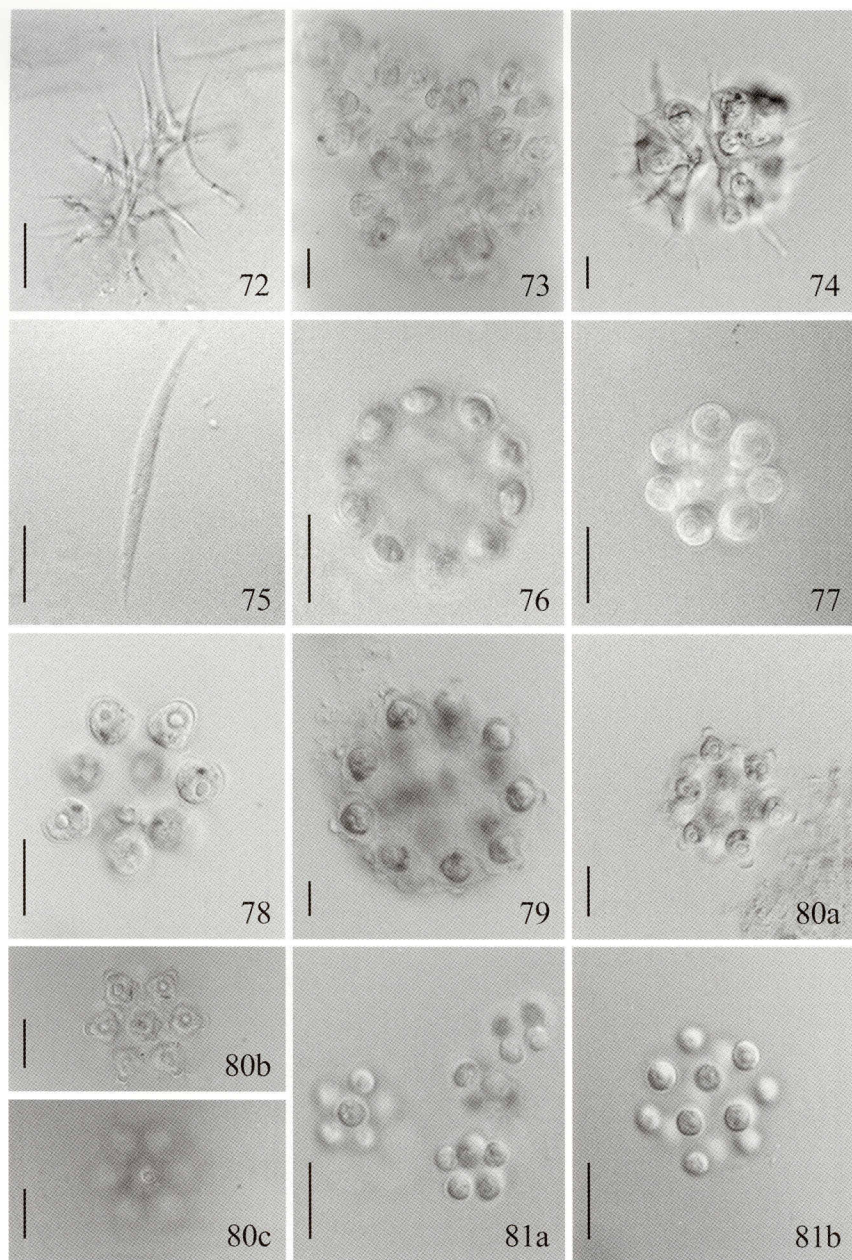
*Treubaria triappendiculata* BERNARD (Figs 70, 126)

Cells: 6.4–7.2  $\mu\text{m}$ . Spines: up to 9.6  $\mu\text{m}$  long.

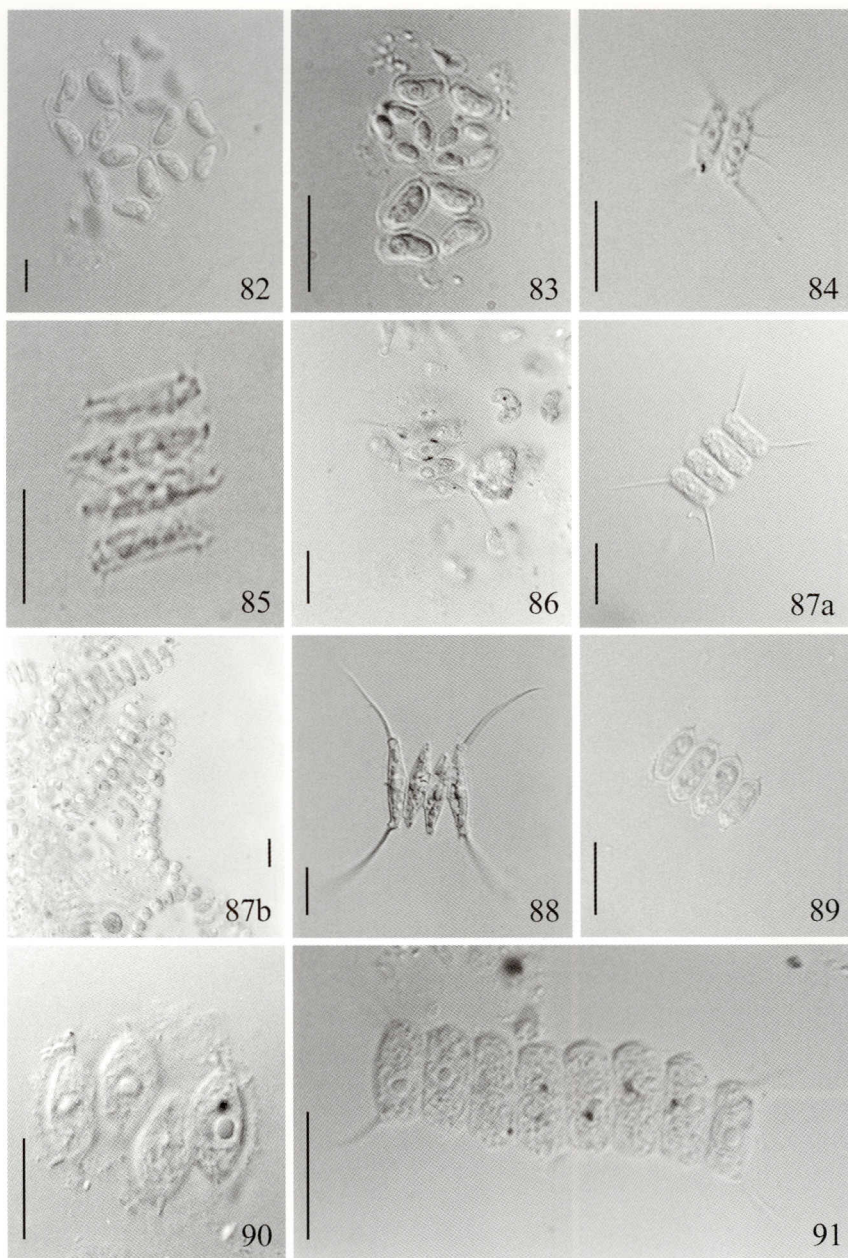
*Westella botryoides* (W. WEST) DE WILDEMAN (Fig. 71)

Coenobia formed by four cells disposed in cross with or without a hole between them, frequently forming syncoenobia of 16 or more cells. Cells are ovate to rounded, with a smooth cell wall. Chloroplast is parietal filling  $\frac{3}{4}$  of the cell periphery, with one pyrenoid. Cells: 3.3–8.8  $\mu\text{m}$  in diameter.

For México exists one previous record without description or illustration (PÉREZ MENDOZA 2003).

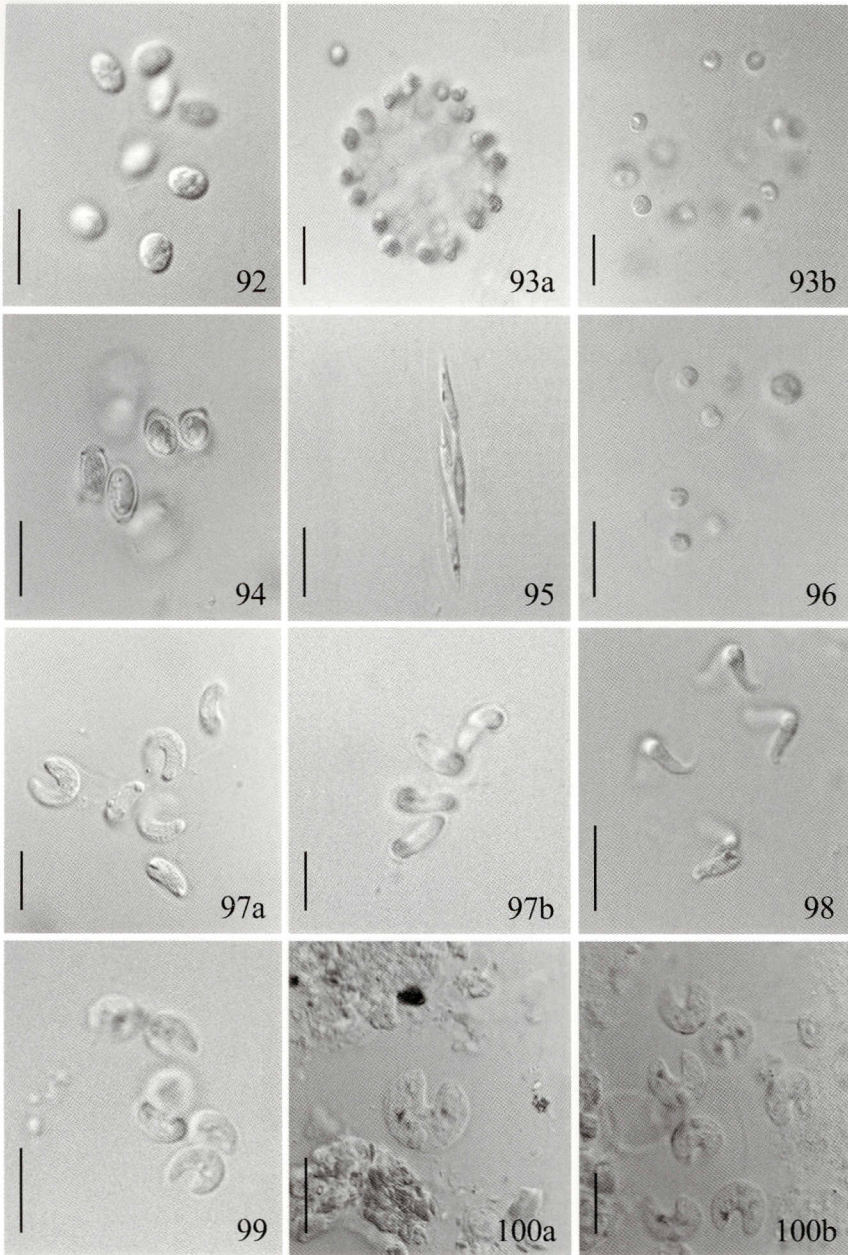


Figs 72–81. **72** – *Ankistrodesmus falcatus*; **73** – *Botryococcus braunii*; **74** – *B. terribilis*; **75** – *Closteriopsis acicularis*; **76** – *Coelastrum indicum*; **77** – *C. microporum*; **78** – *C. pseudomicroporum*; **79** – *C. pulchrum* (typical); **80a–c** – *C. pulchrum* f. *taverae* nov. f., a) focus on the middle of coenobium, b) focus on the surface of coenobium, c) focus on one free process; **81a–b** – *Coenococcus tetrasporus*; Bars = 10  $\mu$ m.

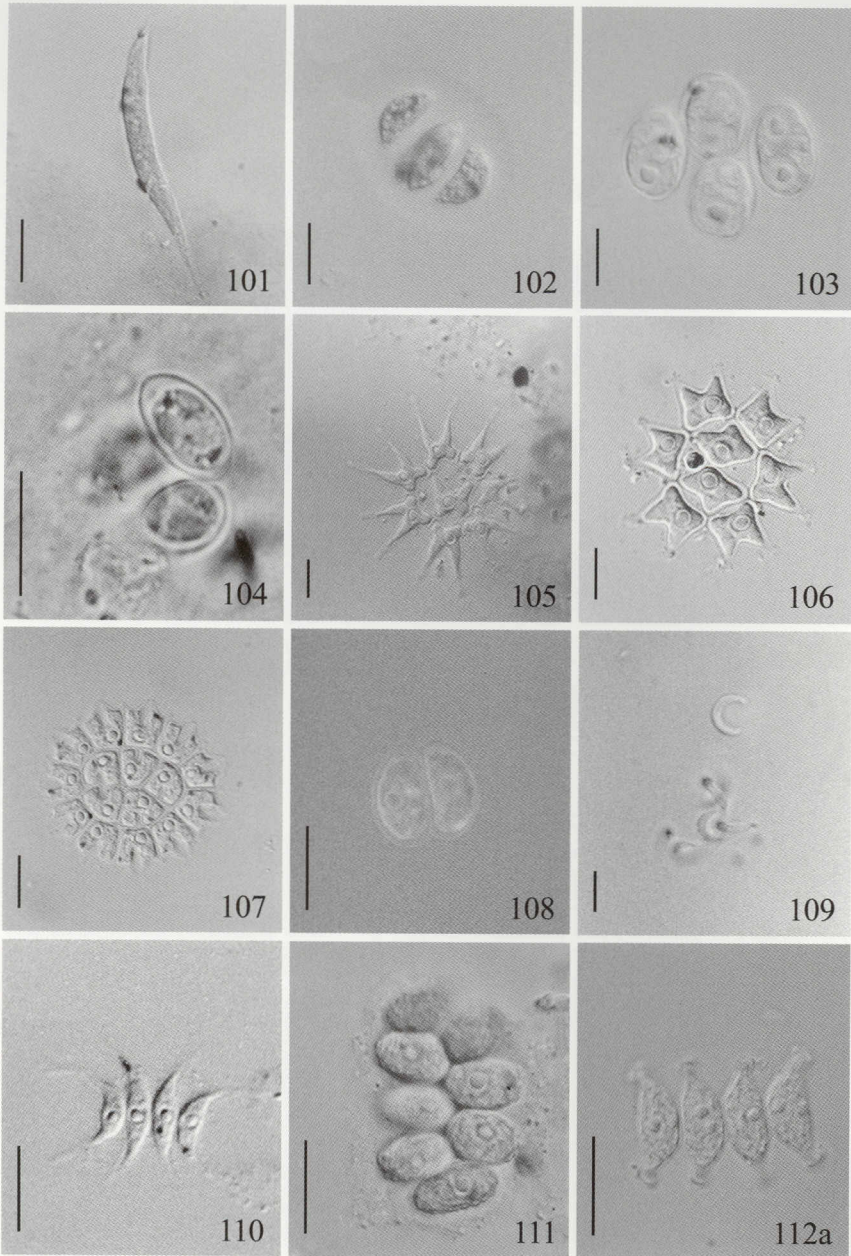


Figs 82–91. **82** – *Crucigenia mucronata*; **83** – *Crucigeniella apiculata*; **84** – *Desmodesmus abundans*; **85** – *D. armatus* var. *spinosus*; **86** – *D. lefevrei*; **87a–b** – *D. maximus*, b) syncoenobia; **88** – *Desmodesmus opoliensis*; **89** – *D. serratus*; **90** – *D. spinulatus*; **91** – *Desmodesmus* sp. Bars = 10µm.

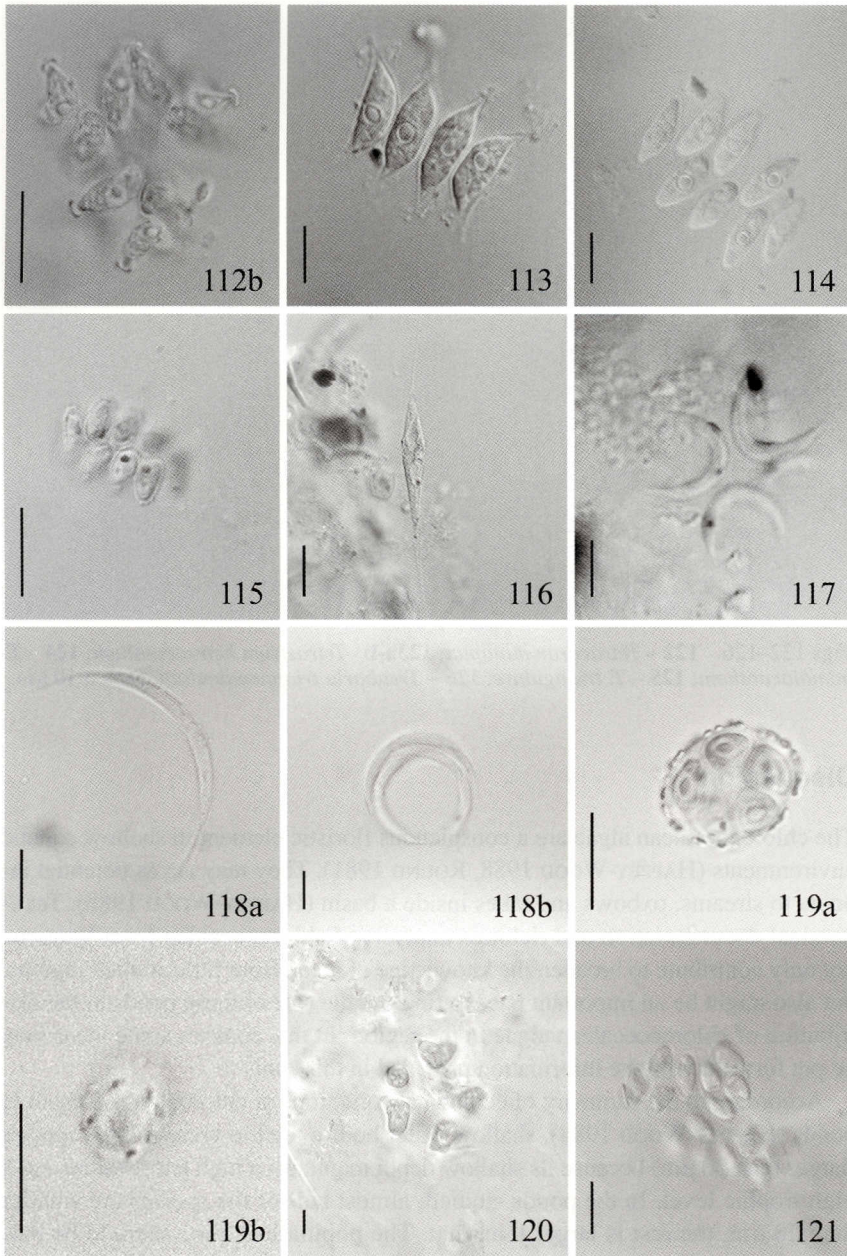




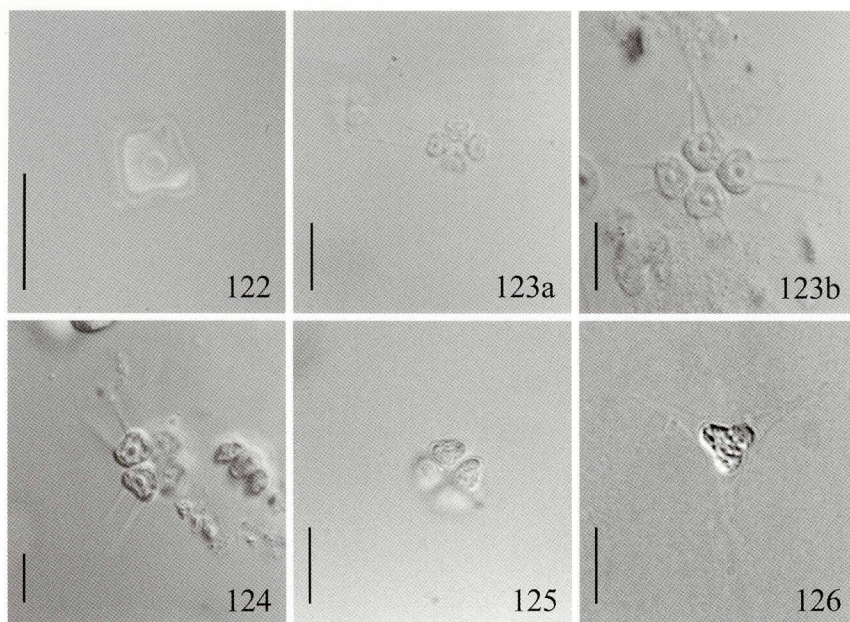
Figs 92–100. **92** – *Dictyosphaerium ehrenbergianum*; **93a–b** – *D. pulchellum*; **94** – *Granulocystopsis coronata*; **95** – *Gregiochloris lacustris*; **96** – *Hindakochloris insularis*; **97a–b** – *Kircheneriella irregularis* var. *irregularis*; **98** – *K. irregularis* var. *spiralis*; **99** – *K. lumaris*; **100a–b** – *K. obesa*. Bars = 10  $\mu$ m.



Figs 101–112a. **102** – *Korshikoviella limnetica*; **102** – *Nephrocytium lunatum*; **103** – *Oocystis borgei*; **104** – *O. lacustris*; **105** – *Pediastrum duplex* var. *gracillimum*; **106** – *P. subgranulatum*; **107** – *P. tetras*; **108** – *Pseudodidymocystis planctonica*; **109** – *Raphidocelis* sp.; **110** – *Scenedesmus acuminatus*; **111** – *S. arcuatus* var. *platydiscus*. **112a** – *Scenedesmus indicus*. Bars = 10  $\mu$ m.



Figs 112b–121. **112b** – *Scenedesmus indicus*; **113** – *S. obliquus* var. *dimorphus*; **114** – *S. obtusus*; **115** – *S. verrucosus*; **116** – *Schroederia setigera*; **117** – *Selenastrum bibraianum*; **118a–b** – *S. gracile*; **119a–b** – *Siderocelis ornata*; **120** – *Sorastrum americanum*; **121** – *Tetrachlorella alternans*. Bars = 10  $\mu$ m.



Figs 122–126. **122** – *Tetraedron minimum*; **123a-b** – *Tetrastrum heteracanthum*; **124** – *T. homoiacanthum*; **125** – *T. triangulare*; **126** – *Treubaria triappendiculata*. Bars = 10  $\mu\text{m}$ .

## Discussion

The chlorococcalean algae are a conspicuous floristic element in shallow aquatic environments (HAPPEY-WOOD 1988, ROUND 1981). They may act as potential inocula to streams, oxbows and lakes inside a basin (HAPPEY-WOOD 1988). Taxonomical documentation and richness analysis of chlorococcalen from Veracruz not only contribute to broaden the knowledge of algae from little studied regions, but also might be an important base to find out the role of these ponds in the distribution of chlorococcalean algae in the region. In this context, some ideas may be put forward with the information provided in this study.

According to the summary of ecological conditions of chlorophytes present in ponds (HAPPEY-WOOD 1988), shallow water bodies tend to present large species (larger than 20  $\mu\text{m}$ ) because its shallow depth maintains a high temperature and a high trophic level. In the ponds studied, almost half of the species are smaller than 20  $\mu\text{m}$ , the rest is larger than that. The populations thus seem to be balanced in size composition and diversity of size could facilitate their dispersion occurring not only to other shallow environments (streams and slow flowing rivers), but also to other lakes and reservoirs. Thus, the chlorococcalean algae we have found may constitute nanoplankton elements (< 20  $\mu\text{m}$ ) as well as phytoplankters (> 20  $\mu\text{m}$ ) in these other environments. This indicates that they are good colonizers of lakes and reservoirs in the neighborhood.

HAPPEY-WOOD (1988) pointed out the trophic level where chlorococcalean algae live. Certainly in shallow ponds in an area with strong agricultural activity like Veracruz, one may expect a predominance of species which denote a eutrophic level; however, we think that chlorococcalean algae in these ponds indicate a wider range in trophic. We have found species like *Gregiochloris lacustris*, *Raphidocelis arcuata* or *Dictyospherium pulchellum*, described as indicative of oligotrophic environments with low organic matter content and only few times previously documented in literature from eutrophic conditions in the Tropics (MARGAIN-HERNÁNDEZ 1981, 1989, TAVERA et al. 2000). This is another argument to predict their possible presence in other deeper water bodies, which could fulfill their role as inoculums.

The sites analyzed share a small number of species (10%) and it was interesting to estimate, based on chlorococcalean richness of species, how diverse this area in Veracruz may be. It was convenient to use the jackknife estimator, which especially considers the role of those rare or unique species, because in our study this number is not so small (37 species). Moreover, taking advantage of the jackknife estimator and supported in the similarity of morphometry and environmental factors among the studied ponds, we analyzed the three sites as quadrats in an area instead of independent communities.

In comparison to other areas in central Mexico and regardless of the larger diversity of environments and larger number of localities sampled there (TAVERA et al. 2000), the jackknife richness proves to be higher in Veracruz (*i. e.*  $94.6 \pm 78$ – $110$  species *versus*  $54.6 \pm 44.3$ – $64.8$  species). As the analysis and the confidence limits of variance embraced the whole composition of species and as limits were close to the main value, the assessment of richness of chlorococcalean algae in shallow environments in Veracruz may be considered reliable to recognize the floristic potential in the region. The results of this study of shallow aquatic environments is a step toward for the establishment of latitudinal patterns in the distribution of freshwater algae.

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### Resumen

Se presenta la flora de clorofíceas unicelulares y cenobiales de algunos charcos de la planicie costera del Golfo de México, con una caracterización taxonómica y ecológica de las especies. Se registran 69 táxones, incluyendo una forma nueva. La mayoría de las especies tienen una distribución amplia (85.5%), otras son de distribución tropical (5.8%): algunas (4.4%) son sólo de distribución templada y otras (4.3%) son propias de aguas cálidas en la zona templada. Se discute la importancia de estas algas en los charcos, la posibilidad de dispersión hacia otros ambientes acuáticos de la zona y la relevancia que puede tener el registro de la flora de este tipo de ambientes someros en la distribución geo-gráfica de las especies.

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