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Cyanoprokaryota (Cyanobacteria) in karst environments in Yucatán, Mexico

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Abstract: Some water bodies in karst environments of the Yucatán peninsula are rich in tropical species of cyanoprokaryote metaphyton. We present species of Chroococcales and Oscillatoriales from seven different families and identify 14 new records for Mexico where four are described as new species (*Asterocapsa xcaamalensis*, *Chlorogloea halkab*, *Cyanosarcina caribeana*, and *Synechococcus socialis*). The unique ecological conditions of alkaline wetlands at varying depth levels appear to promote richness of Cyanoprokaryota, an important group representative of the biodiversity in the peninsula. The area is part of the Caribbean subregion and is included among the 25 key sites of diversity worldwide. Of the species documented in this study, 82% have been recorded in the literature for this subregion and half of these species have a circumscribed distribution to the Caribbean.
Key words: Caribbean region, Chroococcales, freshwater algae, new species, Oscillatoriales, sinkholes, wetlands.

Resumen: Algunos cuerpos de agua en ambientes cársicos de la península de Yucatán son ricos en especies de cyanoprokariontes metafíticas tropicales. Se presentan las especies de Chroococcales y Oscillatoriales de siete diferentes familias y se identifican 14 nuevos registros para México, de los que cuatro constituyen nuevas especies (*Asterocapsa xcaamalensis*, *Chlorogloea halkab*, *Cyanosarcina caribeana* y *Synechococcus socialis*). Las condiciones ecológicas únicas de los humedales alcalinos con distintos niveles de profundidad parecen promover la riqueza de Cyanoprokaryota, un grupo importante de la biodiversidad en la península. El área estudiada es parte de la subregión del Caribe, que está incluido entre los 25 sitios clave de la diversidad mundial. De las especies documentadas en este estudio, el 82% se han registrado en la literatura para esta subregión y la mitad de estas especies tienen una distribución circunscrita al Caribe.
Palabras clave: algas de agua dulce, cenotes, Chroococcales, especies nuevas, humedales, Oscillatoriales, región Caribeña.

The Yucatán peninsula is composed of limestone, lacks rivers and mountains and has only lentic aquatic ecosystems. The so-called "cenotes" (from the Mayan "tzonot", sinkhole) are the primary natural bodies of water forming a continuum at the basement layer. However, shallow bodies of water called ¨sascaberas¨ (from the Mayan "saskab", white earth), created artificially by filtration and accumulation of rain water, have been made since the Maya pre-Hispanic period for the supply of construction material. Our research in the cenotes and sascaberas revealed an interesting variety of Cyanoprokaryota, composed mostly of typical tropical species.

Cenotes and sascaberas of the Yucatán peninsula offer important sources of flora to the area and may be highly valuable in terms of biodiversity, particularly since the peninsula is part of the Caribbean biogeographic subregion, an area included among the 25 key biodiversity sites worldwide (Myers *et al*., 2000). According to some studies of algae (Rejmánková *et al*., 2004; Komárek *et al*., 2005; Komárek and Komárková-Legnerová, 2007a), the diversity of Cyanoprokaryota in this subregion form an important component of the metaphyton, benthos, periphyton, and plankton communities; their richness is associated with the unique ecological conditions of alkaline wetlands at different depth levels. These wetlands are a characteristic environment of the Yucatán peninsula, in Central America and the Caribbean islands (Greater and Lesser Antilles), as well as the Florida peninsula and northern South America (Komárek, 1984, 1989, 1995; Komárek and Novelo, 1994; Komárková-Legnerová and Tavera, 1996; Vymazal *et al*., 2002; Novelo and Tavera, 2003; Rejmánková *et al*., 2004).

This paper describes 34 species, including 14 new re-

cords for Mexico where four are described as new species, representing a contribution to the knowledge on the biodiversity of microorganisms in the Yucatán peninsula. From the biogeographical point of view this diversity is also relevant since the Yucatán is part of the provinces that comprise the Caribbean subregion (Morrone, 2006), where prior evidence supports the existence of species of cyanoprokaryotes common to this subregion (see studies from previous paragraph).

Material and methods

Study area. The study areas included the Xcaamal cenote (20° 36' 19.4" N; 89° 42' 32.2" W), the Cholul cenote (21° 02' 43.0" N; 89° 32' 31.4" W) and the sascaberas Seminario (21° 01' 17.2" N; 89° 33'24.3" W), Vergel (20° 56' 30.3" N; 98 ° 34' 22 .4" W), and Xoclán (20° 58' 28.1" N; 89° 39' 35.2" W), all shallow, warm, alkaline bodies of water (Table 1). Soil composition, climate, vegetation, and geology of the peninsula and morphometry of aquatic environments are well documented (see Olmsted and Durán-García, 1990; Herrera-Silveira *et al*., 1998; Bautista-Zúñiga *et al*., 2004; Rzedowski, 2006). Vascular aquatic vegetation (Schmitter-Soto *et al*., 2002) is present in the littoral zone of all sites studied and samples were collected mainly from the metaphyton community (*i.e*. among vascular vegetation).

Methods. The common hydrology parameters such as temperature, pH, and conductivity as well as dissolved oxygen were measured *in situ* using portable Conductronic (Mexico) equipment. The data shown in Table 1 represent averages of three measurements taken once in the dry and rainy seasons in the years 2003 to 2005. Total phosphorus was analyzed by the acidic digestion method, as well as total inorganic nitrogen; NO_3-N through the cadmium reduction method; NO_2-N by the diazotization method; and NH_4-N by the salicilate method following the Hach procedures (Hach Co., 1997).

Samples were collected with a 10 μm mesh and preserved in 2.5% formalin. Observations were made using photonic microscopes (Optiphot Nikon and Carl Zeiss Axio Imager) equipped with differential interference contrast (DIC) and epifluorescence. Epifluorescence photographs were taken using auto-fluorescence excitation filters UV-1A (355/10 nm) and DAPI 01 (360/55 nm, 460/50 nm) with a combination of contrasting techniques (DIC and DAPI) to achieve the images shown in Figures 72 and 75. Collections were maintained in the Herbarium of Biological Sciences Campus UADY in the FICOYUC-PRIORI collection with the exception of newly discovered species that were maintained in the Herbarium of Facultad de Ciencias (FCME – UNAM), in the Phycological Yucatán collection. We described new species according to the rules of the International Code of Botanical Nomenclature (Vienna Code, McNeill *et al*., 2006). Species Herbarium references are listed according to location (Xcaamal = Xc; Cholul = Ch; Seminario = Se; Vergel = Ve; Xoclán = Xo), sample number order and collection date. Measurements of cells and colonies represent the minimum and maximum value, in parenthesis we give the extreme or rare values.

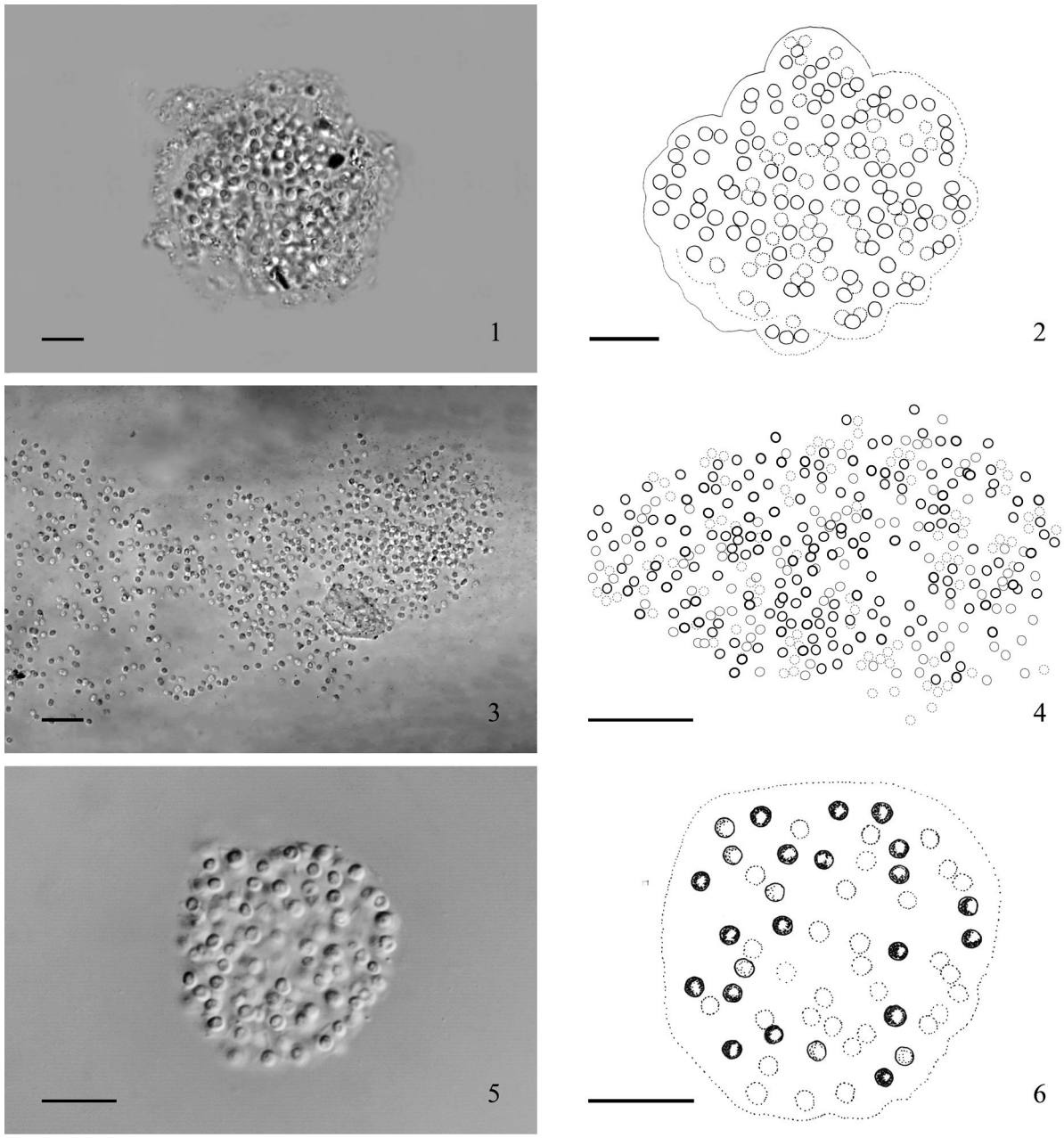
Results

Physical and chemical status of water bodies. Data on temperature, pH, conductivity, and dissolved oxygen are given in Table 1 as average values for the dry and rainy seasons. Nutrients were determined only once in the rainy season of 2005 as values of dissolved inorganic nitrogen (DIN) and total phosphorus. The mean value of DIN (1.4 mg l^{-1}) was only two times the mean value of total phosphorus (0.7 mg l^{-1}). Moreover, conductivity was higher during the dry season in all sites except for Cholul with almost the same value.

Descriptions of species.
Order Chroococcales
Family Merismopediaceae

Table 1. Physical and chemical parameters measured in the sites studied during the dry and the rainy season. The statistics were calculated over all values.

Locality	Temperature °C		pH units		Conductivity µS cm $^{-1}$		Dissolved oxygen mg l^{-1}		Nutrients mg l^{-1}	
	dry	rainy	dry	rainy	dry	rainy	dry	rainy	DIN	Ptot
Cholul	30	28	7.3	7.0	1,250	1,241	5.0	5.6	2.70	0.62
Seminario	28	26	7.0	7.3	1,990	1,000	7.2	5.3	1.00	0.50
Vergel	29	27	8.2	7.0	1,400	746	11.0	11.4	1.10	0.46
X'caamal	29	27	8.0	7.0	1,900	700	6.8	9.0	1.10	0.64
Xoclán	32	29	7.0	8.8	1,800	811	7.0	3.6	1.10	1.28
Variance	2.94		0.41		232,832.62		6.60		0.53	0.11
Arithmetic mean	28.5		7.5		1,283.80		7.19		1.40	0.70
SD	1.71		0.64		482.52		2.57		0.72	0.33



Figures 1-6: 1-2 (Xo-822) *Aphanocapsa elachista*; 3 (Se-801), 4 (Ve-745) *Aphanocapsa holsatica*; 5-6 (Se-730) *Aphanocapsa incerta*. Scale = 10 μm.

Subfamily Merismopedioideae
Aphanocapsa elachista W.West & G.S.West 1846
Figures 1-2
= *Microcystis pulverea* f. *elachista* (W.West & G.S.West) Elenkin 1938; *Microcystis elachista* (W.West & G.S.West) Starmach 1966.

Colonies are irregularly spherical with aqueous, colourless mucilage that is sometimes difficult to distinguish and formed a wide margin around the cells. Cells are distributed in low density, spherical in shape and occurred in pairs following cell division; cells are pale blue-green in colour with a homogeneous content. Colonies are small, up to 65.0 μm in diameter with cells ranging in diameter from 2.5-2.8 μm. On some occasions diminutive picoplankton (bacteria) appeared immersed in the mucilage of colonies.

Ecology: This species is non-abundantly present in Xoclán and Seminario.

Herbarium: Se-729, Xo-751, Se-800, Xo-822.

Notes: This is a planktonic species in clear lakes, sporadically occurs in swamps, likely cosmopolitan (Komárek and

Anagnostidis, 1999). Up to now, this species has not been associated with karst environments, even when it is widely distributed (Schumacher, 1961; Casco and Toja, 1991; Padisák *et al*., 1998). To our knowledge it grows also in this type of environment.

Aphanocapsa holsatica (Lemmermann) Cronberg & Komárek 1994 Figures 3-4
= *Clathrocystis holsatica* Lemmermann 1903; *Microcystis holsatica* (Lemmermann) Lemmermann 1907

Colonies are large with an irregular shape and aqueous, colourless mucilage that is difficult to visualize and sometimes appearing lattice-like. Cells are pale blue-green with a homogeneous content; cells appear in irregular and dense groups inside the colony at times and appear separated at other times. Cells are (1.4-) 2.0-2.6 μm in diameter.

Ecology: Present (not abundant) in Vergel, Xoclán, Xcaamal, and Seminario, in large, isolated colonies.

Herbarium: Se-733, Ve-745, Xo-751, Xc-744, Se-801, Xc-804, Ve-815, Xo-822.

Notes: This is a planktonic species, variable in cell size up to 3.0 μm. They are common in temperate (Komárek and Anagnostidis, 1999) as well as in tropical lakes in South America (Yacubson, 1972; Sant'Anna *et al*., 2004). A population similar to this species (*A*. cf. *holsatica*) was registered in the state of Hidalgo, Mexico (Komárek and Komárková-Legnerová, 2002) in similar biotopes. Its presence in calcareous environments is rare.

Aphanocapsa incerta (Lemmermann) Cronberg & Komárek 1994 Figures 5-6
= *Polycystis incerta* Lemmermann 1899; *Microcystis incerta* (Lemmermann) Lemmermann 1907; *Microcystis pulverea* var. *incerta* (Lemmermann) Crow 1923; *Microcystis pulverea* f. *incerta* (Lemmermann) Elenkin 1938; *Anacystis incerta* (Lemmermann) Drouet & Daily 1952

Colonies are spherical, enveloped by a very fine and colourless mucilage and occur in low density (one diameter separating distance), except after division. Colonies are microscopic and small, ranging in size up to only 40.0 μm in diameter. Cells are pale blue-green with a clear chromatoplasm lacking granules or aerotopes. Cells are 1.6-2.7 μm. in diameter.

Ecology: Few specimens were present in Seminario during the rainy season.
Herbarium: Se-730.

Notes: This is a common temperate and tropical species in plankton of eutrophic water bodies (Komárek and Anagnostidis, 1999). This species has also been registered in Mexico City (Komárek and Komárková-Legnerová, 2002) and in the states of Michoacán (Hernández-Morales, 2011), and Veracruz, Mexico (Vázquez and Blanco-Pérez, 2011), also in alkaline and limestone environments.

Aphanocapsa intertexta Gardner 1927 Figures 7-8
Colonies are irregular with aqueous, homogeneous, colourless, and nearly invisible common mucilage. On rare occasions cells have spherical individual envelops (narrow) with homogeneous content (lacking granules). After division cells are observed in pairs. Cells distributed densely and irregularly inside the colony. Colonies are small and cell diameter range from 1.0-1.3 μm.

Ecology: We found limited specimens only in Xcaamal during the rainy season; we did not observe reproduction of the colonies.

Herbarium: Xc-744, Xc-762.

Notes: This species was observed by Komárek and Komárková-Legnerová (2007a) in Belize, also in alkaline environments. According to these authors, populations do not coincide entirely with Gardner's *A. intertexta* ecology (Gardner, 1927), however the morphological similarity leads us to consider that the species may have a plasticity that allows it to grow from the dry conditions of any wetland (perhaps what Gardner described as subaerial) to flooded conditions. For this reason, we have identified our population according to the species name assigned by Gardner. This is a new record for Mexico.

Aphanocapsa nubilum Komárek & Kling 1991 Figure 9-10
= *Microcystis pulverea* var. *racemiformis* Nygaard 1949; *Microcystis pulverea* f. *racemiformis* (Nygaard) Hollerbach 1955

Colonies are basically spherical and enveloped by a fine, aqueous, colourless mucilage. Colonies are small and typically 18.9-30.0 μm in diameter. Cells are 1.0-2.0 μm in diameter, pale blue-green in colour with a homogeneous content, often in pairs and densely aggregated.

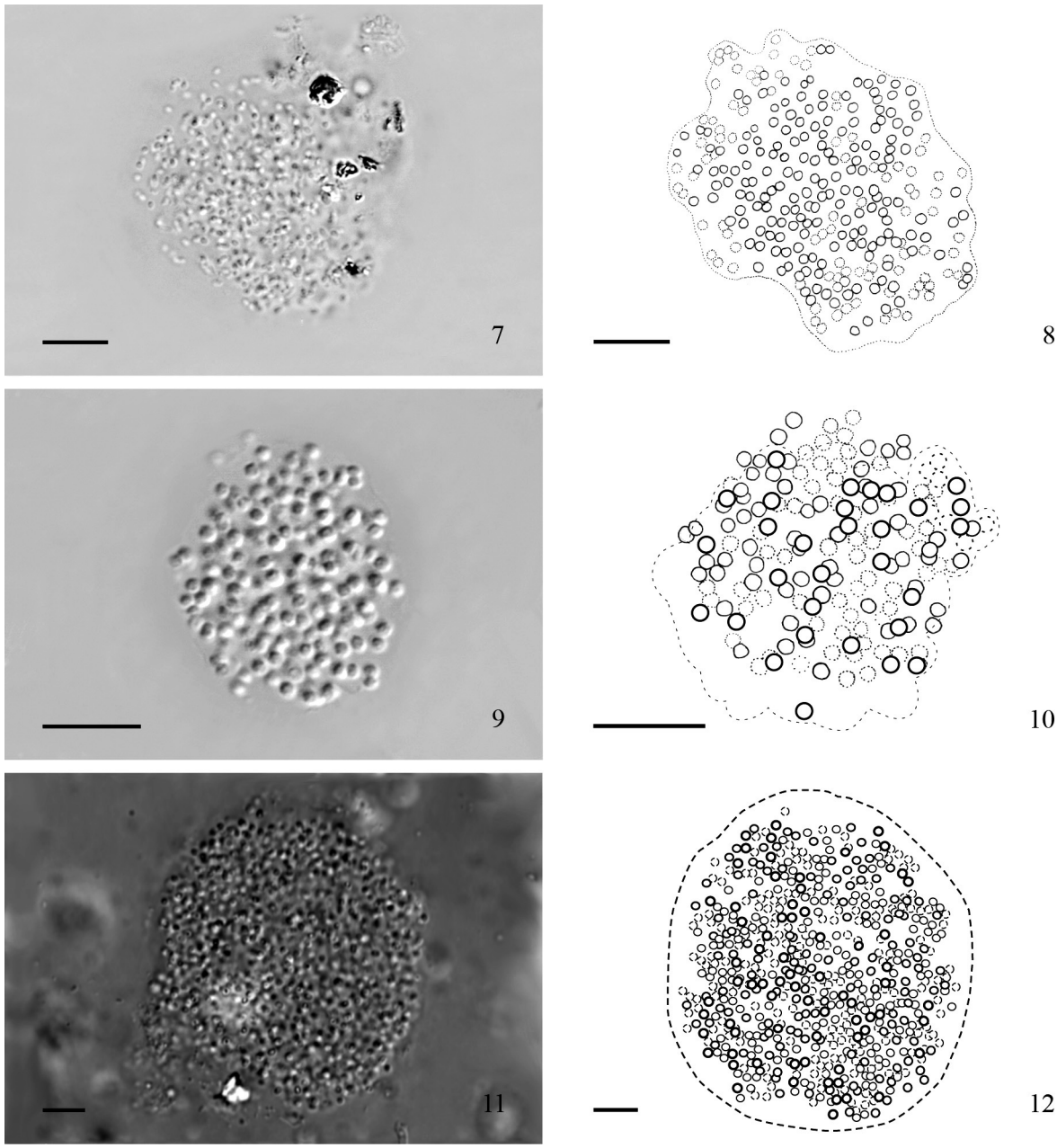
Ecology: We found few specimens only in Xcaamal.

Herbarium: Xc-762, Xc-806.

Notes: Described as planktonic in clear lakes but observed in Lake Victoria, Uganda (Komárek and Kling, 1991); and also registered in Mexico City and in the states of Puebla (Komárek and Komárková-Legnerová, 2002), Veracruz (Vázquez and Blanco-Pérez, 2011), and Quintana Roo karst wetlands (Calderón-Medina, 2006). According to Komárek and Anagnostidis (1999) it is probably a cosmopolitan species and in our opinion karst wetlands are at the end of their ecological range, judging by its presence, rare in the Yucatán peninsula

Aphanocapsa venezuelae Schiller 1956 Figures 11-12
Colonies are spherical or irregular in shape with aqueous, colourless mucilage. Cells occur in low density; they are pale blue-green in colour with evident chromatoplasm, and few evident granules. Colonies are large, 68.0-270.0 μm in diameter with cells 1.9-2.5 μm in diameter. Adult cells are distant from one another at least 2.0 μm.

Ecology: Observed as metaphytic in the littoral zone



Figures 7-12: 7-8 (Xc-744) *Aphanocapsa intertexta*; 9 (Xc-806), 10 (Xc-762) *Aphanocapsa nubilum*; 11-12 (Se-732) *Aphanocapsa venezuelae*. Bar = 10 μm.

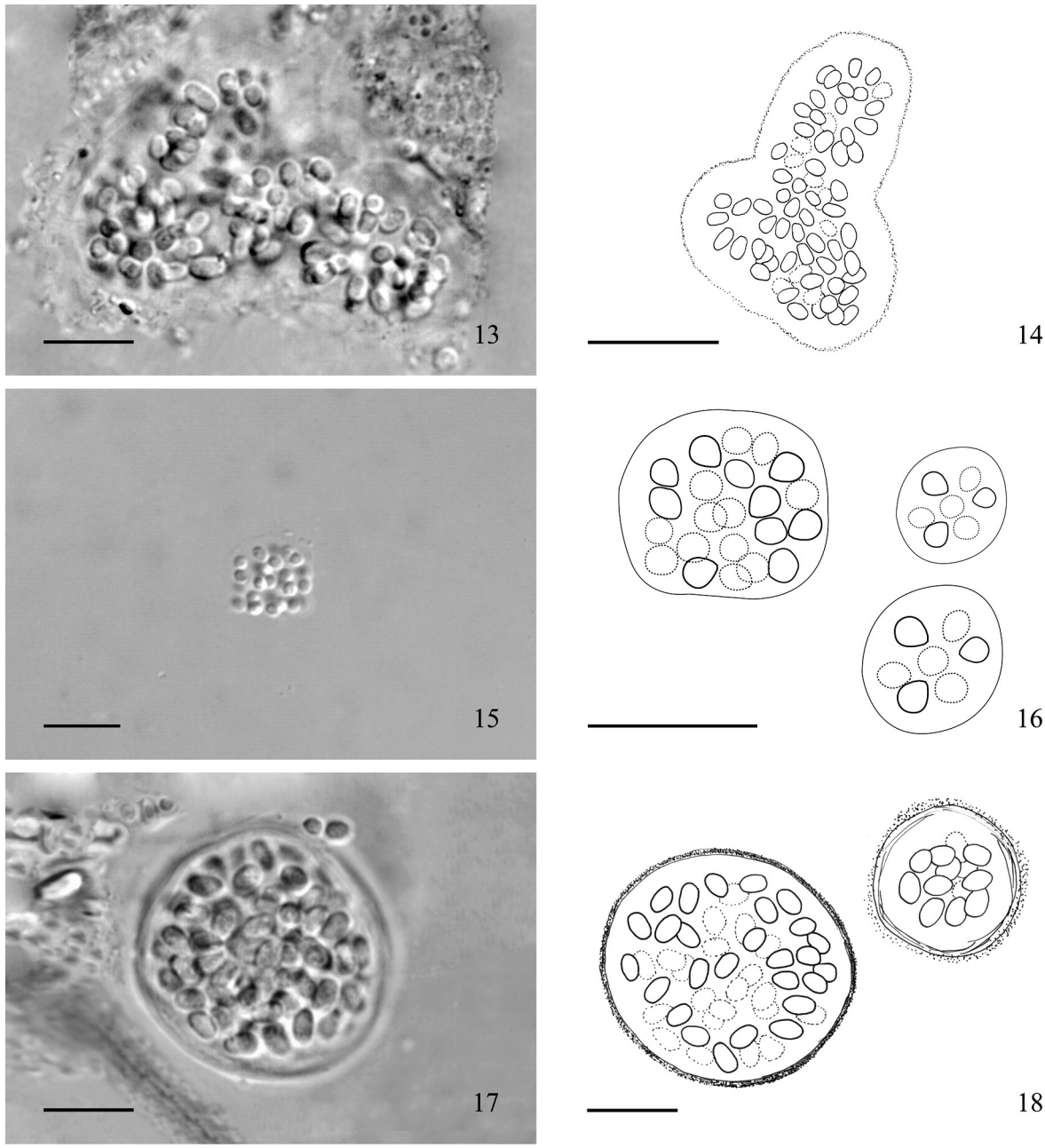
only in Seminario; occurring in low abundance among other cyanoprokaryotes. Colonies of our specimens were larger than those described for *A. venezuelae* from Belize by Komárek and Komárková-Legnerová (2007a), where colonies were 42.0-70.0 μm in diameter; however, diameter of cells and their arrangement in the colonies were similar.

Herbarium: Se-732, Se-801.

Notes: Colonies were observed in Belizean marshes, with a diffuse margin (Komárek and Komárková-Legnerová, 2007a); this species seems to be typical in tropical marshes. Yucatán colonies have a much larger diameter than the samples from Belize, but the morphological similarity is remarkable, suggesting that there may be variation in the size of colonies in this species. This species is only known in the Caribbean region and is a new record for Mexico.

Subfamily Gomphosphaerioideae

Coelomoron microcystoides Komárek 1989 Figures 13-14
Colonies are irregular with aqueous, wide, colourless muci-



Figures 13-18: 13 (Xc-744), 14 (Ve-747) *Coelomoron microcystoides*; 15-16 (Xc-806) *Coelomoron tropicale*; 17 (Xo-752), 18 (Ve-748) *Coelomoron vestitum*. Scale bar = 10 μm.

lage; oval cells are located from the centre to the periphery of the colony. Medium size colonies of up to 52.0 μm long consisted of 2.5-4.5 μm long and 1.8-2.7 μm wide cells.

Ecology: One of the most abundant and widely distributed species, present in all the studied localities in both seasons.

Herbarium: Se-730, Se-731, Se-732, Xc-744, Ve-746, Ve-747, Xo-750, Xo-751, Xo-752, Se-800, Xc-805, Xc-807, Ve-815, Ve-816, Xo-821, Xo-822.

Notes: This is a tropical species, described as metaphytic and rare plankton in Cuba, Mexico and South Africa (Komárek, 1989; Komárek and Anagnostidis, 1999). Cells in our samples were slightly larger than those described from Cuba and had clearly visible mucilage. According to our data and the literature, this species is typical of karst environments.

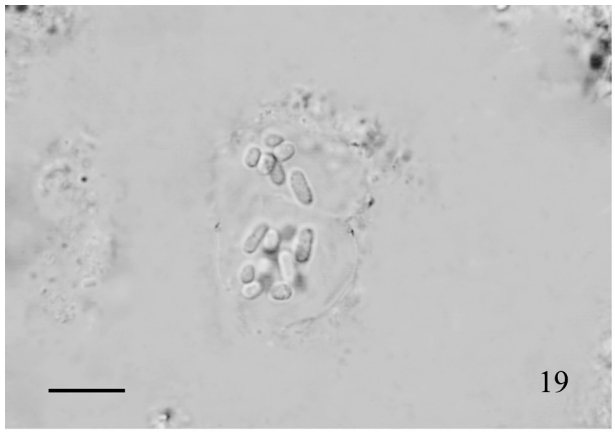
Coelomoron tropicale Senna, Peres & Komárek 1998
Figures 15-16

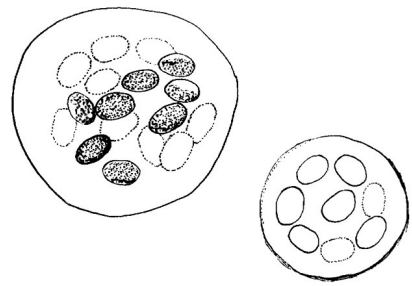
Colonies are spherical, sometimes consisting of sub-colonies and limited by a fine, colourless mucilage. A dense arrangement of radial cells is observed at the periphery of the colonies; cells are egg-shaped with a homogeneous, pale blue-green content. Colonies are small, up to 20.0 μm in diameter composed of cells 1.8-2.4 long and 1.4-2.7 μm in width.

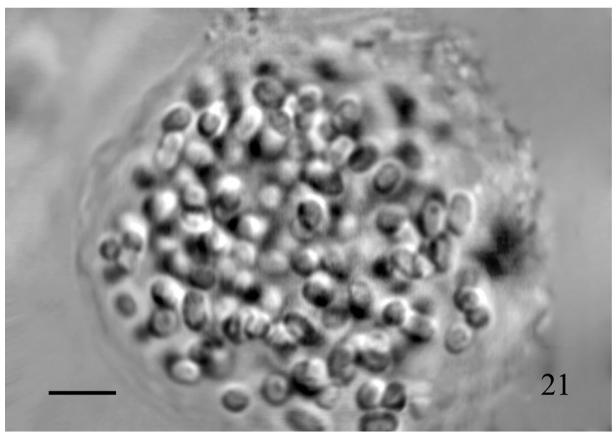
Ecology: Present in Xcaamal in the dry season, rare at the littoral edges. This species is probably a true element of plankton but populations like ours, similar to a small *C. tropicale*, were considered metaphyton in Sao Paulo, Brazil (Sant'Anna *et al*., 2004).

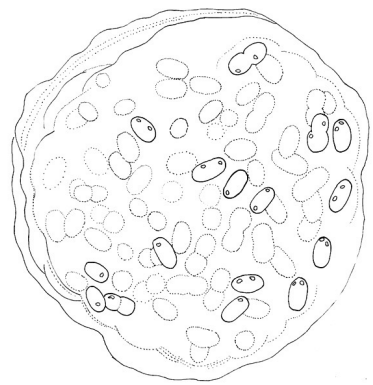
Herbarium: Xc-806, Xc-808.

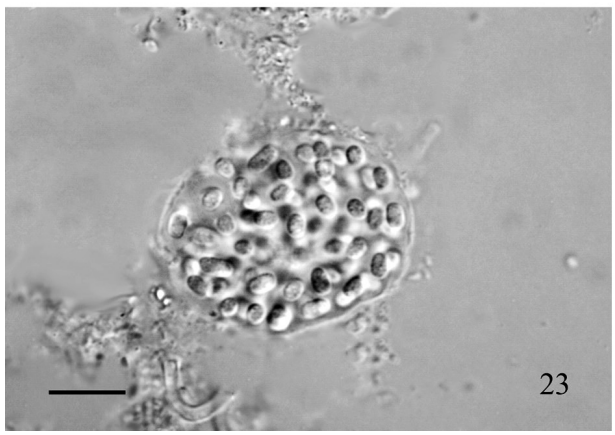
Notes: This species was described in Brazil and although it has been observed in South Africa (Komárek and Cronberg, 2001) and in Cuba (Komárek, 1989); it is not yet sufficiently documented. We think that in addition to morphological

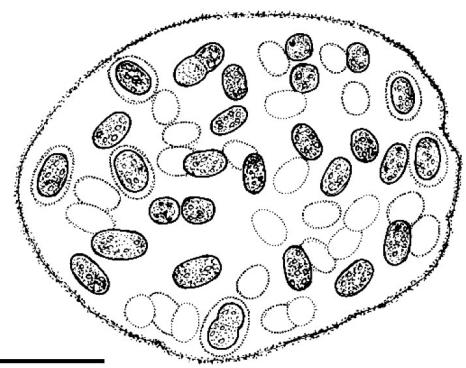












Figures 19-24: 19 (Xo-752), 20 (Ve-748) *Aphanothece comasii*; 21-22 (Xo-751) *Aphanothece conglomerata*; 23-24 (Ve-747) *Aphanothece granulosa*. Scale bar = 10 μm.

variability, it may also take planktonic metaphytic forms. Sant'Anna *et al*. (2004) mention that species of this genus are common in tropical and subtropical regions. This is a new record for Mexico and except for the records of Cuba, has not been observed in karst environments. To our knowledge can grow there, but not common.

Coelomoron vestitum Komárek 1989 Figures 17-18
Colonies are spherical and often have a thick cover of firm mucilage. Cells have a wide, oval shape, blue-green colour, and radially distributed along the periphery of the colony. In young colonies there are some mucilaginous stalks projecting from peripheral cells at the colony centre. Colonies are 30.0-45.0 μm in diameter with cells 4.0-6.0 μm long, 2.0-3.5 μm wide.

Ecology: Present in Vergel and in Xoclán; abundant in the rainy and dry seasons.

Herbarium: Ve-748, Xo-752, Ve-815, Xo-822.

Notes: This species was described from alkaline swamps in Cuba (Komárek, 1989). It is probably only metaphytic. Our colonies were smaller than those described from Cuba (80.0 μm in diameter). This is a new record for Mexico and according to our data and literature is present only in the Caribbean region in karst environments.

Family Synechococcaceae
Subfamily Aphanothecoideae
Aphanothece comasii Komárková-Legnerová & Tavera 1996 Figures 19-20
Colonies are spherical to ellipsoidal in shape with a wide, distinct, colourless mucilaginous envelope. Cells are densely and irregularly aggregated at the centre of the colony. Reproduction occurs by release of cells and colony division. Colonies are small, 20.0-40.0 μm in diameter, composed of wide-oval cells 4.5-4.7 μm long and 2.3-2.8 μm wide.

Ecology: Present in Xoclán and Vergel, not abundant.

Herbarium: Ve-748, Xo-752, Ve-815, Xo-822.

Notes: This species, described from the Lake Catemaco, in eastern Mexico (Komárková-Legnerová and Tavera, 1996), is present in Cuba (Komárek and Anagnostidis, 1999), Belize (Komárek and Komárková-Legnerová, 2007a), and in the Guadeloupe island (Bi-Eau, 2002). It is a variable planktonic and metaphytic species and according to Komárek and Komárková-Legnerová (2007a), commonly encrusted with carbonate and detritus in the mucilage. We rarely observed the carbonate incrustations, while detritus incrustations were common. According to our data and literature it is common in karst environments.

Aphanothece conglomerata Rich 1932 Figures 21-22
Colonies are spherical with a colourless firm, wide and well-defined mucilage. Cells have a wide oval shape, are pale blue-green in colour with a granular content. Cells are arranged in dense clusters in young colonies but formed separate aggregates in the older ones. Colonies are 29.0-90.0 μm in diameter and composed of 6.6-9.0 μm long, 4.1-5.7 μm wide cells.

Ecology: This species occurred in low numbers in metaphyton from Vergel, Xoclán, and Seminario, during both seasons.

Herbarium: Se-732, Ve-749, Xo-751, Se-801, Ve-816, Xo-822.

Notes: According to Komárek and Anagnostidis (1999), *Aphanothece conglomerata* is a well defined tropical and subtropical species, planktonic or metaphytic. It has been described in South Africa, Venezuela, and the USA. There are also records from Brazil (Azevedo *et al*., 1999) and Mexico in the karst wetlands of Quintana Roo (Calderón-Medina, 2006). Our data and the literature indicate that it is common in karst environments.

Aphanothece granulosa (Gardner) Komárek & Komárková-Legnerová 2007 Figures 23-24
= *Aphanothece microscopica* var. *granulosa* Gardner 1927.

Colonies are isolated and irregular in shape, enveloped by thin, colourless mucilage. Some cells have an individual envelope. The oval cells are gray blue-green and distinctively granular. Colonies are small, up to 60 μm in diameter and composed of 7.2-7.6 long and 4.0-5.2 μm wide cells.

Ecology: In the rainy season only this species rarely occurred in the metaphyton in Vergel and Xoclán. Specimens were small and the mucilaginous envelopes were covered by detritus and bacterial cells isolated.

Herbarium: Ve-747, Xo-752.

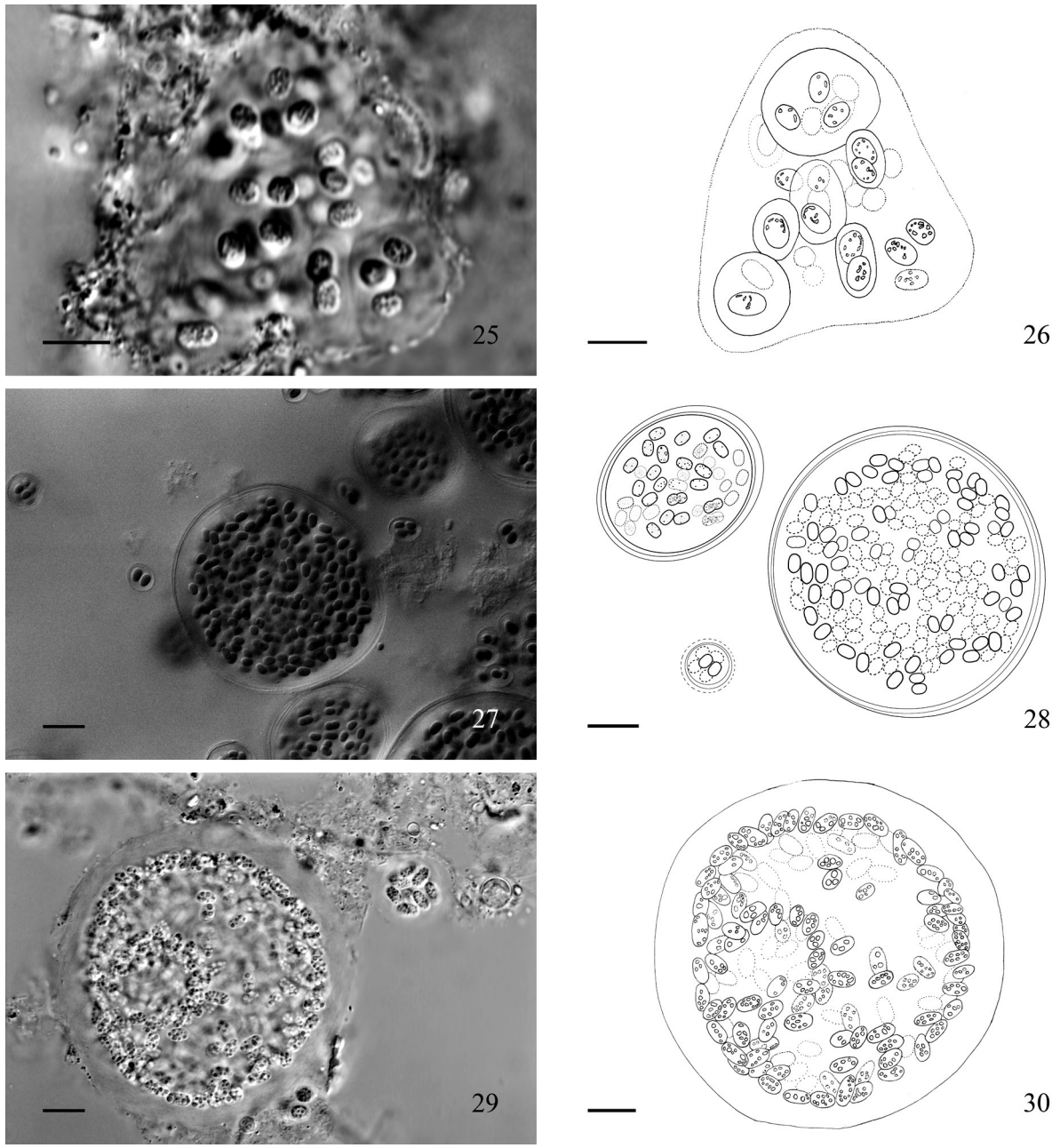
Notes: This species is present in marshes in Belize, occurring in benthic biofilms among other cyanoprokaryota. According Belizean (Komárek and Komárková-Legnerová, 2007a), Puerto Rican (Gardner, 1927), and our own registered ecology, this species may grow in littoral (metaphytic) and subaerophytic regions at the edges of shallow water bodies, in karst regions. This is a new record for Mexico.

Aphanothece hardersii Schiller 1956 Figures 25-26
Colonies are spheroid to irregular in shape. Mucilage is hyaline, colourless, and often aqueous or indistinct. Small groups of cells, usually in low density, inside colonies are sometimes enveloped by their own thin, colourless envelopes. Cells are oval and wide in shape with a blue-green or olive-green colour, and always a defined granular content, sometimes with an evident chromatoplasma. Colonies are mainly 60.0-70.0 (-120.0) μm in diameter consisting of 4.8-6.4 (-8.5) μm long and (3.5-) 4.6-4.8 μm wide cells.

Ecology: This species was present in Vergel and in Seminario, not abundant and only during the rainy season.

Herbarium: Se-729, Ve-749.

Notes: This species was described for Isla de Las Aves (Venezuela) in 1956, in salty, guano-rich pools and was not

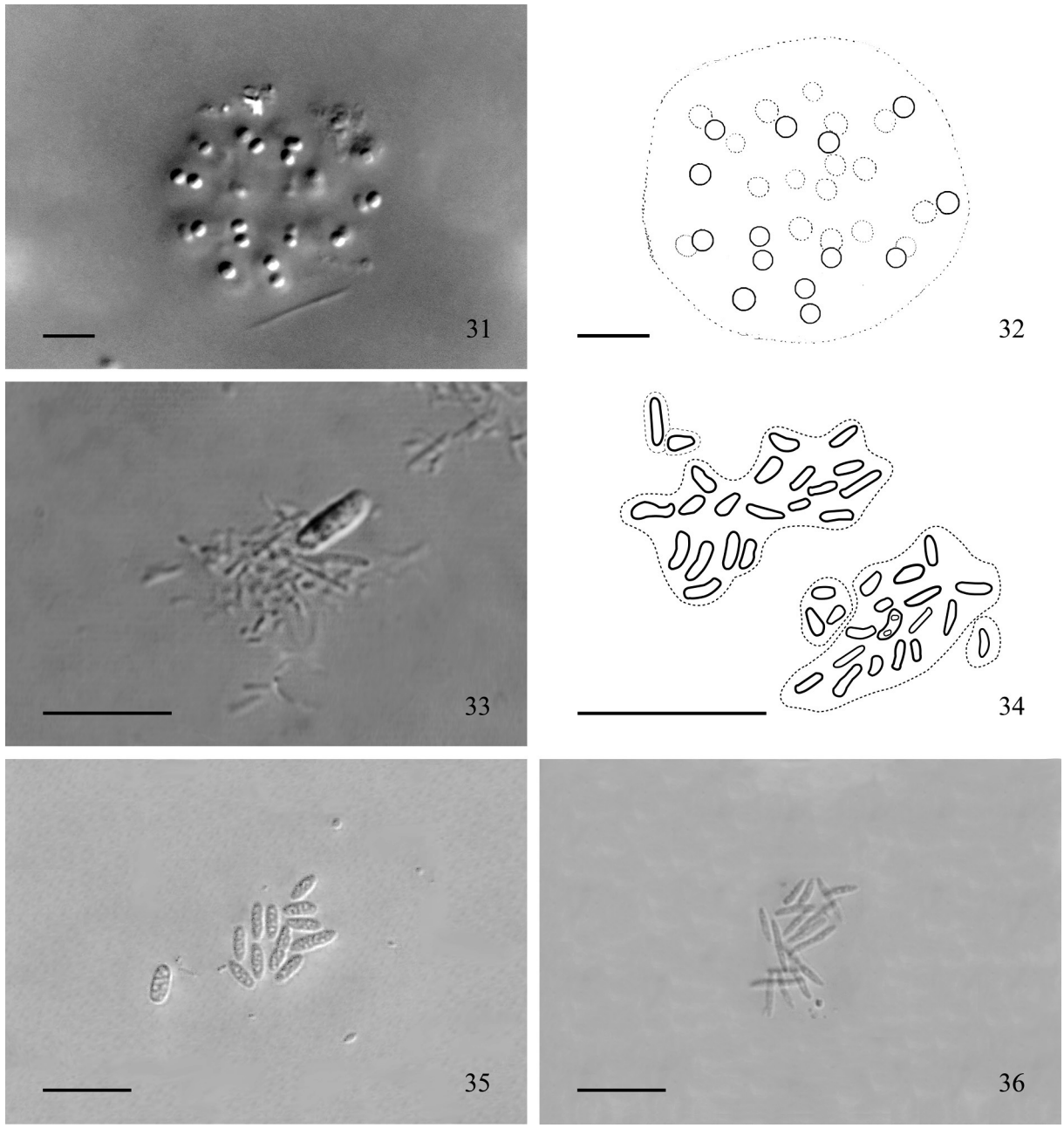


Figures 25-30: 25-26 (Ve-749) *Aphanothece hardersii*; 27, 28 (Ch-742) *Aphanothece stagnina*; 29-30 (Xo-821) *Aphanothece variabilis*. Scale bar = 10 μm.

observed anywhere until Komárek and Komárková-Legnerová (2007a) registered it in Belize, also in a karst environment. This is a new record for Mexico.

Aphanothece stagnina (Sprengel) A.Braun in Rabenhorst 1865 Figures 27-28
= *Coccochloris stagnina* Sprengel 1807; *Aphanothece prasina* A.Braun in Rabenhorst 1863; *Aphanothece piscinalis* Rabenhorst 1865; *Aphanothece stagnina* var. *nemathece* Frémy 1930.

Colonies begin with a spherical shape and become lobed, with a firm, brown mucilage, and the development of sub-colonies. Mucilage of individual cells and sub-colonies has no pigment and is inconspicuous. Cells are cylindrical with rounded ends, homogeneous content, and dark olive-green colour. The cells are distributed more densely toward the periphery of the colony. Colonies have 10.0-120.0 μm and cells are 3.5-5.0 μm long and 2.0-2.5 μm wide.



Figures 31-36: 31-32 (Se-729) *Radiocystis geminata*; 33 (Se-800), 34 (Ve-747) *Rhabdoderma tenuissimum*; 35 (Xc-744), 36 (Xc-804) *Rhabdogloea subtropica*. Scale bar = 10 μm.

Ecology: Occurred in small numbers in Seminar in the rainy season and abundant in Cholul in one sample from the rainy season.

Herbarium: Ch-742; Se-733.

Notes: There are several records in African and American localities; tropical populations remain poorly characterized. According to Komárek and Anagnostidis (1999) it may be periphytic although colonies can be released. We think this is consistent with its abundance in the metafiton of Cholul cenote. *Aphanothece stagnina* seems to be a characteristic species of small eutrophic bodies of water. There are several records of this species in Mexico (Vazquez and Blanco-Pérez, 2011); however, this is the first positive record in karst areas.

Aphanothece variabilis (Schiller) Komárek 1995
Figures 29-30
= *Cyanogastrum variabile* Schiller 1956.
Colonies are more or less spherical; mucilage is colourless, homogeneous, firm, and has sometimes delicate layers; its

external margin is clearly visible. The colonial mucilage is distant from cells by a wide margin. Cells are blue-green in colour, ellipsoidal in shape, and with a fine granular content. Colonies have 20.0-80.0 μm in size and cells are 3.2-4.0 μm long and 1.8-2.7 μm wide.

Ecology: This species was present in Vergel and Xoclán, abundant in both sascaberas and rarely occurred in Xcaamal.

Herbarium: Ve-746, Ve-748, Ve-749, Xo-750, Xo-751, Ve-815, Ve-816, Xc-806, Xo-821, Xo-822.

Notes: Komárek and Komárková-Legnerová (2007a) noted that this species is variable and it may be distributed widely in swamps of low elevation and in the littoral zone of shallow bodies of water. It is considered a pantropical species. In Cuba, this species is common in metaphyton from different aquatic environments, but individual colonies are able to suspend, free-living in plankton (Komárek, 1995). Our material had smaller cells than the Cuban and Belizean populations. According to our data and literature, this species is typical of karst areas.

Radiocystis geminata Skuja 1948 Figures 31-32

Colonies are spherical, limited by a wide, thin, colourless mucilage with an aqueous, barely visible margin. The cells are spherical to slightly oval, with a homogeneous content without granulations or visible aerotopes and arranged radially. Colonies are 50.0-60.0 μm in diameter and composed of cells 2.5-3.7 μm long and 2.0-4.0 μm wide.

Ecology: Only a few samples were collected from Seminario in the rainy season. Ecological conditions were consistent with those described for the species.

Herbarium: Se-729.

Notes: Komárek and Anagnostidis (1999) consider this species as typical of the temperate zone, although there are several records of this species in Mexico: Catemaco, Veracruz and Tecuitlapa, Puebla (Komárek and Komárková-Legnerová, 2002) and in Cuba (Gómez-Luna *et al*., 2010). In our country, this is the first record in karst environments.

Subfamily Synechococcoideae

Rhabdoderma tenuissimum Komárek & Kling 1991

Figures 33-34

Colonies are irregular and enveloped by highly delicate mucilage. Each colony has a small number of grey to pale blue-green coloured cells that are elliptical to slightly spindle-shaped and oriented in one direction in young colonies. Colonies are small, 10.0-15.0 μm in diameter and composed of cells 2.8-3.0 μm long and 0.5-0.9 μm wide.

Ecology: In Vergel, this species was present only in the rainy season as very small isolated colonies, often mixed with *Synechococcus socialis*. Specimens from Seminario were also observed as individual cells and were abundant in both seasons. Most of the colonies in both localities showed irregular distribution of cells, likely an indication of older colonies.

Herbarium: Se-729, Se-730, Se-733, Ve-745, Ve-746, Ve-747, Se-800, Se-801.

Notes: This species was described from Lake Victoria, Uganda by Komárek and Kling (1991). According to Komárek and Anagnostidis (1999) it is characteristic from swamps in the tropical zone, but this is the first record for karst environments. This is a new record for Mexico.

Rhabdogloea subtropica Hindák 1984 *emendavit* Tavera, Novelo & López Figures 35-37

Diagnosis: Coloniae libere natantes, irregulares ad rotundatas. Tegumentum gelatinosum, homogeneum, sine structura. Cellulae grisaceae vel pallide caeruleo-virides, interdum contento ad apices granulato. Coloniae magnitudine varia, 25.0-35.0 μm diametro. Cellulae (2.5-) 3.5-10 μm longae, (0.9-) 1.1-1.6 (-2.0) μm latae.

Colonies are irregular in shape and enveloped by a fine, colourless mucilage. Cells are distributed irregularly and with variable density; they are straight, spindle-shaped, pale greyish or pale blue-green in colour, with a homogeneous content. Some specimens have granules at both apical ends (facultative). Colonies are 25.0-35.0 μm in diameter and composed of cells (2.5) 3.5-10 μm long and (0.9-) 1.1-1.6 (-2.0) μm wide.

Ecology: The species was present in Seminario and Xcaamal.

Herbarium: Se-732, Xc-744, Se-800, Xc-804.

Notes: Occurrence of this species is described as planktonic from flooded areas. However, between *Rhabdogloea subtropica* and *R. planctonica* (Teiling) Komárek only the former occurs in the littoral zone of pools in Cuba (Hindák, 1984). Since there is only one drawing and no photographs of this species, we believe that the scarcity of material has restricted the documentation of its variability. Thus, it is important to incorporate the characteristics given here for the redefinition of this species. We have observed this species in shallow environments, as described here, thus we consider *R. subtropica* as typical of karst wetlands. This is a new record for Mexico.

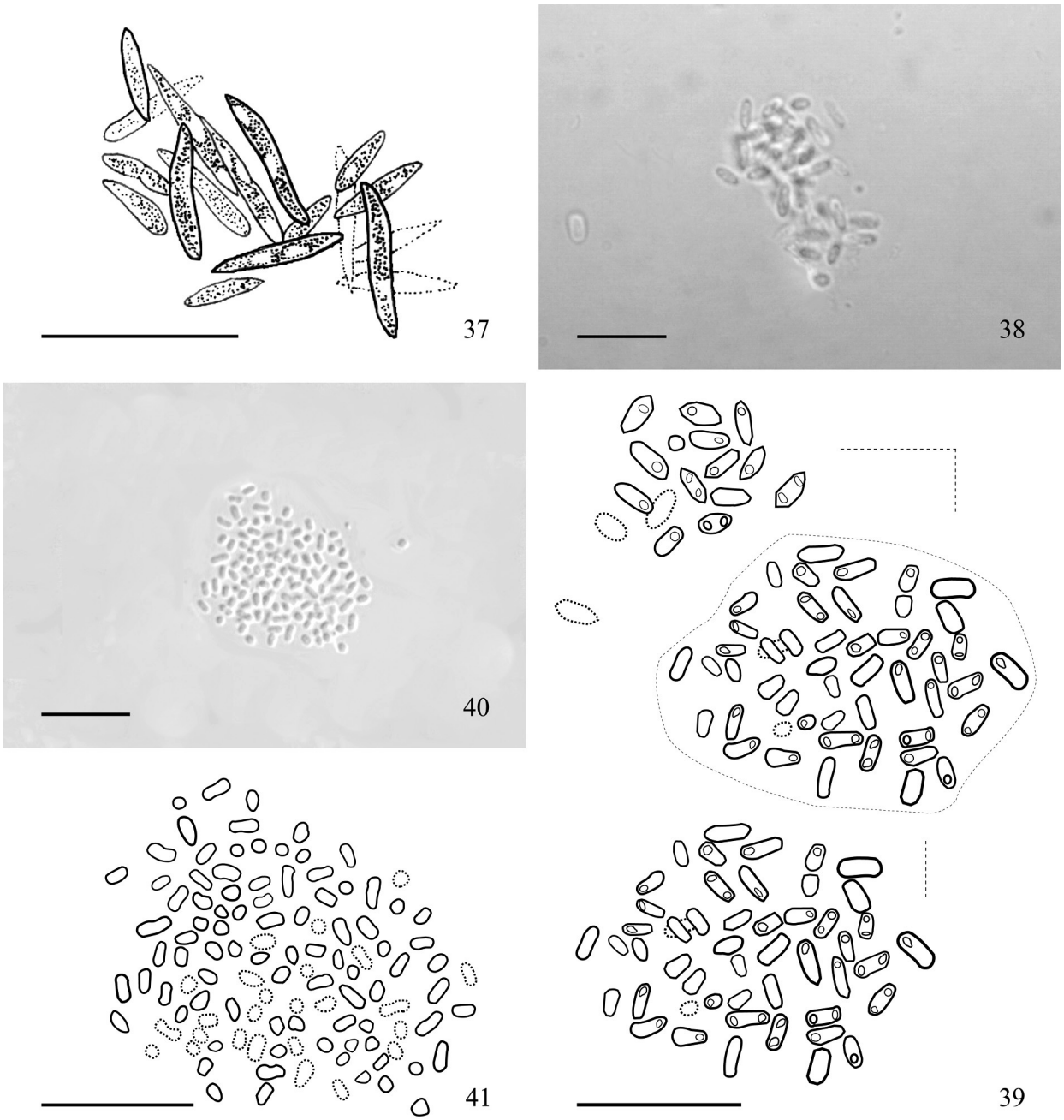
Rhabdogloea yucatanensis Komárek & Komárková-Legnerová 2007 Figures 38-41

Colonies are irregular with an aqueous mucilage observable using DIC. Cells are small, slightly curved or straight, cylindrical or spindle-shaped with conical ends and irregularly distributed with an overall constant separation from each other. Cells have small granules (solitary) in both ends. Colonies are small with a diameter of 15.0-17.0 μm and composed of cells (1.7-) 2.5-4.4 μm long and 1.0-2.0 μm wide.

Ecology: This species was present in Seminario and in Xcaamal in both seasons; it was rarely observed.

Herbarium: Se-732, Se-729, Xc-744, Xo-750, Se-800, Xc-806.

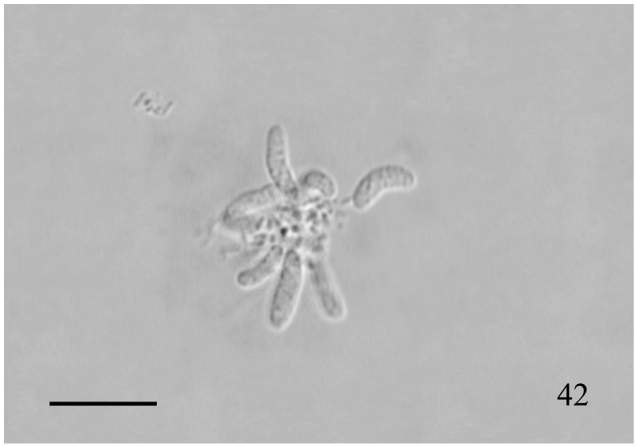
Notes: This species was described by Komárek and

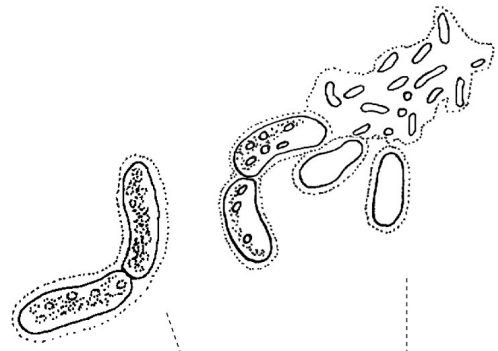


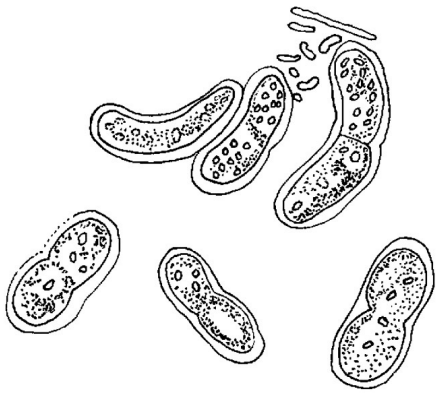
Figures 37-41: 37 (Se-800) *Rhabdogloea subtropica*; 38 (Se-800), 39 (Xo-750) *Rhabdogloea yucatanensis*; 40 (Se-732), 41 (Xc-744) *R. yucatanensis*, cells with the "star-like arrangement" described for *R. brasilica*. Scale bar = 10 μm.

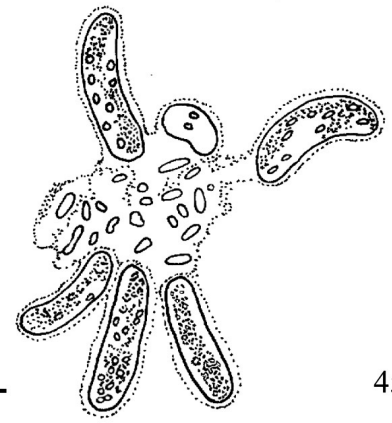
Komárková-Legnerová (2007a) as benthic and periphytic in the littoral zone of Belizean karst marshes and rarely in floating algae mats. These authors refer to the similarity of some samples of *Rhabdogloea yucatanensis* to *R. brasilica* Azevedo & Kováčik 1996, and we agree with this observation. For example, some colonies without granules exhibited groups of cells with the "star-like arrangement" described for *R. brasilica* (Azevedo and Kováčik, 1996) (Figures 40 and 41, in Se-732 and Xc-744). This is a new record for Mexico.

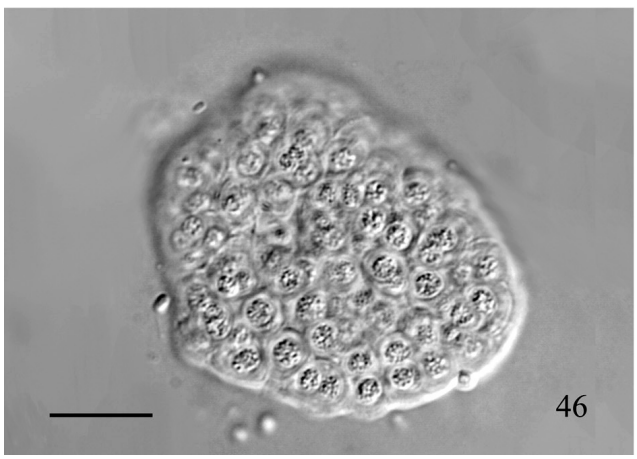
Synechococcus socialis Tavera, Novelo & López sp. nov.
Figures 33, 42-45
Cellulae irregulariter aggregatae, aliquando solitariae vel binae, tum conjunctae angulum formantes, cylindricae curvaeque, unaquaeque tegumento mucilaginoso, viridi-

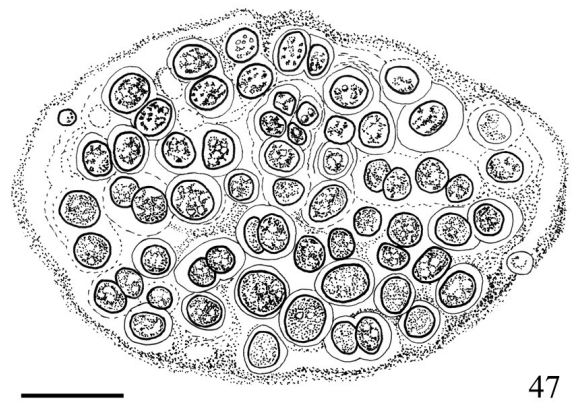












Figures 42-47: 42-45 (Ve-747) *Synechococcus socialis*; 46-47 (Xc-806) *Asterocapsa xcaamalensis*. Scale bar = 10 μm.

cyaneae, 4.0-10.0 μm longae, 1.6-3.0 μm latae, contento subtiliter granulari, granulis grandibus regulariter dispersis praestantibus.

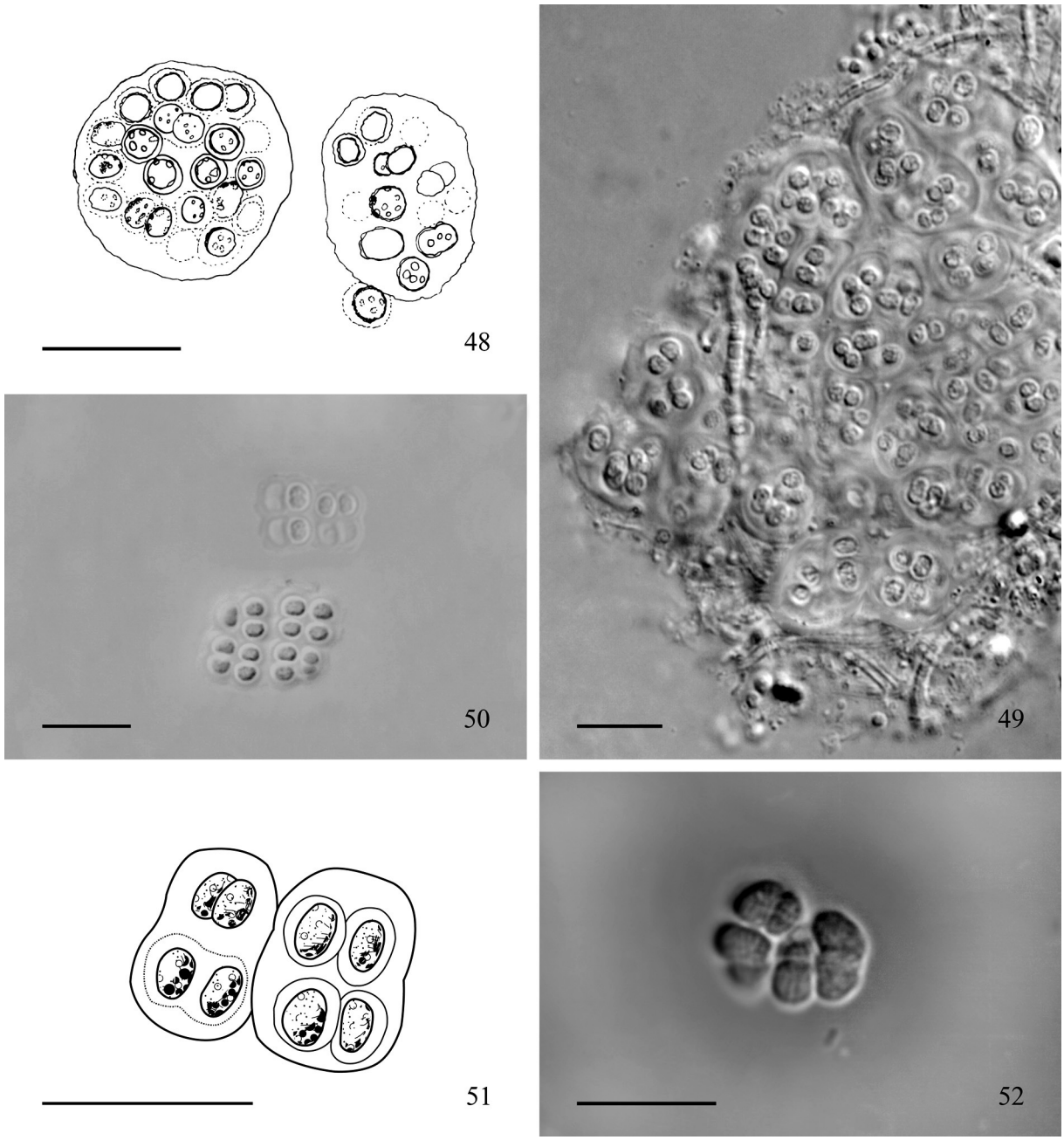
Locus typicus: Mexico, Vergel sascabera (20° 56' 30.3" N; 98° 34' 22 .4" W).

Holotypus: Figura nostra 45; Iconotypus ex specimine Ve-747.2.

Cells occur in irregular clusters or in pairs, sometimes isolated; cells are arranged at an angle with primarily a curved cylindrical shape, enveloped by individual mucilage, sometimes distinctive. Cells are 4.0-10.0 μm long and 1.6-3.0 μm wide, pale blue-green in colour with notorious granules that stand out from finely granulated cell content.

Etymology: The name refers to the common habit of association of this species.

Ecology: This species was present in Vergel and Xcaamal.



Figures 48-52: 48 (Xo-821), 49 (Xc-806) *Asterocapsa xcaamalensis*; 50 (Xo-822), 51(Xo-750) *Chroococcus mipitanensis*; 52 (Xo-751) *Cyanosarcina caribeana*. Scale bar = 10 μm.

Populations from Vergel were often associated to *Rhabdoderma tenuissimum*.

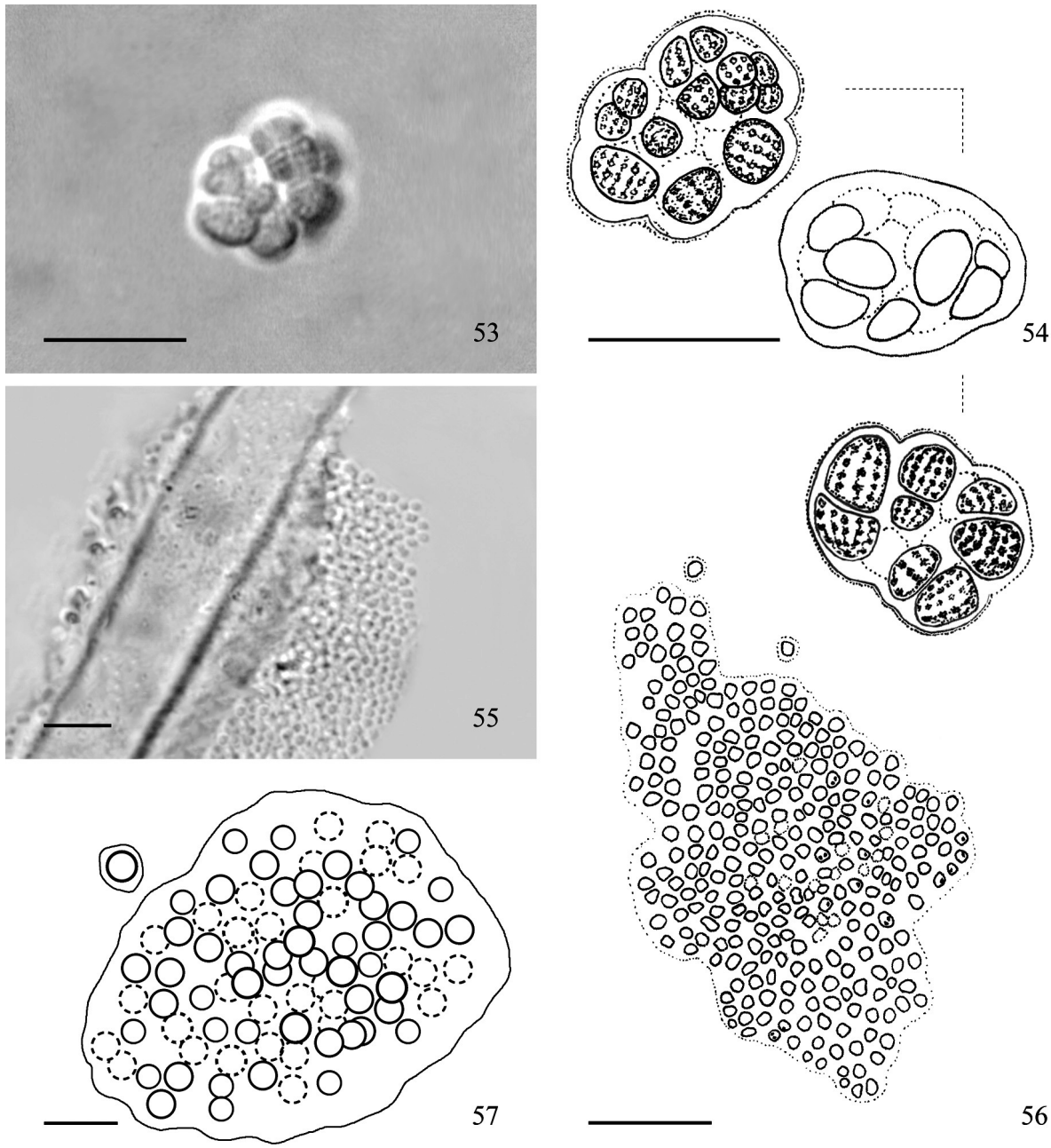
Herbarium: Xc-744, Ve-745, Ve-746, Ve-747, Xc-762, Xc-804, Xc-806, Xc-808, Ve-815.

Notes: Our samples were morphologically very conservative. They seem to be morphologically similar to *Synechococcus koidzumii* Yoneda 1943, which was described from thermal springs in Japan (Komárek and Anagnostidis, 1999). But differences in size, shape, angular condition, and cells content as well as the ecology, suggest that the Yucatán populations are a different entity.

Family Chroococcaceae

Asterocapsa xcaamalensis Tavera, Novelo & López sp. nov. Figures 46-49, 70-72

Coloniae applanatae vel ubi juvenes plus minusve sphaeri-



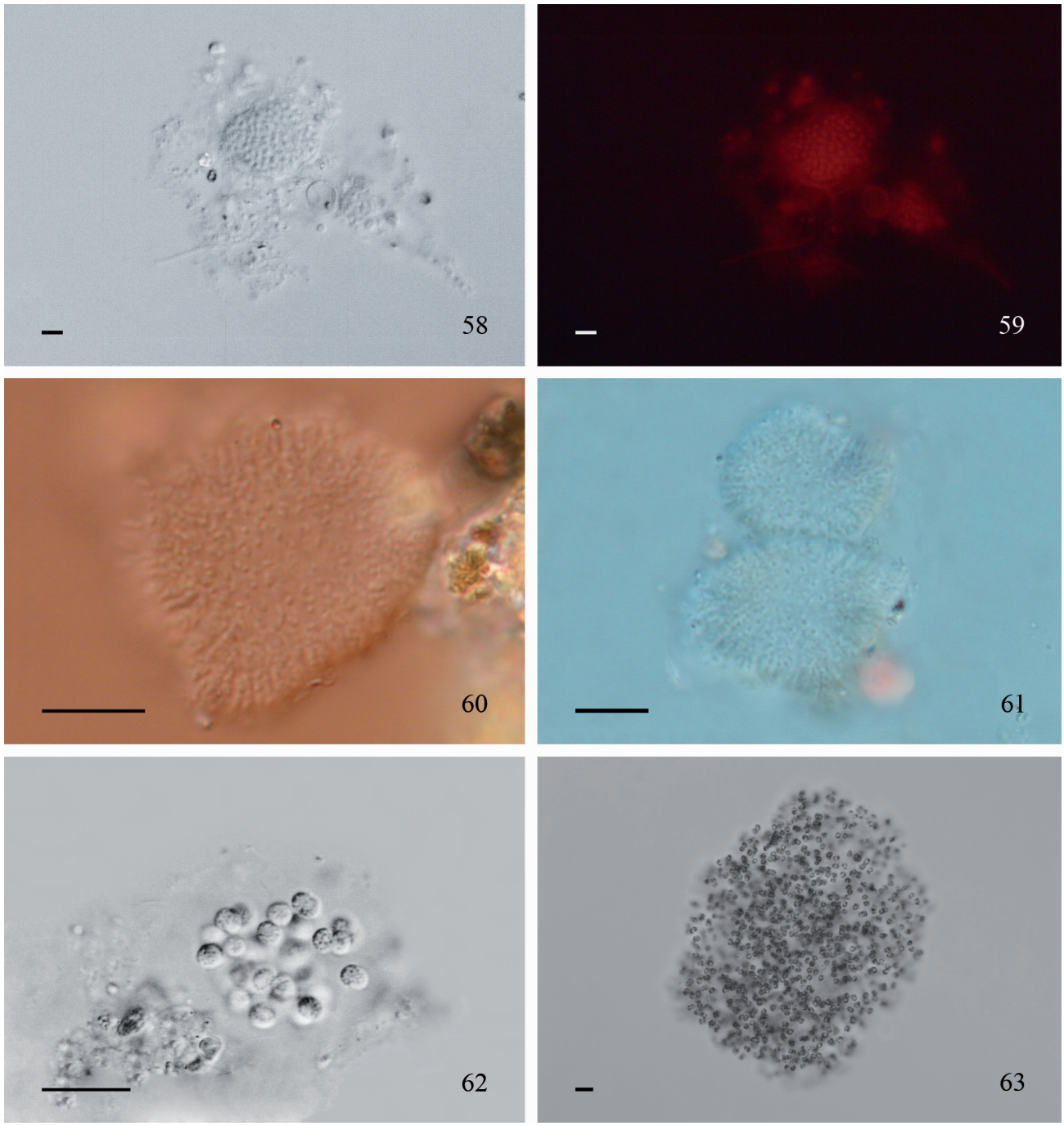
Figures 53-57: 53 (Xo-751), 54 (Se-733) *Cyanosarcina caribeana*; 55-56 (Xc-806) *Chlorogloea epiphytica*; 57 (Xc-762) *Chlorogloea gardneri*. Scale bar = 10 μm.

cae, 24.0-70.0 μm in diametro; mucilago coloniali valde firmo, cellulis 1.8-3.5 μm diametro. Cellulae coloniarum juvenium singulatim tegumento firmo, plus minusve radialiter dispositae. Reproductio per aperturam marginis mucilagi colonialis et separationem cellularum individualium. Vitae cyclus complexus, nannocytos pruducens.

Locus typicus: Mexico, Xcaamal cenote (20° 36' 19.4" N; 89° 42' 32.2" W).

Holotypus: Figura nostra 47; Iconotypus ex specimine Xc-806.1.

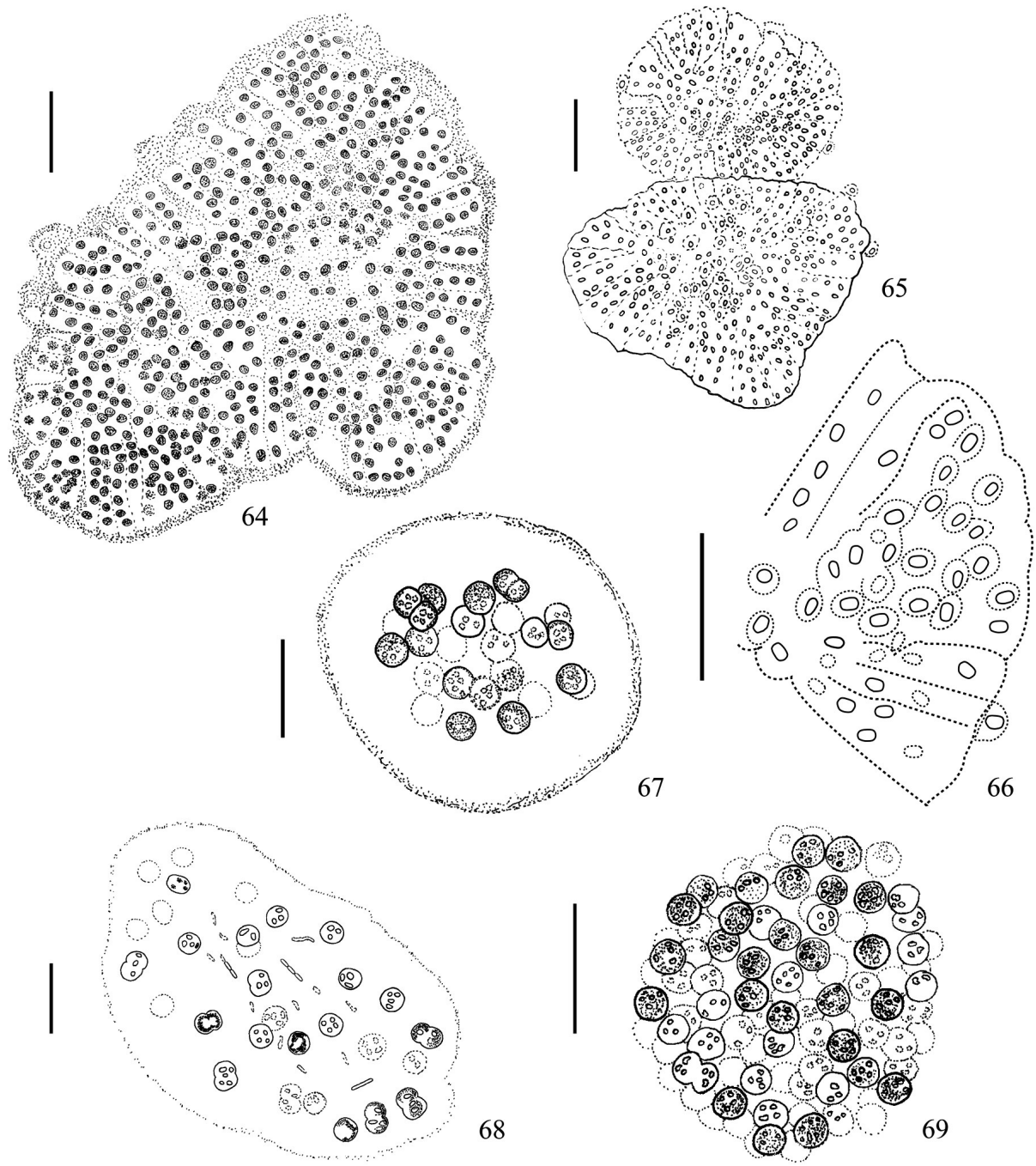
The colonies are flattened to a more or less spherical shape (young), isolated as juveniles or aggregated in subcolonies of adults, forming clusters that reach 80.0-130.0 μm in diameter. The colonial mucilage is very firm. In old colonies, the cells are arranged irregularly in common mucilage, while cells in the younger colonies take a slightly



Figures 58-63: 58-59 (Xc-806) *Chlorogloea gardneri* (59: auto-fluorescence excitation in same exemplar with UV-1A filter); 60-61(Xc-744) *Chlorogloea halkab*; 62 (Xo-821) *Microcystis comperei*; 63 (Xo-821) *Microcystis protocystis*. Scale bar = 10 μm.

oval or spherical shape with a slimy individual envelope. Cells from younger colonies are firm and defined and are basically radially oriented in the colony. During maturation, both the individual and the colonial cells become irregular and tend to be flat with stratified mucilage. The cells content is distinctly granular.

Division of cell occurs by irregular binary fission. Reproduction occurs by the opening of the margin and separation of individual cells. The life cycle is characterized by development of spherical colonies with many cells (called "occasional status" by Komárek, 1993). Nanocytous stages are also seen associated with the clusters formed by mother colonies, sub-colonies and single cells. Colonies are 24.0-70.0 μm in diameter, consisting of cells 1.8-3.5



Figures 64-69: 64-66 (Xc-744) *Chlorogloea halkab*; 67 (Xc-806) *Microcystis comperei*; 68 (Ve-745) *Microcystis protocystis*; 69 (Xc-806) *Microcystis preudofilamentosa*. Scale bar = 10 μm.

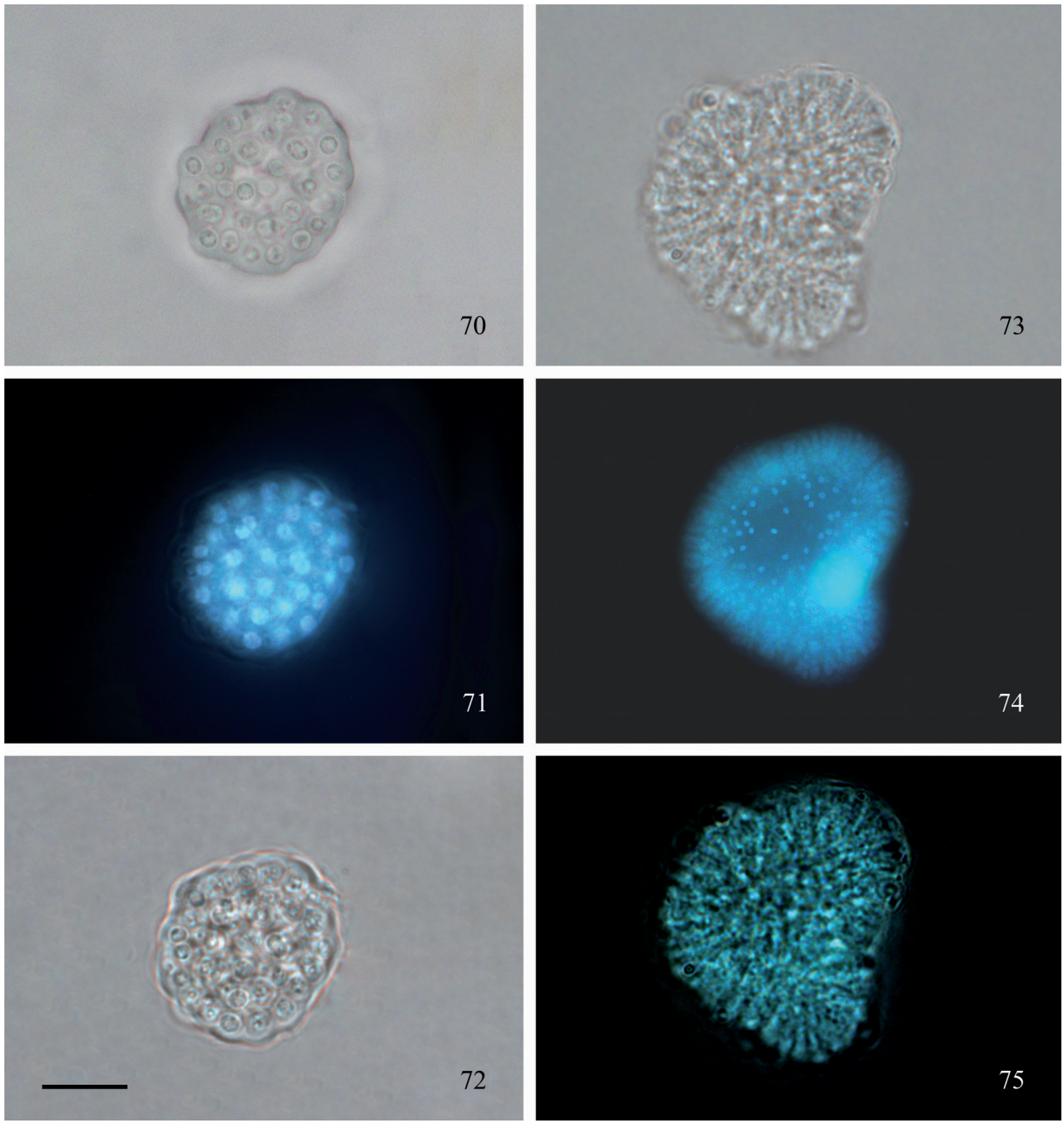
μm in diameter.

Etymology: The name refers to the place.

Ecology: Our samples were free-living in Xcaamal as well as in Xoclán. Samples were not abundant and seemed to prefer the dry, hot season.

Herbarium: Xc-744, Xo-750, Xc-806, Xo-821.

Notes: This species is closely related to species in Belize, particularly *Asterocapsa stagnina* Komárek & Komárková-Legnerová 2007 and *A. nidulans* Komárek & Komárková-Legnerová 2007, sharing a similar ecology and a complex life cycle. However, several morphological differences in *A. xcaamal* indicate its clear separation: development of many clusters enveloped by a firm sheath, colonies size, colour and presence of only few warts over the sheaths and cells. Epifluo-



Figures 70-75: 70-72 (Xo-750) *Asterocapsa xcaamalensis*; 73-75 (Xc-744) *Chlorogloea halkab*. Photographs 70 and 73: DIC pictures of each species; photographs 71 and 74: auto-fluorescence excitation with DAPI 01 filter shows disposition of cells from the same specimens; photographs 72 and 75: Simulations of 3D reconstructions combining DIC and DAPI in the same specimens are artificial images to simultaneously enhance content and disposition of cells as well as the structure of mucilaginous envelop. Scale bar = 10 μm.

rescence photographs highlighted the characteristic arrangement of cells in *A. xcaamalensis* (Figures 70-72).

Chroococcus mipitanensis (Wońoszyńska) Geitler 1925
Figures 50, 51

Colonies are oval in shape with lightly structured, colourless mucilaginous envelopes. Cells commonly occur in small groups and maintain an oval form according to the typical pattern-division of cells in this species. Colonies are 7.0-20.0 μm in size; cells are 1.7-2.5 μm in diameter.

Ecology: All populations were observed in small numbers in Vergel, Xoclán, and Seminario during the dry and rainy seasons.

Herbarium: Se-733, Ve-746, Xo-750, Se-800, Ve-816, Xo-822.

Notes: This species lives in metaphyton, in littoral zones

of lakes; occasionally it also occurs in plankton. This is a pantropical species common in karst environments of Belize (Komárek and Komárková-Legnerová, 2007a) and Cuba (Komárek and Novelo, 1994).

Cyanosarcina caribeana Tavera, Novelo & López sp. nov. Figures 52-54

Coloniae irregulares cellulis in sarcinis conglomeratis, mucilago firmo secus marginem cellulae in coloniae margine. Cellulae griseae vel cyaneo-virides, forma irregulares, plerumque semicirculares, 3.7-6.9 μm longae, 3.0-3.4 μm latae, granulis ita ordinatis dispositis ut cellulae aspectu regulariter rugoso videantur. Coloniae magnitudine varia, 12.0-20.0 μm.

Locus typicus: Mexico, Xcaamal cenote (20° 36' 19.4" N; 89° 42' 32.2" W).

Holotypus: Figura nostra 54; Iconotypus ex specimine Se-733.1.

Colonies are irregular in shape with sarcinoid-agglomerated cells. The mucilage is firm and follows the margin of cells at the edge of colonies. Cells are greyish to blue-green and primarily semicircular with some irregularities. They have a peculiar alignment of granules giving cells a typically rough appearance. Colonies are 12.0-20.0 μm in size, composed of cells 3.7-6.9 μm long and 3.0-3.4 wide.

Etymology: The name refers to its presence in Mexico and Belize, which are part of the Caribbean subregion.

Ecology: This species is metaphytic and planktonic. Abundant populations were observed in Cholul and in Xoclán, Xcaamal, and Seminario, only in the rainy season. In all localities, it was possible to observe free-living small colonies detached from the large metaphytic masses.

Herbarium: Se-729, Se-730, Se-733, Ch-742, Xc-744, Xo-750, Xo-751, Xc-762.

Notes: A very limited material of this species was previously recorded in calcareous wetlands with low conductivity in Belize (as *Cyanosarcina* sp. by Komárek and Komárková-Legnerová, 2007a). The size of cells and colonies is highly variable in this species. These authors reported cells of 5.0-12.0 μm, although size depends on the frequency of cell division.

Family Entophysalidaceae
Subfamily Entophysalidoideae
Chlorogloea epiphytica Komárek & Montejano 1994
Figures 55, 56

Colonies are compact, amorphous to spherical-like in shape, enveloped by colourless fine mucilage. Cells are oval to spherical in shape, distributed in rows oriented to the periphery of the colony (visible only when individuals are attached to a substrate). Cell content is pale blue-green in colour with distinguishable chromatoplasm. Reproduction occurs by fragmentation of colonies and separation of individual cells sized (1.7-) 2.0-2.3 μm in diameter.

Ecology: This species is metaphytic and periphytic (upon filamentous algae) but fragments and large portions of colonies are liberated to the water column. Abundant colonies of variable size, mainly free-living, were present only at the littoral zone of Xcaamal.

Herbarium: Xc-744, Xc-762, Xc-804, Xc-805, Xc-806.

Notes: In our specimens, cell diameter was slightly smaller than originally described from central Mexico by Komárek and Montejano (1994), also living in karst environments.

Chlorogloea gardneri Komárek & Komárková-Legnerová 2007 Figures 57-59

Colonies are more or less spherical with firm mucilage lying slightly distant from the cells, which are arranged irregularly and densely. Some rows of cells could be distinguished at the periphery of the colonies, especially with the use of chlorophyll-a autofluorescence. The cells are spherical, regular or irregular in shape, and gray-green in colour with a homogeneous content. Colonies are 58.3-70.0 μm in size, composed of cells 2.0-4.5 μm in diameter. Reproduction occurs by release of solitary cells from the colony.

Ecology: Only a few specimens were found free (metaphytic) on the shores of Xcaamal.

Herbarium: Xc-762, Xc-806.

Notes: Epifluorescence photographs highlighted the characteristic arrangement of cells in *Chlorogloea gardneri* (Figure 59). The species has been described in karst wetlands of Belize (Komárek and Komárková-Legnerová, 2007a) as metaphytic and epiphytic. The population from Xcaamal has the same ecology. This is a new record for Mexico.

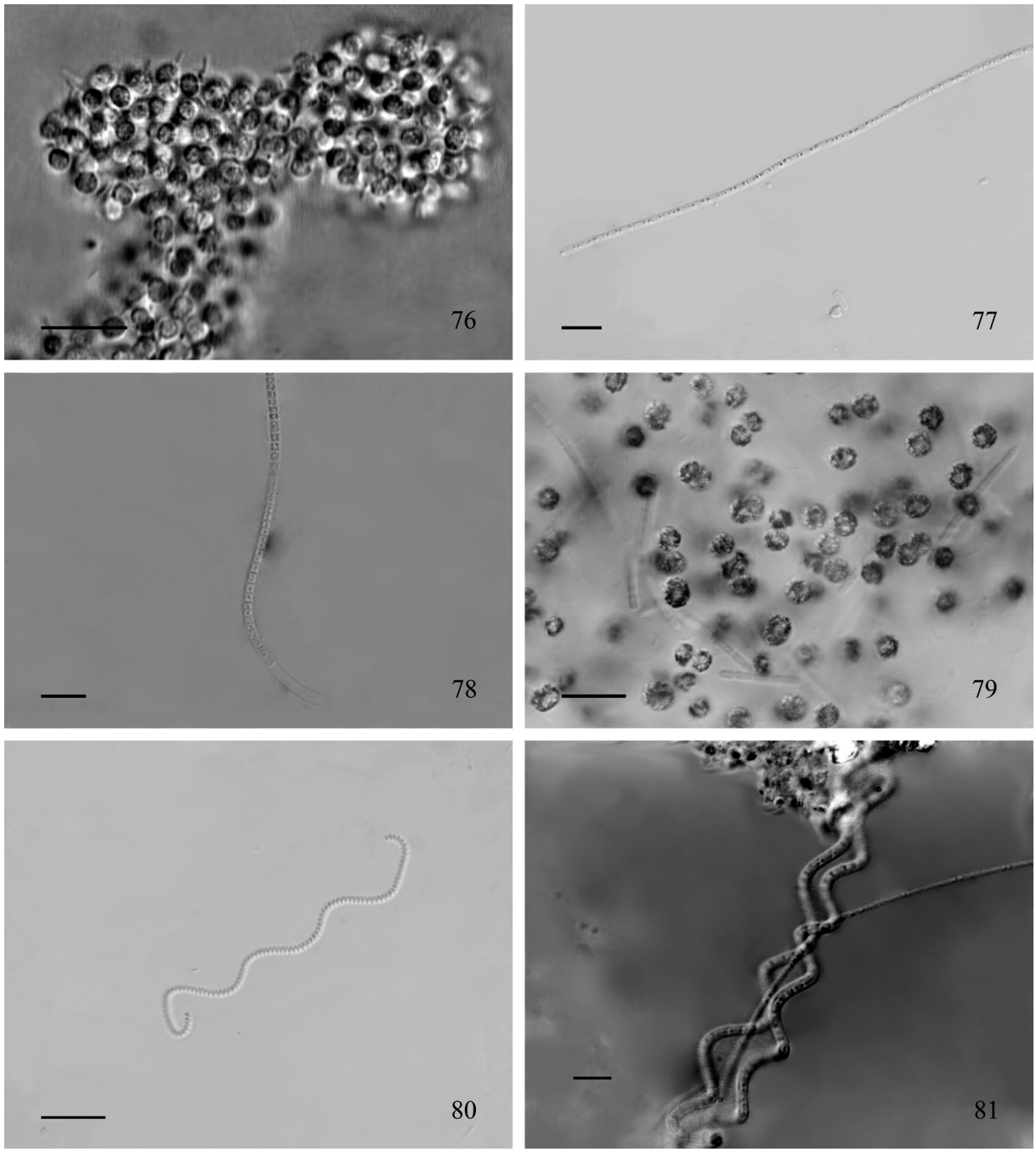
Chlorogloea halkab Tavera, Novelo & López sp. nov. Figures 60-61, 64-66, 73-75

Coloniae mucilaginosae, applanatae, plus minusve discoidales, e subcoloniis constatae; mucilago aspectabili in coloniae margine, manifesto, incolorato. Cellulae cyaneo-virides vel griseae, e centro versus periferiam seriatim dispositae; tegumentum aliquando cellulas individuales vel greges parvas cellularum involvens; cellulae contento homogeneo, ovatae vel sphaericae, interdum asymmetricae. Coloniae parvae, ad 40.0 μm. Cellulae sphaericae 0.5-1.0 μm diametro; cellulae ovatae 1.0 μm longae, 0.5-0.7 μm latae. Reproductio per fragmentationem coloniarum et separationem cellularum individualium per marginem mucilagi.

Locus typicus: Mexico, Xcaamal cenote (20° 36' 19.4" N; 89° 42' 32.2" W).

Holotypus: Figura nostra 64; Iconotypus ex specimine Xc-744.1.

Colonies are composed of sub-colonies and are mucilaginous and flattened with a discoid shape. The mucilage is visible as well defined and colourless at the edge of the colony. Cells are pale blue-green to greyish in colour and arranged in rows from the centre to the periphery of the



Figures 76-81: 76 (Se-800) *Microcystis preudofilamentosa*; 77 (Xo-821) *Geitlerinema unigranulatum*; 78 (Xo-821) *Limnothrix borgertii*; 79 (Ve-745) *Pseudanabaena voronichinii*; 80 (Xc-804) *Spirulina subtilissima*; 81 (Xo-751) *Leptolyngbya lagerheimii*. Scale bar = 10 μm.

colony. Sometimes envelopes are visible surrounding individual or small groups of cells, which are homogeneous in content; cells are typically oval or spherical although sometimes asymmetrical. Colonies are small, up to 40.0 μm in diameter. Spherical cells are 0.5 to 1.0 μm in diameter; oval cells are 1.0 μm long and 0.5-0.7 μm wide. Reproduction occurs by fragmentation of the colonies and by separation of individual cells through the edge of the mucilage.

Etymology: Halkab is a Mayan word that means to become free.

Ecology: This species was observed in Xcaamal and rarely in metaphyton among aquatic vascular vegetation that was present in the littoral zone. We believe that this species may also have an epiphytic quality (attached to the stems of

vascular plants), as do other *Chlorogloea* species, however, our specimens came from the water column, defining them as a free-living in metaphyton species.

Herbarium: Xc-744, Xc-806.

Notes: To our knowledge, only six *Chlorogloea* species from tropical regions are known (Komárek and Anagnostidis, 1999), none of which coincided morphologically with our populations. Komárek *et al*. (2005) recorded *C. gessneri* Schiller 1956 in Belize, and according to the Schiller's illustration of *C. gessneri*, our population was morphologically similar. However, Schiller described *C. gessneri* from saline water in Isla de Las Aves, Venezuela, which does not match the local Mexican and Belizean ecology. Our photographs with auto-fluorescence (Figures 73-75) clearly show the shape of the typical Chlorogloean-organization of the cells in the colonies, causing us to name our population with a new epithet.

Family Microcystaceae

Microcystis comperei Komárek 1984 Figures 62, 67

Spherical colonies are enveloped by abundant, thin, colourless and slightly externally granulated mucilage. Cells are rounded and distributed in low density homogenously in the periphery of the colonies. Cells contain many aerotopes and divide by two perpendicular planes. Colonies are predominantly small, up to 70.0 μm in diameter, consisting of cells 4.0-5.0 μm in diameter.

Ecology: We observed very few specimens in populations from Xoclán and Seminario (rainy and dry seasons) and in Xcaamal (dry season). Scarce external incrustations were observed in mucilage of the colonies in Xoclán.

Herbarium: Se-731, Xo-750, Xo-821, Xc-806.

Notes: Specimens from Yucatán colonies were medium-sized and cells varied in the degree of agglomeration. Although cells and colonies were of smaller diameter and varied in colour and morphology they remain consistent with those described from Cuba (Komárek, 1984). This is a new record for Mexico, typical from karst environments.

Microcystis protocystis Crow 1923 Figures 63, 68, 79

Colonies are irregular in shape and enveloped by a very fine and aqueous mucilage. Cells are pale blue-green to greyish in colour, full of aerotopes, and homogeneously distributed at low density inside the colony. Colonies are highly variable in size, ranging from 60.0 to 500.0 μm in diameter and consisting of cells 3.0-4.0 μm in diameter.

Ecology: Population in our localities were scarce. The species was observed in the rainy season in Vegel and Xcaamal it occurred rarely in Xoclán and Xcaamal during the dry season. *Microcystis protocystis* is a true element of plankton but it is present also at the littoral edges.

Herbarium: Xc-744, Ve-745, Xc-807, Xo-821.

Notes: This species is characterized as pantropical (Komárek and Anagnostidis, 1999). It has been observed several times in Mexico, but this is the second time that is recorded in karst environments, also in the Yucatán peninsula (Box-Toro, Cobá and Ixin-há, by López-Adrián and Barrientos-Medina, 2007).

Microcystis pseudofilamentosa Crow 1923 Figures 69, 76

Colonies are pseudofilamentous, irregular in shape, composed of subcolonies, and enveloped by aqueous mucilage. Cells are spherical, densely agglomerated and blue-green in colour, with many aerotopes. Colonies are 22.0-60.0 μm in size and are composed of cells 2.6-3.3 μm in diameter.

Ecology: In our study locations, abundant metaphytic and planktonic populations of this species were observed in Vergel during the rainy season and in Seminario and Xcaamal during the dry season.

Herbarium: Ve-745, Ve-746, Ve-748, Ve-749, Se-800, Se-802, Xc-806.

Notes: According to Komárek and Anagnostidis (1999) this is probably a widely distributed species because up today, it has been observed in India and Sri Lanka and in Tierra del Fuego, Argentina. Cells from our specimens were slightly smaller than those previously described. This is a new record for Mexico and the first time recorded in karst environments.

Order Oscillatoriales

Family Pseudanabaenaceae

Subfamily Pseudanabaenoideae

Geitlerinema unigranulatum (Singh) Komárek & Azevedo 2000 Figures 77, 82

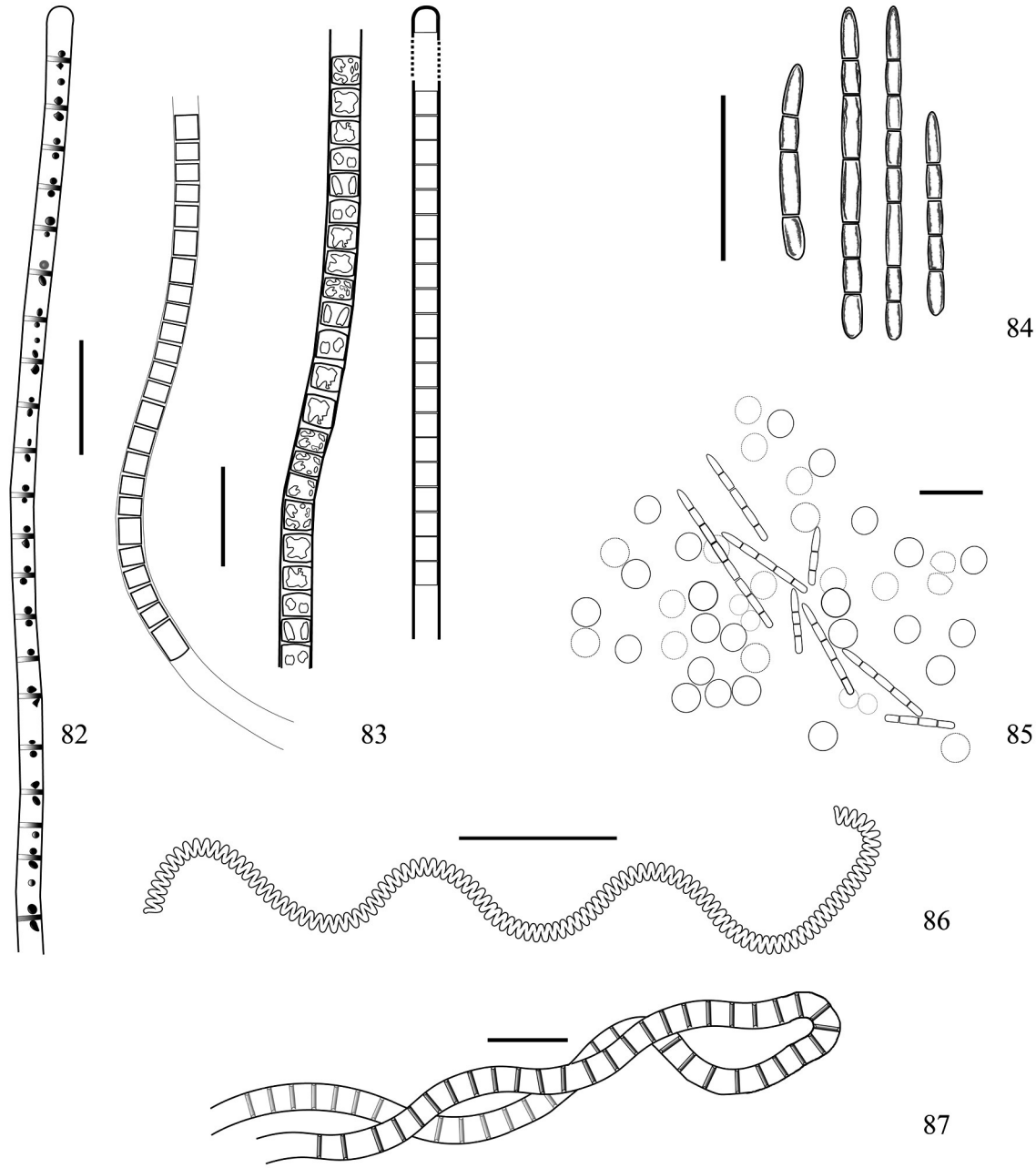
= *Oscillatoria quadripunctata* var. *unigranulata* R.N.Singh 1939

Filaments are long and solitary without visible sheaths. Trichomes are pale blue green to greyish in colour, straight to slightly flexuous and cylindrical in shape. Trichomes have very thin septa, lack constrictions at cross-walls, and are not attenuated toward the ends. Cylindrical cells are rounded at the apex and have homogeneous content with one prominent granule near the septa; sometimes a clear chromatoplasma is visible at the cell wall. Cells are 3.1-8.6 μm long and 1.3-1.8 (-2.0) μm wide.

Ecology: We observed only one population in Xoclán, in low abundance during the dry season.

Herbarium: Xo-821.

Notes: This species is not very common in the tropics. According to Komárek and Anagnostidis (2005) it seems to be slightly halophytic and in African lakes exhibits straight trichomes. Komárek and Azevedo (2000) consider this species as benthic and secondary free-living in plankton of eutrophic ponds. It is known also to occur in India (Komárek and Anagnostidis, 2005). In Mexico, this species has been recorded only in karst environments (Komárek and Komárková-Legnerová, 2002).



Figures 82-87: 82 (Xo-821) *Geitlerinema unigranulatum*; 83 (Xo-821) *Limnothrix borgertii*; 84-85 (Xc-807) *Pseudanabaena voronichinii*; 86 (Xc-804) *Spirulina subtilissima*; 87 (Xo-823) *Leptolyngbya lagerheimii*. Scale bar = 10 μm.

Limnothrix borgertii (Lemmermann) Anagnostidis 2001
Figures 78, 83
= *Lyngbya borgertii* Lemmermann 1907
Solitary filaments are long with thin sheaths. Trichomes are blue-green in colour, straight to slightly curved, cylindrical in shape and non-constricted at cross-walls with wide, clear septa; they are not attenuated toward the ends. Cells are cylindrical and rounded at the apex with a homogeneous content and several aerotopes at the centre. Cells are 2.0-4.0 μm long and 2.0-3.2 μm wide.

Ecology: We observed this species in low abundance during the dry season in Xoclán and in Seminario.

Herbarium: Se-802, Xo-821.

Notes: This species is planktonic in lakes in Sri Lanka (Komárek and Anagnostidis, 2005). This is the first record for this species in karst environments and is a new record for Mexico.

Pseudanabaena voronichinii Anagnostidis 2001
Figures 79, 84-85
= *Oscillatoria mucicola* Voronichin 1949
Solitary filaments are short and thin without sheath. Trichomes are straight and cylindrical in shape, blue-green in colour and motionless; they have thin septa and are composed of 2-8 cells. Cells are conically rounded at the apex with a homogeneous content; aerotopes are absent, and there is a visible chromatoplasma near the cell wall. Reproduction occurs by fragmentation of the filament which is endogloeic with a certain parallel order within the sheath of the host organism. Cells measure 2.8-4.7 μm long and 1.0-3.3 μm wide; trichomes measure 6.0-22.5 μm long.

Ecology: Present in the rainy season in Vergel and in Xcaamal in both seasons. This species was living endogleoic in the mucilage of *Microcystis protocystis*, in samples Xc-744 and Xc-807.

Herbarium: Xc-744, Ve-745, Xc-762, Xc-807.

Notes: It is remarkable the coincidence of association as endogloeic of *Microcystis protocystis*. This association has also been observed in Brazilian water bodies (Komárek and Komárková-Legnerová, 2007b). This is the first record for this species in karst environments and is a new record for Mexico.

Subfamily Spirulinoideae
Spirulina subtilissima Kützing ex Gomont 1892
Figures 80, 86
Trichomes are solitary or mixed with other cyanoprocaryotes and appear light blue-green in colour. Filaments are regular turned. The coil turns to the right and although they are very close, do not touch to each other. The sheath is very thin, fine and colourless. Trichomes are generally straight although sometimes slightly undulating. Septa are invisible and the cell content is homogeneous. Cells are rounded at the apex and were 0.5 to 0.8 μm wide; the diameter of the coil is 1.6 μm and the distance between turns is 0.7-1.0 μm. Trichomes measure 60.0-100.0 μm long.

Ecology: Observed very rarely only in Xcaamal during the dry season.

Herbarium: Xc-804, Xc-806.

Notes: This species is considered to be widely distributed (Komárek and Anagnostidis, 2005). There are previous records in freshwater karst environments in Florida, USA (Whitford, 1956) and Romania (Caraus, 2003). It is a new record for Mexico.

Subfamily Leptolyngbyoideae
Leptolyngbya lagerheimii (Gomont) Anagnostidis & Komárek 1988 Figures 81, 87
= *Lyngbya lagerheimii* Gomont 1982; *Spirocoleus lagerheimii* Möbius 1989; *Spirocoleus lagerheimii* (Gomont) Compère 1990
Solitary, large filaments sometimes are entangled with others and irregularly-spiralled. Sheaths are well defined, smooth, and colourless. Trichomes are pale blue-green in colour and slightly constricted at the thick cross-walls. The apex of the cell is not attenuated. Cells are quadratic, lack granules and are 2.7-4.0 μm long and 3.5-4.0 μm wide. Distance between spirals is 11.0-13.0 μm.

Ecology: An abundant population present only in Xoclán.

Herbarium: Xo-751, Xo-823.

Notes: This species was described originally from Brazil and is probably cosmopolitan (Komárek and Anagnostidis, 2005). There are previous records in freshwater karst environments in Florida, USA (Whitford, 1956) and Romania (Cărăuş, 2003). It is a new record for Mexico.

The diversity of Cyanoprokaryontes presented in this study includes 34 species from six Chroococcales and Oscillatoriales families. The most diverse families included the Merismopediaceae and Synechococcaceae families and new species belonging to the families Synechococcaceae, Entophysalidaceae and Chrooccaceae. A few species occurred abundantly: *Aphanothece variabilis*, *Chlorogloea epiphytica*, *Coelomoron microcystoides*, *C. vestitum*, *Cyanosarcina caribeana*, *Microcystis pseudofilamentosa,* and *Synechococcus socialis*, whereby *C. microcystoides* was the most abundant species with the widest distribution (present in all locations). Nine species were common (perhaps in small numbers, but in at least two locations), six species occurred in small numbers (or rarely, but occurred in at least three locations) and 12 species were classified as rare, present in only one location or two locations and in very small numbers, although present throughout the year (*Aphanocapsa incerta*, *A. intertexta*, *A. nubilum*, *A. venezuelae*, *Aphanothece granulosa*, *Chlorogloea gardneri*, *Coelomoron tropicale*, *Geiltlerinema unigranulatum*, *Leptolyngbya lagerheimii*, *Limnothrix borgertii*, *Radiocystis geminata*, and *Spirulina subtilissima*).

With the exception of *Radiocystis geminata*, all species recorded in this study had a wide tropical distribution. *Aphanocapsa elachista*, *Aphanothece stagnina*, and *Microcystis protocystis* have the widest distribution in Mexico and 14 species (41%) have an exclusive Caribbean distribution.

According to a database documentation on literature of freshwater algae (Novelo and Tavera, 2011), *Aphanocapsa holsatica*, *Aphanothece comasii*, *A. conglomerata*, *A. variabilis*, *Chlorogloea epiphytica*, *Chroococcus mipitanensis*, and *Radiocystis geminata* are poorly recorded in Mexico, with two or less registers in the country. The Cyanoprokaryota of Mexico that are currently listed as having only an exclusive Caribbean distribution are *Aphanocapsa intertexta*, *A. venezuelae*, *Aphanothece granulosa*, *A. hardersii*, *Asterocapsa xcaamalensis*, *Chlorogloea halkab*, *C. gardnerii*, *Coelomoron tropicale*, *C. vestitum*, *Cyanosarcina caribeana*, *Microcystis comperei*, *Rhabdogloea subtropica*, *R. yucatanensis*, and *Synechococcus socialis*.

Discussion

According to the values presented in Table 1, the temperature was a very stable parameter in aquatic environments in the Yucatán localities. Only in the dry season Xoclán had an extreme temperature considering the variance, *i.e*. distant from the mean in a larger value of standard deviation. It is striking that in all localities, the pH reaches neutral values because this is a karst region. The conductivity in the dry season showed higher values than in the rainy season; rain water led to a dilution effect of ions in the water. Except Xoclán dissolved oxygen had little variance in the sites studied. According to the average concentrations of nutrients, the ratio N:P showed less availability of nitrogen (Hillebrand and Sommer, 1999). This imbalance apparently favoured the Cyanoprokaryota, as they are able to utilize a variety of inorganic and organic sources of combined nitrogen, including urea and amino acids.

The number of species of sascaberas was similar to the number of species observed in the cenote Xcaamal: Seminar 15 records, Vergel 14 records, Xoclán 15 records, and Xcaamal 18 records; the cenote Cholul had only one sample and therefore cannot be included in this comparison. In this study, seven species were classified as abundant and we note that their presence was not dependent on to the existence of a natural (cenotes) or artificial (sascaberas) environment. This was also true for rare species or species occurring in small numbers, indicating that artificial sascaberas create environments that play an important role in the biodiversity of the region as well as harbour flora typical to natural environments.

Ecological characterization of the species recorded in this study has been confirmed with the literature and we found that 57% of the species are present in tropical wetlands. It is worth noting that most of these records in wetlands come from calcareous areas. A smaller percentage of species (27%) had a wider occurrence, mostly in tropical and subtropical lakes and only 16% had a cosmopolitan record in both lakes and wetlands. Seventy seven percent of the species recorded in this study live in karst areas. Of these, 43% have a remarkable abundance in the studied localities and 85% of the species that showed low abundances have not been documented in karst areas. Our results indicate that the Cyanoprokaryota flora in this study must be regarded as typical to tropical, wetland-type limestone environments.

As for the geographical distribution of species, Belize and Mexico share 12% of records. In fact when Cuba, the Guadeloupe Island, Puerto Rico, and Venezuela are included, 94% of the species documented in this study have been reported in the Caribbean subregion. It is remarkable that approximately half of these species, especially those belonging to families Chroococcaceae and Entophysalidaceae are restricted to the Caribbean subregion. Future panbiogeographic analysis will resolve both, the role of the Caribbean subregion and the American distribution of genera such as *Asterocapsa* and *Chlorogloea* as well as the disjunction between Africa and Brazil for several genera from other families. Further analysis will require additional elements beyond what we have included in the present study as the biodiversity of the Caribbean tectonic plate is complex. For example, fauna, the most studied in terms of inventory, lacks fossil record information to support the presence of many species. As a consequence, several models have been generated to explain the origin of animal diversity in the Caribbean (Rosen, 1975; MacFadden, 1981), where the arc of volcanic islands encompassing the West Indies plays an important role (Duncan and Hargraves, 1984).

Certainly, the challenges for developing ecological profiles and distributions of cyanoprokaryotes require a continuous floristic work because the inventory of microorganisms is far from satisfactory. Of the many species of animals, plants, and microorganisms that exist in the tropics we know very little of their biology and still to a lesser extent their distribution. To date, the panbiogeography of Cyanoprokaryota remains limited.

Advances in molecular genetics may support the relationships, possible origins, and distribution patterns of all Caribbean cyanoprokaryontes. Nevertheless, their morphological description is crucial at the inventory level, as a step toward more targeted studies. In that sense, this work strengthens the significant contributions of other researchers on the characterization of the biota from the Caribbean subregion.

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