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New records of planktonic dinoflagellates (Dinophyceae) from the Mexican Pacific Ocean

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Abstract

Phytoplankton samples were taken during several oceanographic cruises in the Mexican Pacific Ocean (1998–2000), following three different protocols of collection and analysis, and from the material we report six new records of planktonic dinoflagellates in the region. Two species, *Asterodinium spinosum* and *Brachydinium capitatum*, are unarmored, another species, *Actiniscus pentasterias*, has internal siliceous skeletons, whereas *Thoracosphaera heimii* usually develops a calcareous coccoid vegetative stage. *Calciodinellum operosum* produces calcareous cysts that were also found in this study, and *Achradina pulchra* has an internal skeleton of organic material. Three species, *A. spinosum*, *B. capitatum* and *C. operosum*, were represented by very few specimens, whereas all others were more frequent. Brief descriptions and illustrations of these species by light and scanning electron microscopy are provided. The methods and techniques to study this group have been diverse and useful in finding a greater diversity. The world distribution of the species recorded here is revised.

Keywords: dinoflagellates; Mexican Pacific Ocean; new records; phytoplankton.

Introduction

Dinoflagellates (Class Dinophyceae) belong to a very diverse and heterogeneous microalgal group, which is very important in the marine phytoplankton. These algae (together with diatoms), contribute significantly to both the biomass and productivity of coastal pelagic systems. The number of extant species of marine phytoplankton is around 1880 (Sournia 1986, Sournia et al. 1991) or approximately 2000 (Taylor 1987, Steidinger and Tangen 1997).

In the Mexican Pacific Ocean, dinoflagellates have been studied from floristic and taxonomic points of view, beginning with early work of Kofoid (1907); subsequently, in adjacent waters Kofoid studied and described many dinoflagellates. Later, Allen (1941) recorded the planktonic dinoflagellates from southern California. There are further reports from Osorio-Tafall (1942), Hernández-Becerril (1988a,b,c, 1989, 1991, 1992) and Licea et al. (1995), who carried out studies in more tropical waters (i.e., Gulf of California, Acapulco, Gulf of Tehuantepec).

These studies have concentrated mostly on the armored (or thecate) fraction of dinoflagellates, whose external structures preserve well using even collection methods such as nets or bottles and routine preservatives (Lugol's solution or formalin). The unarmored (or naked) dinoflagellates have been less studied, and their contribution to phytoplankton productivity may have been underestimated. Other dinoflagellates with internal skeletons or producing calcareous stages have not been reported in Mexican waters so far, although a recent paper contributed to our knowledge of dinoflagellate cysts in the Gulf of California (Mexican Pacific Ocean) (Morquecho and Lechuga-Devéze 2003).

Despite continuing investigations of phytoplankton collected off the Mexican Pacific coast, important areas still remain unstudied, among them the so-called Tropical Mexican Pacific Ocean, which may prove to be species-rich. Our analysis of phytoplankton, obtained and studied following different protocols, from various oceanographic cruises carried out recently off the Pacific coast of Mexico, has revealed several interesting dinoflagellate species that are new records for the country.

Materials and methods

Between 1998 and 2000 samples were taken following three different protocols:

1. Samples collected off the coast of Michoacan (9–10 April, 1999) by net (54 μm mesh), in vertical hauls from 100 m to surface, fixed with 4% formalin (Table 1, Figure 1). Some forms smaller than the net mesh size were found, probably because of clogging of the net.
2. Bottle samples (generally 5 l) were taken off the coast of Baja California (5–14 December, 1998), at surface (1–1.5 m), and filtered (filters 1.2 μm) by gravity (Table 1, Figure 1). Before the complete filtration, 10–20 ml of the concentrated material were divided into: (a) a reference sample fixed with Lugol's solution and glutaraldehyde (Østergaard 1998), (b) material for observation *in vivo* by light microscopy, and (c) an inoculum for establishing culture-isolations of single cells by the dilution method (Throndsen 1997).
3. Bottle samples (4 l) were taken from several fixed stations off the coast of Baja California (20 March–1 April, 1998) and the Gulf of Tehuantepec (8–15 April, 2000), at three different depths (5, 25, 50 m), and were filtered (filters 0.45 μm) with a vacuum pump

Table 1 New records of dinoflagellates from the Mexican Pacific Ocean, with locations (Figure 1) and study protocols used.

Species	Localities	Protocol
Achradina pulchra Lohmann	4 Tehuantepec	3
Actiniscus pentasterias (Ehrenberg) Ehrenberg	1, 2, 4 BC and Tehuantepec	1, 3
Asterodinium spinosum Sournia	3 Michoacan	1
Brachydinium capitatum Taylor	2 BC	2
Calciodinellum operosum Deflandre *emend*. Montresor	4 Tehuantepec	3
Thoracosphaera heimii (Lohmann) Kamptner	1, 2, 4 BC and Tehuantepec	3

BC=Baja California.

(Bollmann et al. 2002), and then were rinsed with distilled water (Table 1, Figure 1).

Material was studied directly from the net samples, the filtered and fixed samples, and the filters by light microscopy (LM) in fresh mounts. Observations by scanning electron microscopy (SEM) were also made, using material treated conventionally (mounted, air-dried and coated with gold). A Zeiss (Mexico City, Mexico) Axiolab light microscope (bright field and phase contrast, with attached camera -Contax 167 MT [Tokyo, Japan]) and a JEOL 1200 EX scanning electron microscope (Tokyo, Japan) were used for our observations.

Terminology and systematics follow recent proposals by Fensome et al. (1993) and Steidinger and Tangen (1997).

Results

We identified 6 species of dinoflagellates, which are briefly described and illustrated by LM and/or SEM. Some relevant references are annotated for each species and conspicuous synonyms are also provided. Table 1 provides the complete species list.

Systematic account of *Actiniscus pentasterias* (Ehrenberg) Ehrenberg (Figures 2–4)

Division Dinoflagellata (Bütschli) Fensome et al.; Subdivision Dinokaryota Fensome et al.; Class Dinophyceae Pascher; Subclass Gymnodiniphycidae Fensome et al.; Order Gymnodiniales Apstein; Suborder Actiniscineae (Sournia) Fensome et al.

Family Actiniscaceae Kützing; Genus *Actiniscus* Ehrenberg; *Actiniscus pentasterias* (Ehrenberg) Ehrenberg. – Schiller 1937, p. 2, figs 1 a–d (as *Gymnaster pentasterias* Schütt); Bursa 1969, p. 412, figs 1–14; Steidinger and Williams 1970, p. 42, pl. 1, figs 1a–b; Orr and Conley 1976, p. 92, pl. 1, figs 1–11, pl. 2, figs 1–6; Balech 1988, p. 199, pl. 82, figs 22, 23; Larsen and Sournia 1991, p. 320, fig. 21.30; Hansen and Larsen 1992, p. 90, figs. 4.46 a–c; Hansen 1993, p. 486, figs 1–5; Steidinger and Tangen 1997, p. 428, pl. 24; Konovalova 1998, p. 81, figs 19.6 a–v; Bérard-Therriault et al. 1999, p. 163, pl. 81 e–g, i.

The specimens encountered here agree well with all previous descriptions. Whole cells were undetected and only specimens showing the internal, siliceous skeleton were found. Many authors have confirmed absence of chloroplasts in this species (Larsen and Sournia 1991, Hansen 1993). Dimensions: maximum diameter of skeletons ranged between 23–28 μm.

Distribution: specimens were found at various locations, including the coasts of Baja California and the Gulf of Tehuantepec (localities 1, 2, 4; Figure 1). The species was relatively frequent, hence we suggest that its distribution is wide in the Mexican Pacific Ocean.

Systematic account of *Achradina pulchra* Lohmann (Figures 5–8)

Order Ptychodiscales Fensome et al.; Family Amphitholaceae Poche; Genus *Achradina* Lohmann; *Achradina pulchra* Lohmann. – Schiller 1937, p. 5, figs 2 a–c; Nival 1969, p. 126, figs 1–11, pl. 1, figs 1–10, pl. 2, figs 1–12; Larsen and Sournia 1991, p. 314, fig. 21.28; Konovalova 1998, p. 82, figs 19.5 a–b.

Specimens found had no cytoplasm. The internal skeletons have a general oblong shape, with a constriction in the middle. Most of the skeleton is run by longitudinal ridges formed by large granule-like structures, and also has a complex pattern of smaller granules in a zig-zag pattern. The apical hemisphere has a pointed crest which is smooth, with four slit-like openings radiating to the margin. Below this crest, there are two larger, ovoid openings. The antapical end presents a hexagonal or heptagonal pattern of granules, which are larger at the angles and center of this pattern. The dorsal view shows an archeopyle, a large opening. This species is considered to be non-photosynthetic. Dimensions: total length 29–36.5 μm, width 18–21 μm.

Distribution: many specimens of this species were detected in the Gulf of Tehuantepec (locality 4; Figure 1).

Systematic account of *Asterodinium spinosum* Sournia (Figure 9)

Family Brachidiniaceae Sournia; Genus *Asterodinium* Sournia; *Asterodinium spinosum* Sournia. – Sournia 1972, p. 152, fig. 5; Abboud-Abi-Saab 1989, p. 12, fig. 5a; Gómez and Claustre 2003, fig. 2 a (as *Asterodinium gracile* Sournia).

The cells are solitary and delicate, of small size. The shape is star-like, with the body very reduced and with five straight or slightly curved arms or processes. The apical arm is longer, straight and truncate, the lateral arms are thin and delicate, with pointed ends, whereas the posterior arms are slightly shorter and more robust: the left posterior arm bears the prominent nucleus. The cingulum is inconspicuous. There are several oblong and discoid chloroplasts throughout the cell. Dimensions: total length 22–24 μm, width (maximum separation of lateral arms) 26–28 μm, length of apical arm 11.5 μm.

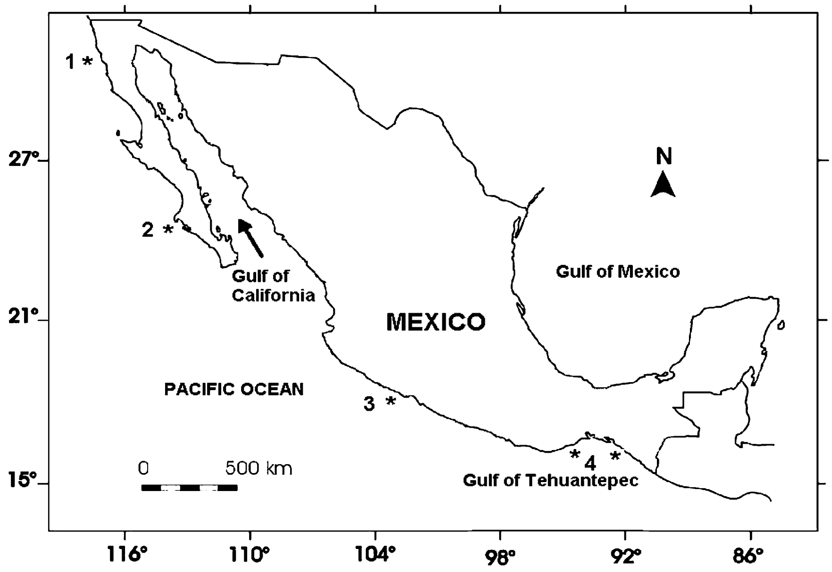


Figure 1 Map of the Mexican Pacific Ocean showing sampling locations.
1=Baja California (Ensenada), 2=Baja California (Bahia Magdalena), 3=Michoacan (Lázaro Cardenas), 4=Gulf of Tehuantepec.

Distribution: species occurring on the coasts of Michoacan (locality 3; Figure 1), with only two specimens found.

Systematic account of *Brachydinium capitatum* Taylor (Figures 10, 11)

Genus *Brachydinium* Taylor; *Brachydinium capitatum* Taylor. – Taylor 1963, p. 75, pl. VIII, figs 1–3; Léger 1972, p. 29, fig.14; Sournia 1972, p. 152, figs 2, 6; Sournia et al. 1979, p. 193, fig. 39; Abboud-Abi-Saab 1989, p. 12, fig. 4b; Steidinger and Tangen 1997, p. 428, pl. 24.

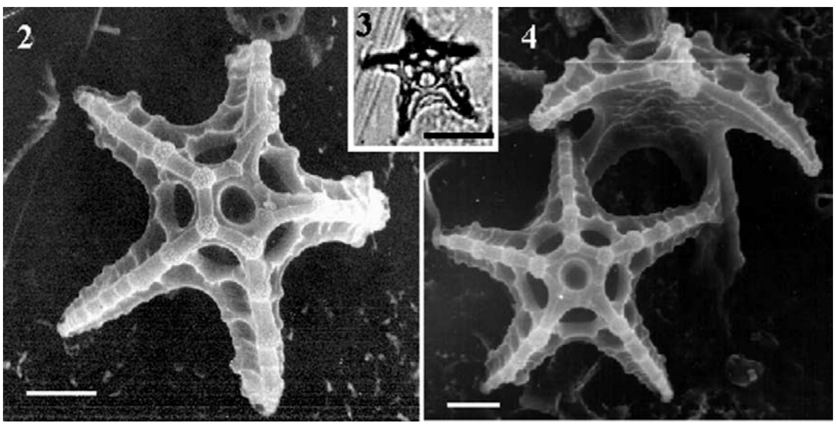
The cells appeared solitary, delicate, of medium size. The cells are asymmetric, with no general shape, four relatively long, curved or more straight arms (or processes), which arise from the body. There is an apical protuberance, eccentric, slightly displaced to the right, and an indentation is present between the two lateral arms and this protuberance; this indentation represents the cingulum. The lateral arms are longer than the posterior arms, tapering toward the tip, which is pointed. The posterior arms are almost symmetric, with the right slightly shorter than the left. The nucleus is parietal, displaced to the right of the body. Numerous chloroplasts throughout the cell. Dimensions: total length 48–50 μm, width (maximum separation of lateral arms) 107–110 μm, maximum length of posterior arms 37 μm.

Distribution: species found in Baja California (locality 2; Figure 1), very rare.

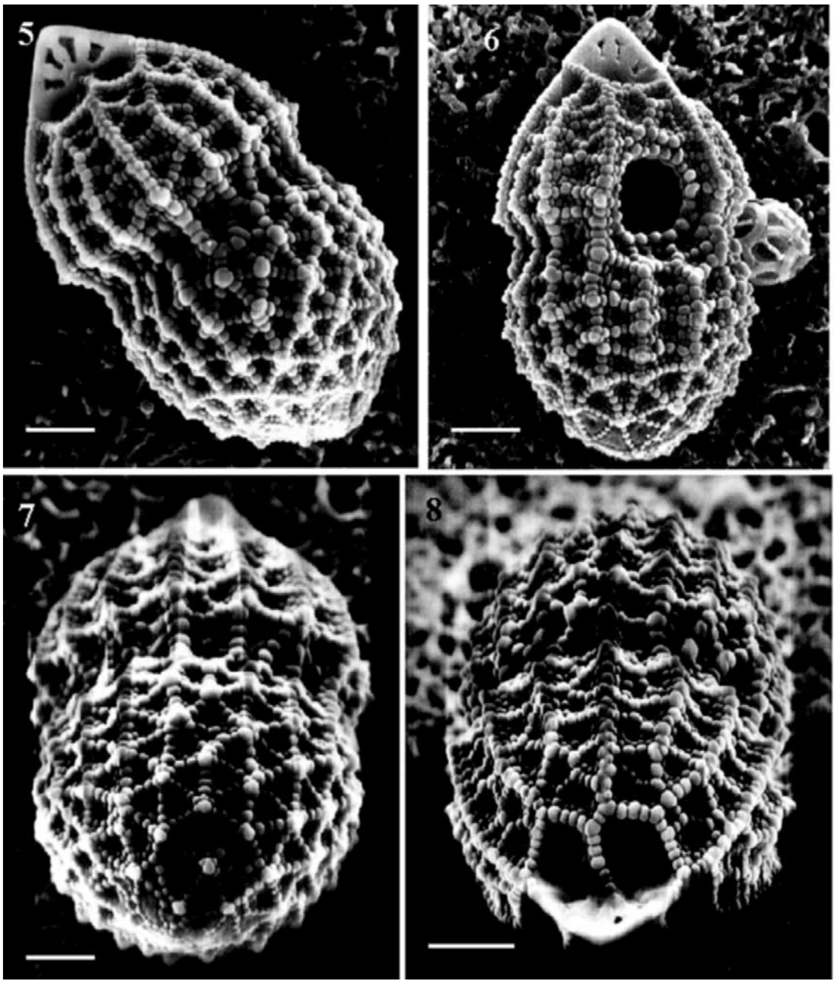
Systematic account of *Calciodinellum operosum* Deflandre *emend*. Montresor (Figure 12)

Subclass Peridiniphycidae Fensome et al.; Order Peridiniales Haeckel; Suborder Peridiniineae; Family Peridiniaceae Ehrenberg; Subfamily Calciodinelloideae Fensome et al.; Genus *Calciodinellum* Deflandre; *Calciodinellum operosum* Deflandre *emend*. Montresor. – Montresor et al. 1997, p. 123, figs 10–13, 19; Williams et al. 1998, p. 86; D'Onofrio et al. 1999, p. 1066, figs 14–16; Sgrosso et al. 2001, p. 81.

In our samples only calcareous cysts were encountered. The cysts show an arrangement of paraplates and a conspicuous apical pore. There are four paraplates sur-



Figures 2–4 *Actiniscus pentasterias*: LM, SEM.
(2) Apical view of a typical internal skeleton with 5 arms and ornamentation in ridges, SEM. (3) Another internal skeleton of a specimen, LM. (4) Two skeletons in apical and lateral view showing surface morphology, SEM. Scale bars=5 μm (Figures 2, 4); 15 μm (Figure 3).



Figures 5–8 *Achradina pulchra*: SEM.
(5) Ventral view of an internal skeleton showing surface ornamentation and the apical crest with four openings. (6) Dorsal view of another specimen, with the archeopyle. (7) Antapical view of a specimen. (8) Apical view of the skeleton, showing the apical crest. Scale bar=5 μm.

rounding the apical pore. Other specimens showed well-developed paratabulation ridges. The surface of the cysts appears granular and has scattered pores. Vegetative cells are photosynthetic. Dimensions: diameter 29–34 μm.

Distribution: very few cysts found in the Gulf of Tehuantepec (locality 4; Figure 1).

Systematic account of *Thoracosphaera heimii* (Lohmann) Kamptner (Figure 13)

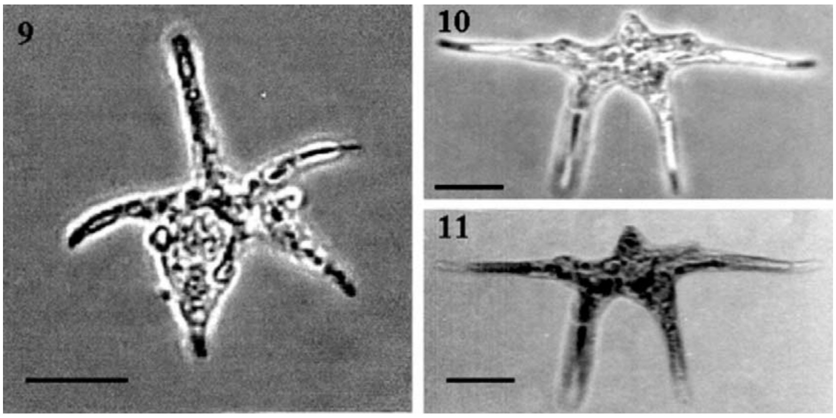
Subclass Prorocentrophycidae Fensome et al.; Order Thoracosphaerales Tangen; Family Thoracosphaeraceae Schiller; Genus *Thoracosphaera* Kamptner; *Thoracosphaera heimii* (Lohmann) Kamptner. Synonym: *Syracosphaera heimii* Lohmann. – Inouye and Pienaar 1982, p. 64, figs 1, 2, 24; Tangen et al. 1982, p. 195, pl. I, figs 1–6; Fensome et al. 1993, p. 168, fig. 171; Steidinger and Tangen, 1997, p. 549; Williams et al. 1998, p. 160.

This species has a particular vegetative form, which is predominantly a coccoid, calcareous stage, for some time considered to be a coccolithophorid (Tangen et al. 1982). The cells are spherical and relatively small, with a large and conspicuous aperture. The surface of the wall is irregular, covered with granules and perforated by small pores. The planospore is non-thecate and a *Gymnodinium*-like cell. All live stages possess chloroplasts (Inouye and Pienaar 1982, Tangen et al. 1982). Dimensions: diameter 10–12 μm, aperture 3–4 μm.

Distribution: occurred in a relatively common manner in Baja California and the Gulf of Tehuantepec (localities 1, 2, 4; Figure 1).

Discussion

Diversity of planktonic dinoflagellates from the Mexican Pacific Ocean may be considered relatively high: recent reviews indicate an approximate number of 350 taxa (Hernández-Becerril 2003), and for only the Order Dinophysiales, the number of taxa is 90 (Hernández-Becerril et al. 2003). However, unarmored or naked planktonic dinoflagellates have generally been underestimated, ignored or little studied in Mexican waters. This could be mainly due to the methods traditionally used for collecting and studying dinoflagellates, which deteriorate the unarmored fraction. Bottle samples, fixed with Lugol's solution preserve relatively well most naked dinoflagellates, and concentrated samples from passive filtration (this study, protocol 2) are ideal for studying naked forms



Figures 9–11 *Asterodinium spinosum* and *Brachydinium capitatum*: LM.
(9) *A. spinosum*, a complete cell in dorsal view, showing the typical star-like shape of the cell, phase contrast. (10, 11) *B. capitatum*, a cell in dorsal view, showing four processes and numerous chloroplasts, bright field. (11) Same cell, phase contrast. Scale bar=10 μm (Figure 9); 20 μm (Figures 10, 11).

in vivo, to cultivate them, or to preserve them with a mixture of Lugol's solution and glutaraldehyde. We found one unarmored new record, *Brachydinium capitatum* (Table 1) following this method, and we are still working with naked forms that have been cultivated.

There are four possible explanations for finding new records of planktonic dinoflagellates in the Mexican Pacific Ocean: (1) some areas still remain unstudied, particularly in the Tropics, (2) the methods traditionally used to collect and study phytoplankton have underestimated the diversity of certain forms, especially the naked fraction, (3) the routine analyses have been made by poorly trained personnel, who have misidentified or ignored some species difficult to recognize (due to their size or shape) or who lack literature to identify species, and (4) there have been introductions of exotic species into the area.

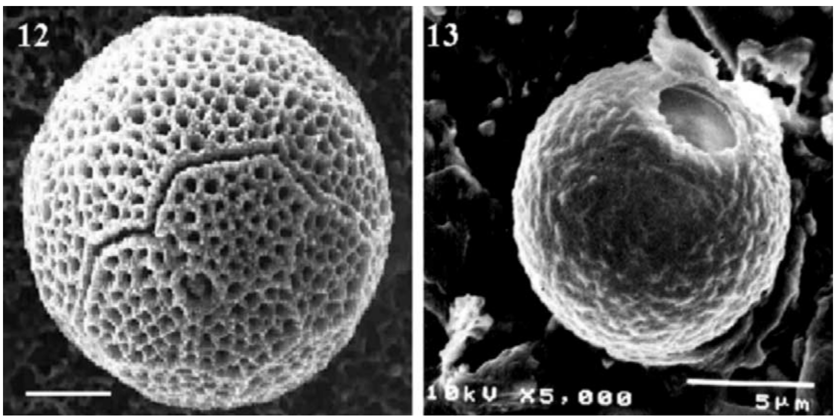
Introduction of planktonic species into the Mexican Pacific waters may only be speculated upon, for medium to long-term studies or monitoring do not exist for most regions. However, this fact has been discussed in the context of increasing events of harmful microalgal blooms (Hallegraeff 1998).

World distribution of the species recorded here indicates that *Achradina pulchra*, *Actiniscus pentasterias* and *Thoracosphaera heimii* are forms very widely distributed in temperate to tropical regions. They may be referred to as "cosmopolitan", with no certainty of their habitat: oceanic or neritic, although they appear more in coastal waters. All locations where we found them are coastal.

The distribution of *Calciodinellum operosum* is not well known and it was only detected at the calcareous cyst stage. It is likely that further collections and studies in Mexican waters will find the vegetative cell, too.

Actiniscus pentasterias has a considerable fossil record (Williams et al. 1998) and all other species found here with a calcareous external/internal structure have also been recorded from fossil material (Fensome et al. 1993). This species is well represented in world waters, and it may also be considered to be "cosmopolitan".

Two genera of the Family Brachydiniaceae, *Asterodinium* and *Brachydinium*, were recently recorded for the first time from the subtropical (Philippine Sea, Sulu and East China Seas) and equatorial western Pacific Ocean (Gómez et al. 2003). The species we report herein for the Mexican Pacific Ocean belong to those genera: *Asterodinium spinosum* and *Brachydinium capitatum*. Therefore, we confirm that the two genera are more widely distributed than previously thought, as they were originally described for Indian Ocean waters (Taylor 1963,



Figures 12–13 *Calciodinellum operosum* and *Thoracosphaera heimii*: SEM.
(12) *C. operosum*, apical view of a cyst with the apical pore and apical plates. (13) *T. heimii*, a complete coccoid cell, showing large aperture and surface granulation. Scale bar=5 μm.

Sournia 1972), and then the species *Brachydinium capitatum*, *Asterodinium gracile* Sournia and *Asterodinium libanum* Abboud-Abi Saab were reported for the Mediterranean Sea (Léger 1972, Gómez and Claustre 2003, respectively). The presence of *Asterodinium* species may well be favored by the progressive warming of the Mediterranean Sea (Gómez and Claustre 2003). The two species are unquestionably tropical forms, probably also neritic, although Sournia et al. (1979) found the species in a supposedly colder area, still in the Indian Ocean.

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