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BLOOM OF *Gonyaulax spinifera* (DINOPHYCEAE: GONYAULACALES) IN ENSENADA DE LA PAZ LAGOON, GULF OF CALIFORNIA

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ABSTRACT. During a sampling on 24 September 2012 in the coastal lagoon, Ensenada de La Paz, a small bloom of the dinoflagellate *Gonyaulax spinifera* was detected. Its abundance varied from 401 to 1342 × 103 cells L^{-1}. Cells of *G. spinifera* ranged from 34 to 50 µm in length and 22 to 35 µm in width (n = 30). Seawater temperature and salinity were 29 °C and 35.5, respectively. The species composition of the bloom was recorded. The phytoplankton community had high species richness, resulting from a mix of benthic and pelagic diatoms and dinoflagellates, as well as cyanobacteria that occurred with low frequency. This brief proliferation lasted around three hours and may have been caused by tidal water accumulation along the shore. Although *G. spinifera* is a producer of yessotoxin, no fish or invertebrates were apparently killed by this bloom, which was rapidly dispersed by tides and wind-forcing.

Keywords: Bloom, Dinoflagellates, *Gonyaulax spinifera*, *Protoceratium reticulatum*, Gulf of California

Florecimiento de *Gonyaulax spinifera* (Dinophyceae: Gonyaulacales) en la laguna Ensenada de La Paz, Golfo de California

RESUMEN. Durante un muestreo el 24 de septiembre de 2012 en la laguna costera Ensenada de La Paz se detectó un pequeño florecimiento del dinoflagelado *Gonyaulax spinifera*. Los valores de abundancia variaron de 401 a 1342 × 10^3 céls L^{-1}. Los especímenes de *G. spinifera* presentaron un intervalo de tallas de 34 a 50 µm de longitud y de 22 a 35µm de ancho (n = 30). La temperatura del agua fue de 20 °C y la salinidad fue de 35.5. Se determinó la composición de especies durante este florecimiento. Como resultado de la mezcla de especies bentónicas y pelágicas de diatomeas y dinoflagelados, así como de algunas cianobacterias poco frecuentes, la comunidad del fitoplancton presentó una riqueza de especies alta. Esta pequeña proliferación se observó por alrededor de 3 horas y pudo ser ocasionada por la marea acumulándola en la línea de costa. Aunque *G. spinifera* es una especie productora de yessotoxinas, no se observaron peces ni invertebrados muertos durante este florecimiento, el cual se dispersó rápidamente por efecto de la marea y la fuerza del viento.

Palabras claves: Florecimiento, Dinoflagelados, *Gonyaulax spinifera*, *Protoceratium reticulatum*, Golfo de California.

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INTRODUCTION

Dinoflagellate red tides are frequent and periodic throughout the year in Bahía de La Paz in the southwestern part of the Gulf of California (Gárate-Lizárraga *et al*., 2001). A systematic monitoring of marine microalgae blooms in this bay began in the summer of 2000 because of an extensive bloom of *Cochlodinium polykrikoides* (Gárate-Lizárraga *et al*., 2004). Blooms monitoring has been important for knowing the species involved, if they are toxic or not and eventually to predict and manage harmful algal blooms. The majority of red tides in Bahía de La Paz coasts are produced by dinoflagellates species (Gárate-Lizárraga *et al*., 2001; 2006). Few records of *Gonyalax* red tides exist. *Gonyaulax polygramma* (Pouchet) Kofoid, 1911 is the main blooming species in several sites in the Gulf of California: Bahía de Los Ángeles (Millán-Núñez, 1988), Ensenada de La Paz (Gárate-Lizárraga *et al*., 2001), Bahía de La Paz (Gárate-Lizárraga *et al*., 2006), and off Isla Espíritu Santo (Gárate-Lizárraga, 2006). *Gonyaulax* belongs to the order Gonyaulacales F.J.R.Taylor, 1980 and it is one of the most widely represented genera of the dinoflagellates, occurring in temperate and tropical seas and in brackish and fresh water (Kofoid, 1911; Taylor, 1976). This order is characterized by a strongly asymmetrical organization of the thecal plates. The apical pore complex is also asymmetrical and it is never connected to the 1′ by a canal plate as in the case of the Peridiniales. The typical plate formula is 4′, 6″, 6c, 5s, 5‴, 2″″ according to Fensome *et al*. (1993). *Gonyaulax* is the representative genus of this order; it has a round to polygonal body, a cingulum strongly cavozone (deeply excavated), median but may be offset ventrally, sulcus distinct, thecal plates may be thick and strongly patterned, antapical spines are often present. Currently, there are 121 species (and infraspecific) names of *Gonyaulax* in the AlgaeBase database, out of which 72 have been listed as accepted (Guiry & Guiry, 2014). Only a few species in this genus produce toxins and red tides (Rhodes *et al*., 2006).

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This report describes the first bloom of *Gonyaulax spinifera* (Claparède & Lachmann) Diesing, 1866 in the southwestern Gulf of California. The microalgae community present during this bloom is also described.

MATERIAL AND METHOD

On 24 September 2012 a reddish-coloured phytoplankton patch was observed nearby the CICIMAR-IPN pier in Ensenada de La Paz (Fig. 1), which is a shallow coastal lagoon connected to Bahía de La Paz; the inlet is 1.2 km wide and 4 km long and has an average depth of 7 m (Gómez-Valdés *et al*., 2003). The sampling station (24.08°N, 110.21°W) is located in the shallow basin of the southernmost part of the bay. Three red tide samples were collected in 250 mL plastic bottles. Samples were fixed with acid Lugol solution and later used for identification and counting cells. The total phytoplankton, nano- (organism <20 *μm*) and microphytoplankton (organism >20 *μm*) abundances (cells L^{-1}) were estimated simultaneously with species composition identifications of microphytoplankton. Nanophytoplankton was not identified taxonomically.

Subsamples were taken for observations of live phytoplankton. Cell counts were made in 5 mL settling chambers under an inverted Carl Zeiss phase-contrast microscope (Utermöhl, 1958). Sea surface temperature was recorded with a bucket thermometer. Salinity was measured with a refractometer (Model STX3, Vee Gee Scientific, Kirkland, WA). A compound Olympus CH2 microscope was used to measure cells. A digital Konus camera (8.1 MP) was used for recording images.

RESULTS AND DISCUSSION

The phytoplankton patch (~10 m long, 2 m wide) occurred during high tide. The bloom lasted about 3 h and disappeared during ebb tide. This bloom could be the result of accumulation of cells along the shore, as other red tides that have occurred in the lagoon (Gárate-Lizárraga *et al*., 2006). The phytoplankton community within this red tide was composed of 69 microalgae taxa, including 33 species of Dinophyta, 30 Bacillariophyta, 4 cyanobacteria, 1 euglenophyte, and 1 prasinophyte. Species richness ranged from 41 to 61 species. The high richness resulted from a mix of benthic and pelagic diatoms and dinoflagellates, as well as cyanobacteria that occurred with a low frequency. The microalgae species list and their abundances are summarized in Table 1. Total phytoplankton abundance in samples varied from 601 to 1496 × 10^3 cells L^{-1}. Micro-phytoplankton was numerically more important (avg. = 952 × 10^3 cells L^{-1}) than nano-phytoplankton (avg. = 79 × 10^3 cells L^{-1}). Nano-phytoplankton was mainly composed by small flagellates and naviculoid diatoms. On the basis of abundance and the number of species, dinoflagellates were the most important group, followed by diatoms. Seven species of *Gonyaulax* were identified and displayed iconographically: *Gonyaulax spinifera* (Figs. 2, 3, and 4), *G. polygramma* (Fig. 7), *Gonyaulax cochlea* Meunier, 1919 (Figs. 9, and 10), *G. digitalis* (Fig. 15), *G. hyalina* Ostenfeld & Schmidt, 1901 (Figs. 16, and 17), *G. birostris* F. Stein, 1883 (Fig. 18), and *G. fusiformis* H.W.Graham, 1942 (Fig. 19). *G. spinifera* was the dinoflagellate species responsible for this bloom. At that time seawater temperature was 31 °C and salinity reached 35.5. Cells of *G. spinifera* were slightly longer than wide. The epitheca had convex sides and a small apical horn. The hypotheca has 2–4 antapical spines. The sulcus extends almost the full length of the cell. The cingulum is deeply excavated. Cell surface is ornate (Fig. 4). Striae are associated with round trichocyst pores. Single cells ranged from 34 to 50 μm in length and 22 to 35μm in width. The shape was variable and made identification difficult. The *G. spinifera* group (Kofoid, 1911) includes three species with similar morphological features, which can easily be confused: *G. spinifera*, *G. digitalis* (Pouchet) Kofoid, 1911, and *G. diegensis* Kofoid, 1911 (Lewis *et al*., 1999).

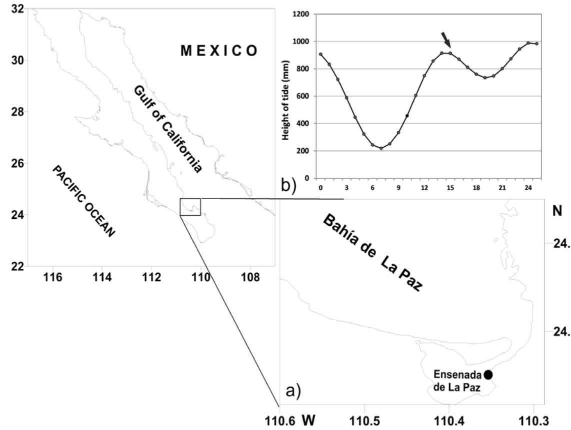


Figure 1. a) Location of bloom dominated by *Gonyaulax spinifera*; b) tidal variation on 24 September 2012. Arrow indicates the time of sampling.

During the examination of live samples we observed the formation of temporary resting states or pellicles in some species of *Gonyaulax* (Figs. 5, 6, 8, 10, 17) and *Scrippsiella spinifera* (Figs. 12, 13, 14). About 30 min after cells were collected, they began to grow and to undergo ecdysis to form a round pellicle. These temporary cysts could be the result of manipulating samples or a response to the microscope light and heat, which may pause adverse conditions

Table 1. Abundance of microalgae species recorded in the Ensenada de La Paz, Gulf of California during proliferation of *Gonyaulax spinifera* on September 2012.

Microalgae species	Sample A cells L^{-1}	Sample B cells L^{-1}	Sample C cells L^{-1}
Bacillariophyta			
Arcuatasigma challengeriense (Castracane) G.Reid, 2012		200	400
Asterionellopsis glacialis (Castracane) Round, 1990	1600		
Asteromphalus arachne (Brébisson) Ralfs, 1861	400	200	600
Asteromphalus heptactis (Brébisson) Ralfs, 1861	400	200	200
Biddulphia tridens (Ehrenberg) Ehrenberg, 1841	200		200
Chaetoceros coarctatus H.S. Lauder, 1864	2400		2800
Chaetoceros diversus Cleve, 1983		2400	
Chaetoceros didymus Ehrenberg, 1845	1400	1200	1600
Chaetoceros socialis H.S. Lauder, 1864	18200	24600	
Chaetoceros sp.	3200	1800	
Climacodium frauenfeldianum Grunow, 1868	1000		
Cylindrotheca closterium (Ehrenberg) Reimann & J.C. Lewin, 1964	200	800	
Fragilariopsis doliolus (Wallich) Medlin & P. A.Sims, 1993	1200		2800
Grammatophora sp.	400		800
Guinardia flaccida (Castracane) H. Peragallo, 1892	400	600	200
Helicotheca tamesis (Shrubsole) M. Ricard, 1987	200	200	200
Hemiaulus membranaceus Cleve,1873	400		200
Nitzschia longissima (Brébisson) Ralfs, 1861	400	400	
Odontella aurita var. *obtusa* (Kützing) Denys, 1982	200		200
Odontella rhombus (Ehrenberg) Kützing, 1849	1200	200	
Paralia fenestrata Sawai and Nagumo, 2005	1200	400	200
Planktoniella sol (C.G.Wallich) Schütt, 1892	200		200
Proboscia alata (Brightwell) Sundström, 1986	200	200	400
Rhizosolenia clevei var. *communis* Sundström, 1984	200	400	200
Skeletonema costatum (Greville) Cleve, 1873	2400	1200	
Stauroneis membranacea (Cleve) Hustedt, 1959	400	400	1200
Stephanopyxis palmeriana (Greville) Grunow, 1884	1200	2400	800
Thalassionema nitzschioides (Grunow) Mereschkowsky, 1902	1200	2000	1600
Thalassiosira eccentrica (Ehrenberg) Cleve, 1904	400		
Toxarium undulatum Bailey, 1854	400		
Total abundance of diatoms	**41200**	**39800**	**14800**
Dinophyta			
Actiniscus pentasterias (Ehrenberg) Ehrenberg, 1854		200	
Akashiwo sanguinea (K. Hirasaka) G. Hansen & Ø. Moestrup in N. Daugbjerg, G. Hansen, J. Larsen, & Ø. Moestrup, 2000	200	400	1600
Cochlodinium polykrikoides Margalef, 1961	2800	4400	7200
Dinophysis acuminata Claparède & Lachmann, 1859	200		200
Dinophysis caudata Saville-Kent, 1881	600	1400	3200
Dinophysis tripos Gourret, 1883	200		1200
Gonyaulax birostris F. Stein, 1883	200	200	
Gonyaulax cochlea Meunier 1919	2400	3600	5200
Gonyaulax digitalis (Pouchet) Kofoid, 1911	600	400	1200
Gonyaulax fusiformis H.W.Graham, 1942			200
Gonyaulax hyalina Ostenfeld & Schmidt, 1901	200	400	
Gonyaulax polygramma (Pouchet) Kofoid, 1911	4200	2400	1200
Gonyaulax spinifera (Pouchet) Kofoid, 1911	401200	892800	1342600
Lepidodinium chlorophorum (M. Elbrächter & E.Schnepf) Gert Hansen, L.Botes & M. de Salas 2007	200	200	400
Lingulodinium polyedrum (F.Stein) J. D. Dodge, 1989	200	200	400
Metaphalacroma skogsbergii Tai, 1934		200	400
Nematodinium armatum (Dogiel) Kofoid & Swezy, 1921	600		
Ornithocercus magnificus Stein, 1883	200	200	
Peridinium quinquecorne Abé, 1927	2200	400	600
Phalacroma favus Kofoid & J. R. Michener, 1911		400	
Prorocentrum gracile Schütt, 1895		200	
Prorocentrum micans Ehrenberg, 1833	200	400	200
Prorocentrum rhathymum Loeblich, Sherley & Schmidt, 1979	200		200
Protoceratium reticulatum (Claparède & Lachmann) Bütschli, 1885	200	200	
Protoperidinium abei (Paulsen) Balech, 1974	400	200	
Protoperidinium claudicans (Paulsen) Balech, 1974	400	400	600
Protoperidinium longipes Balech, 1974		200	
Protoperidinium sp. 1		200	400
Protoperidinium sp. 2		400	
Scrippsiella spinifera G.Honsell & M. Cabrini, 1991	4200	1200	5600
Tripos dens (Ostenfeld & Schmidt) F. Gomez, 2013	200	200	
Tripos fusus (Ehrenberg) F. Gómez, 2013	200	400	200

Table 1. Continued.

Microalgae species	Sample A cells L^{-1}	Sample B cells L^{-1}	Sample C cells L^{-1}
Tripos furca (Ehrenberg) F. Gómez, 2013	200	200	
Total abundance of dinoflagellates	422400	912000	1372800
Cyanobacteria			
Anabaena sp.	4200	1600	
Merismopedia sp.	8200	3800	
Lyngbya majuscula (Dillwyn), Harvey, 1833	5200	10200	2200
Richelia intracellularis J. Schmidt in Ostenfeld & J. Schmidt, 1901	4000	4800	8600
Euglenophyta			
Euglena sp.	200	200	
Prasinophyta			
Pterosperma sp.	200		400
Total abundance of cyanobacteria, euglenophytes and prasinophytes	22000	20600	11200
Microphytoplankton	485800	972400	1398800
Nanophytoplankton	115600	23200	97600
Phytoplankton total abundance	601400	995600	1496400

for these species. In *G*. *spinifera*, *G*. *polygramma* (Fig. 7), *Lingulodinium polyedrum* (F.Stein) J.D. Dodge, 1989 (Fig. 21), and perhaps others members of the group, ecdysis is frequently seen (Kofoid, 1911; Marasovic, 1989). Temporary cysts quickly turn into a vegetative, motile state when conditions become again favorable, thus allowing cells to withstand short-term environmental fluctuations (Anderson, 1998).

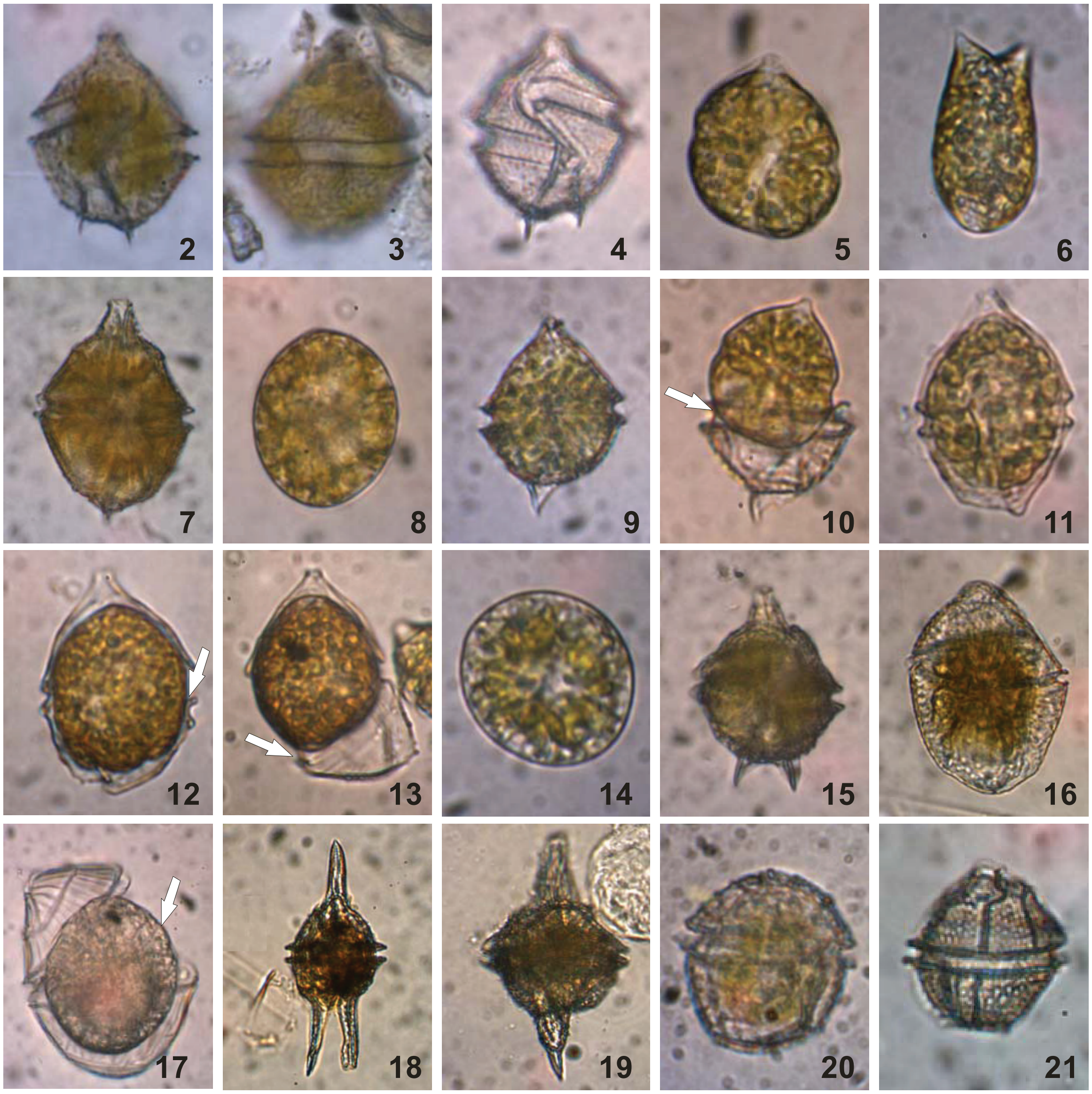
Abundances of *G*. *spinifera* in the three samples were 401, 892, and 1342 × 10^3 cells L^{-1}, respectively. Densities of *G*. *spinifera* in this report were high, compared to a previous record (Gárate-Lizárraga, 2013), but lower than that of Margalef (1956) from blooms in Ría de Vigo (Spain), by Riaux-Gobin & Lassus (1989) in the Riviere de Morlaix in Brittany, or that of Praseno *et al*. (1999) off the coast of western Sumatra in the Indian Ocean. Although this is the first bloom of *G*. *spinifera* in the eastern Pacific along the coast of Mexico, this species is widely distributed in the Gulf of California (Okolodkov & Gárate-Lizárraga, 2006; Esqueda-Lara & Hernández-Becerril, 2010).

Blooms of *G*. *spinifera* are responsible for mass die-offs of marine biota and cause severe damage to fisheries (Praseno *et al*., 1999; Fukuyo *et al*., 2003; Riccardi *et al*., 2009). A massive bloom of *G*. *spinifera* (9 × 10^6 cells L^{-1}) formed on the west coast of Vancouver Island, BC, Canada, caused a substantial shellfish die-off due to hypoxia in Barkley Sound (Forbes *et al*., 1990). Many mussel farms along the Emilia Romagna coast of Italy (northwestern Adriatic Sea) were closed due to excessive levels of yessotoxin (>1 mg YTX equivalents/kg mussels; Riccardi *et al*., 2009). Yessotoxin (YTX) is a disulfated polyether toxin that was first isolated from the yesso scallop (*Patinopecten yessoensis* Jay, 1857) collected in Japan (Murata *et al*., 1987). A bloom of *G*. *spinifera* occurred recently north of San Francisco in August 2011, and extended 80 km along the coast causing a massive die-off of wild marine invertebrates (Rogers-Bennett *et al*., 2012). YTX is produced by *G*. *spinifera* and other plankton, including *Protoceratium reticulatum* (Claparède & Lachmann) Bütschli, 1885 and *L*. *polyedrum* (Rhodes *et al.,* 2006). Although these three species were found in our samples, no fish or invertebrates were apparently killed by this bloom, which was very short and was rapidly dispersed by tides and wind-forcing. On the other hand, four species producers of domoic acid were recorded: *Dinophysis acuminata*, *D*. *caudata*, *D*. *tripos* (Fig. 29), and *Phalacroma favus* (Fig. 30). These species occurred in low densities and could also represent a health public if they proliferate.

Microalgae blooms are still monitored at permanent monitoring stations in Bahía de La Paz. This monitoring program provides data on the occurrence, distribution, and possible causes of harmful microalgae blooms.

New records

During this bloom, several taxa of microalgae were new records for the Gulf of California coasts: the dinoflagellates *Gonyaulax hyalina* (Figs.16–17), *Gonyaulax birostris* (Fig. 18), and *Gonyaulax fusiformis* (Fig. 19); the dinoflagellates *Gonyaulax cochlea* (Fig. 9) and *Lepidodinium chlorophorum* (M. Elbrächter & E. Schnepf) Gert Hansen, L. Botes & M. de Salas 2007 (Fig. 24), the prasinophyte *Pterosperma* sp. (Fig. 40) and the diatom *Arcuatasigma challengeriense* (Fig. 52) are new records for the Mexican Pacific. The diatom *Asteromphalus arachne* (Fig. 50) is a new record for Bahía de La Paz. Because the samples were taken close to the shore, some uncommon species of cyanobacteria, such as *Merismopedia* sp. (Fig. 59), *Anabaena* sp. (Fig. 60) and *Lyngbya majuscula* (Fig. 61), were also collected.



Figures 2–21. Vegetative cells (2–4) and temporary cysts (5–6) of *Gonyaulax spinifera*, vegetative cells (7) and temporary cyst (8) of *G. polygramma*, vegetative cells (9) and temporary cysts (10) of *Gonyaulax cochlea*, vegetative cells (11–12) and temporary cysts of *Scrippsiella spinifera* (13–14), *Gonyaulax digitalis* (15), vegetative cell (16) and temporary cyst (17) of *Gonyaulax hyalina*, *G. birostris* (18), *G. fusiformis* (19), *Protoceratium reticulatum* (20), and *Lingulodinium polyedrum* (21). White arrows indicate the broken theca and the temporary cysts.

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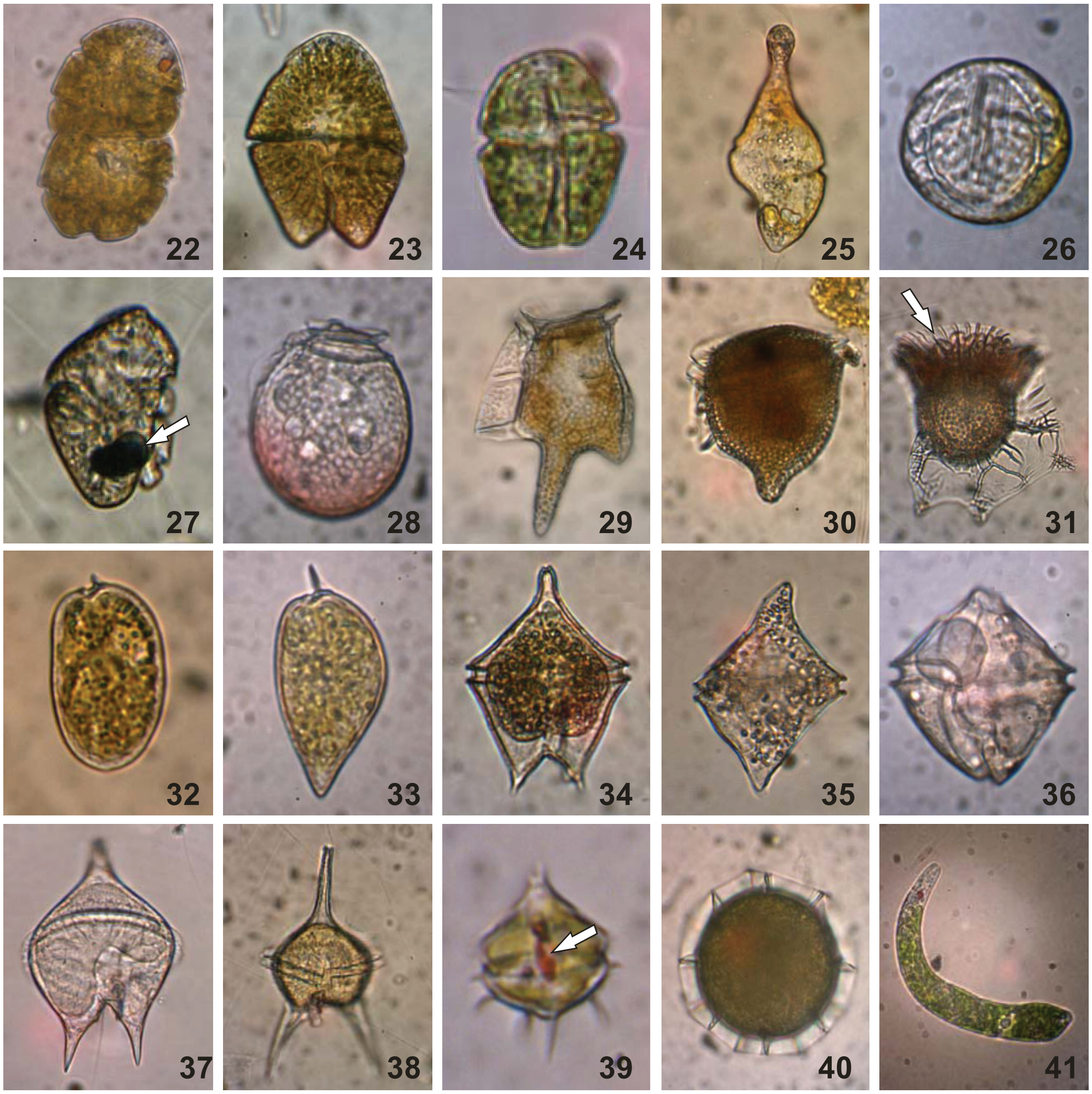

Figures 22–41. *Cochlodinium polykrikoides* (22), *Akashiwo sanguinea* (23), *Lepidodinium chlorophorum* (24), *Ceratoperidinium falcatum* (25), *Actiniscus pentasterias* (26), *Nematodinium armatum*, white arrow indicates the ocelloid (27), *Metaphalacroma skogsbergii* (28), *Dinophysis tripos* (29), *Phalacroma favus* (30), *Ornithocercus steinii* with abundant coccoid cyanobacteria cf. *Synechococcus* (31), *Prorocentrum rhathymum* (32), *P. micans* (33), *Protoperidinium* sp. 1 (34), *P. abei* (35), *Protoperidinium* sp. 2 (36), *P. claudicans* (37), *P. longipes* (38), *Peridinium quinquecorne*, white arrow indicates the bright red stigma in the sulcal area (39), phycoma-stage of *Pterosperma* sp. (40), and *Euglena* sp. (41).

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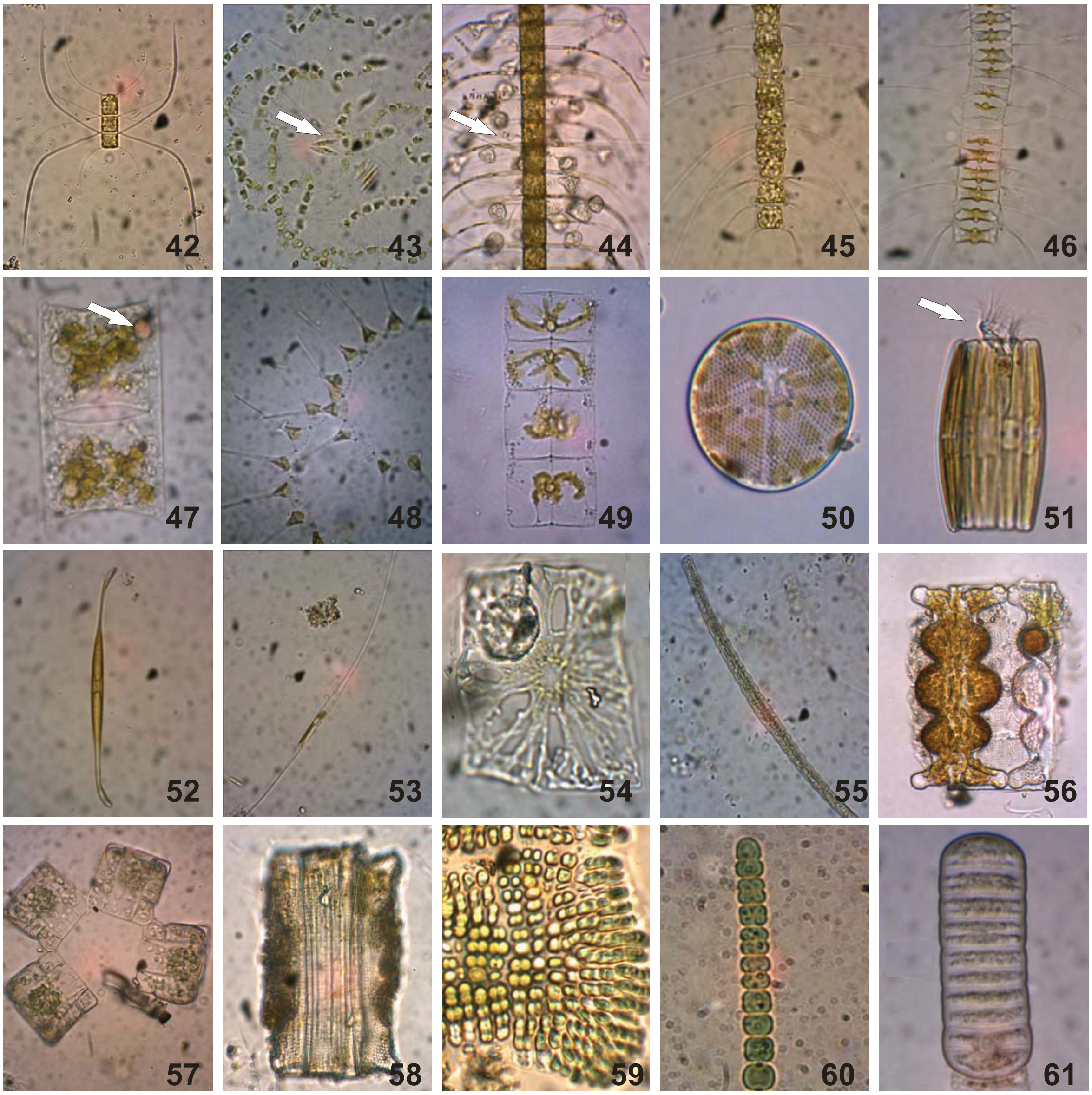

Figures 42–61. *Chaetoceros diversus* (42), *C. socialis*, with of epiphytic diatoms (white arrow) (43), *C. coarctatus*, white arrow indicates to *Vorticella oceanica* (44), *Chaetoceros* sp. (45), *C. didymys* (46), *Hemiaulus membranaceus*, white arrow indicates the cyanobacteria *Richelia intracellularis* (47), *Asterionellopsis glacialis* (48), *Stauroneis membranacea* (49), *Asteromphalus arachne* (50), *Fragilariopsis doliolus* with *Vorticella* sp. (51), *Arcuatasigma challengeriense* (52), *Nitzschia longissima* (53), *Helicotheca tamensis* (54), *Toxarium undulatum* (55), *Biddulphia tridens* (56), *Odontella alternans* (57), *Odontella aurita* var. *obtusa* (58), *Merismopedia* sp. (59), *Anabaena* sp. (60), and *Lyngbya majuscula* (61).

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