



## Taxonomy and systematics

# Diversity of benthic diatoms in the Guerrero Negro Lagoon (El Vizcaíno Biosphere Reserve), Baja California Peninsula, Mexico

## *Diversidad de especies de diatomeas bentónicas en la laguna Guerrero Negro (Reserva de la Biosfera El Vizcaíno), península de Baja California, México*

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Received 30 March 2016; accepted 25 November 2016

Available online 24 February 2017

### Abstract

High species diversity renders benthic diatoms that are useful in assessing environmental impact, as well as an adequate reference for measuring biodiversity in protected areas. Preliminary observations suggested that the Guerrero Negro Lagoon (LGN), located in the Baja California Peninsula, Mexico, is an area with a high diversity of benthic diatoms comprising numerous species of certain genera, orders, class, etcetera, which were not equally diverse or common in other areas, and could thus yield new records for the region. Thus, samples of subtidal sediments from LGN were collected in order to analyze the species composition of epipelagic diatoms by means of optical microscopy. The taxonomic study yielded a list with 232 taxa, which comprised 42 centric diatoms (>18%) and 190 pennates from 74 genera; 14 new records for the Mexican Pacific are included. This supported the hypothesis that epipelagic diatoms from the LGN subtidal constitute assemblages with a high species richness and numerous taxa characteristic of subtropical regions.

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**Keywords:** Bacillariophyta; Biogeography; Biosphere reserve; Protected area; Biodiversity; Diatom floristics; Coastal lagoon; Systematics; Taxonomy

### Resumen

La alta diversidad de diatomeas bentónicas les confiere un uso en la evaluación de impacto ambiental; a la vez, son una referencia adecuada para estimar biodiversidad en áreas protegidas. Observaciones preliminares en la laguna Guerrero Negro (LGN), localizada en la península de Baja California, México, sugirieron que alberga taxocenosis de diatomeas bentónicas con alta diversidad de especies de varios géneros, órdenes, clases, etcétera, que no son igualmente diversas o comunes en otras áreas, por lo que se esperaba encontrar nuevos registros para la región. Con base en esto, se recolectaron muestras de sedimentos del submareal en la LGN con el objetivo de describir la composición de especies de diatomeas epipelágicas mediante microscopía óptica. El análisis taxonómico resultó en una lista de 232 taxones que comprende 42 céntricas (> 18%) y 190 pennadas contenidas en 74 géneros. Se encontraron 14 nuevos registros para el Pacífico mexicano. Las observaciones respaldan la hipótesis de que las diatomeas epipelágicas en el submareal de LGN conforman taxocenosis con elevadas riquezas de especies, conformadas por numerosos taxones característicos de regiones subtropicales.

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**Palabras clave:** Bacillariophyta; Biogeografía; Reserva de la Biosfera; Área protegida; Biodiversidad; Florística de diatomeas; Laguna costera; Sistemática; Taxonomía

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

## Introduction

Benthic diatoms (Bacillariophyta) have been considered the most diverse and productive algal group in marine ecosystems (López-Fuerte, Siqueiros-Beltrones, & Yabur, 2015). Their ecological significance has distinguished them as an adequate reference for estimating biodiversity in marine protected areas (López-Fuerte, Siqueiros-Beltrones, & Navarro, 2010) and as a useful reference for assessing environmental impact (Siqueiros-Beltrones, 2002). Thus, both diversity and ecological aspects of diatoms should be considered essential for having an adequate ecological perspective of any aquatic ecosystem, particularly when elaborating management plans for protected areas.

The Guerrero Negro Lagoon (LGN) is part of the lagoon complex known as the Guerrero Negro-Ojo de Liebre located in the northern and southernmost parts of Baja California Sur (BCS) and Baja California (BC), respectively. It is found within the western mid-part of the Baja California Peninsula and in 1988 it was established as a protected area – Reserva de la Biosfera El Vizcaíno–, which due to its geographic location is considered a biological diversification center (Arellano-Martínez, De La Cruz-Agüero, & Cota-Gómez, 1996). However, notwithstanding the LGN is of utmost importance on environmental issues, and many studies are still required to adequately describe LGN in ecological terms.

Studies on benthic diatom floristics and ecology have been hitherto lacking for the LGN among many other taxonomic and ecological studies, inasmuch that these are scarce for the whole NW Mexican area in general. Most studies on benthic diatoms are related to their role in the diet of abalone (*Haliotis* spp.), a group of economically important species, and other herbivorous mollusks found in the intertidal ecosystems (Siqueiros-Beltrones & Valenzuela-Romero, 2004). Other studies refer to the structure of benthic diatom assemblages growing on macroalgae and plant substrates (Argumedo-Hernández & Siqueiros-Beltrones, 2008; Siqueiros-Beltrones, 2002); while another comprehensive study describes the epipelagic diatom assemblages from mangrove sediments (López-Fuerte et al., 2010).

Preliminary observations of LGN sediments suggested that they could harbor highly diverse assemblages of benthic diatoms with many species of certain taxa (genus, order, class, etcetera) which are not as diverse or common as in other localities of the region, considering both coasts of the Baja California Peninsula. According to this, the LGN could be considered a species diversity hotspot for benthic diatoms, from where certain common and abundant taxa may be exported to other localities, thus being useful to detect connectivity relations with other ecosystems in the NW Mexican region, as well as distributional patterns on the basis of floristics and assemblage structure variations.

Thus, the objective of this study was to describe a significant part of the benthic diatom flora from the LGN based on species richness and composition, focusing on epipelagic forms living in the subtidal sediments, including samples from cold and warm seasons. This study also represents the first estimate of benthic diatom species diversity and provides an insight of their biogeographical affinities. We tested the hypothesis that epipelagic

diatom assemblages from the subtidal sediments in LGN would have a high species richness, containing numerous taxa of distinct biogeographical affinities, as is characteristic in subtropical transitional zones showing high species diversity.

## Material and methods

The Guerrero Negro Lagoon (LGN) is located at 27°35'–27°52' N, 113°58'–114°10' W within the northernmost part of BCS and southernmost BC, Mexico (Fig. 1). This lagoon is part of a complex along with the Ojo de Liebre Lagoon, within the boundaries of El Vizcaíno Biosphere Reserve (Arellano-Martínez et al., 1996); the lagoons have separate mouths that drain into to Sebastián Vizcaíno Bay. The climate is arid with a low annual rainfall (mainly during winter) of <100 mm (Salinas-Zavala, Llinas, & Rodríguez-Estrella, 1991). The LGN has a rectangular shape that extends approximately 2,100 ha, with a maximum length of 13 km and width of 8 km that is connected to Vizcaíno Bay by a narrow channel (Contreras, 1985). It has a shallow bottom that varies in depth, mostly between 2 and 12 m (Lluch-Cota, Castellanos-Vera, Llinas-Gutiérrez, & Ortega-Rubio, 1993) with a maximum of 26 m. Eelgrass (*Zostera marina*) is widely distributed from 6 m deep up to the high tide mark (Eberhard, 1966). The lagoon sediments are composed mainly of gray sand mixed with organic alluvial

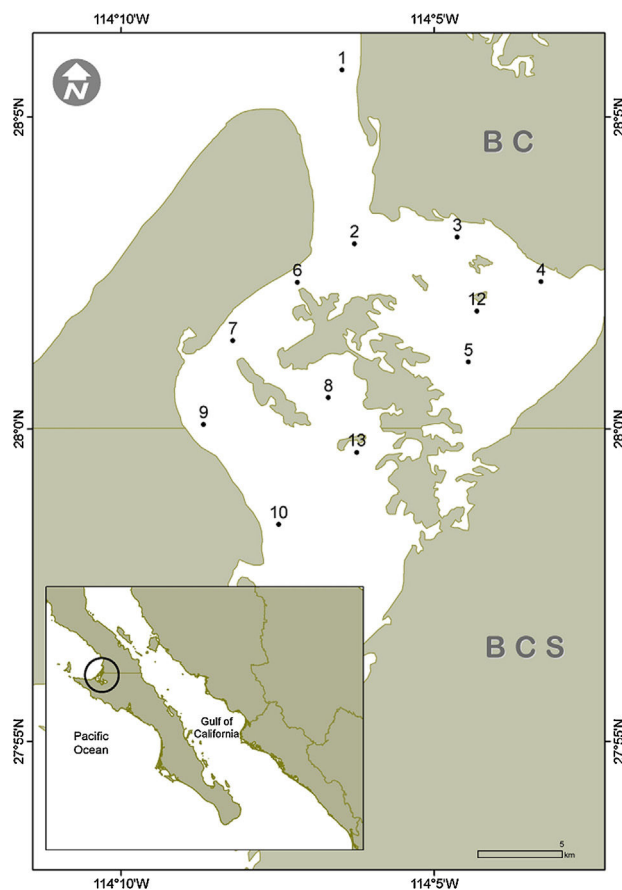


Figure 1. Location of the 12 sampling sites in Laguna Guerrero Negro, BC-BCS, Mexico.

deposits. Both normal and hypersaline salinity gradients have been recorded in the LGN (Lankford, 1977), although it has been considered an isohaline lagoon with salinity values between 35.5–37.5 in winter and 34.7–35.6 in summer (Phleger & Ewing, 1962).

Surficial sediment samples were collected by scuba diving in 12 sites along the subtidal bottom of the Guerrero Negro Lagoon in November 2013, January, June and July 2014 (Fig. 1). The sampling depth varied between 3 and 15 m. In each site, approximately 150 g of sediments were scooped using a 250 mL plastic

jar. In the laboratory, a 50 g subsample was separated, placed in a 100 mL beaker, and drinking water was added up to 100 mL. The beaker was then placed in an ultrasound bucket for 1 min while shaking lightly. Afterwards, the heavier sediments were decanted and disposed of while the remaining sediment suspension was relocated in a 100 mL test tube and left to settle for 2 h. Again, the overlaying water was removed thus leaving in the bottom a concentrate of diatom frustules. From this concentrate an aliquot was used to make fresh preparation for observation of living cells under the microscope, while the rest was submitted

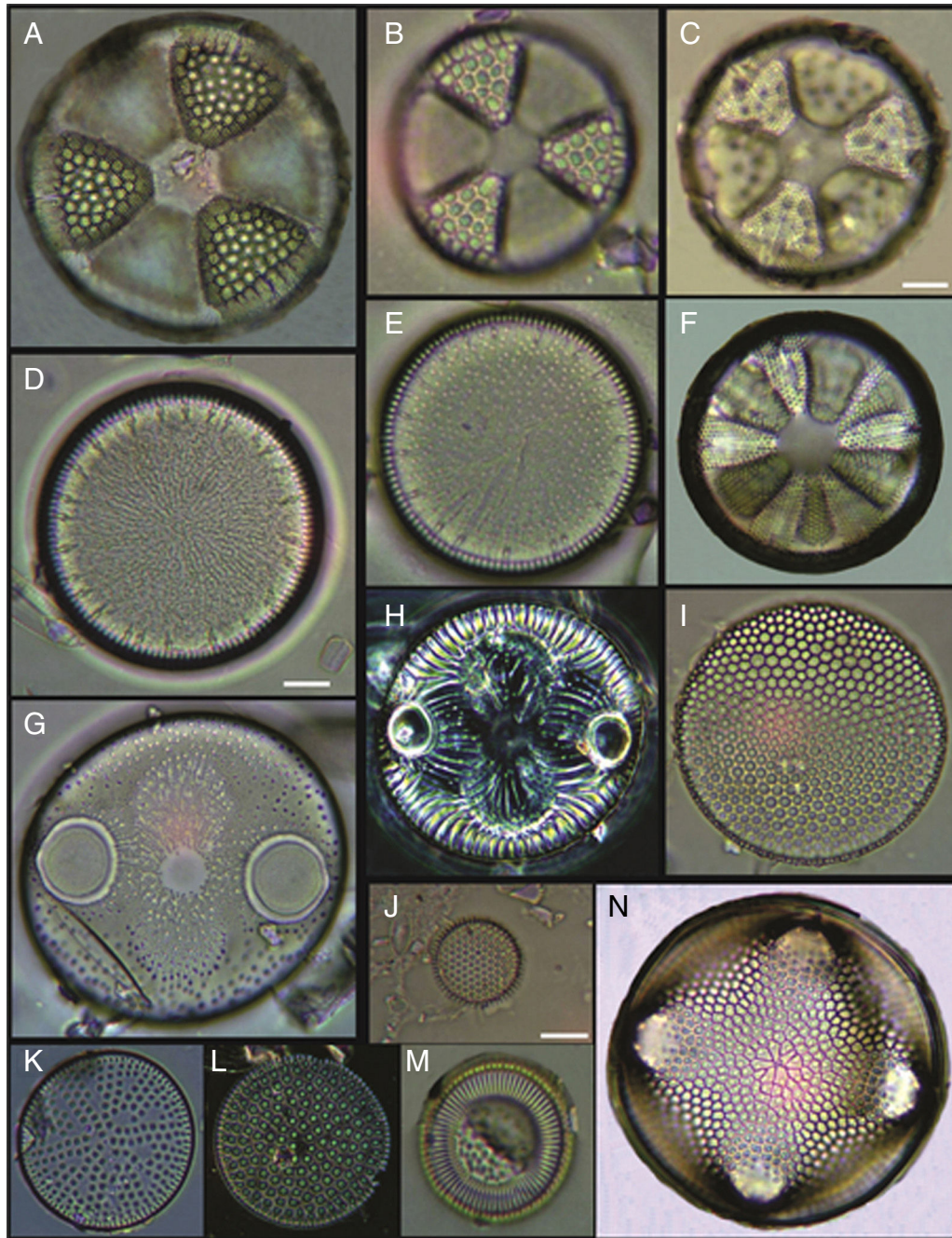


Figure 2. (A) *Actinoptychus aster*, (B) *Actinoptychus senarius*, (C) *Actinoptychus oppenoorthi*, (D, E) *Ehrenbergiulva granulosa*, (F) *Actinoptychus adriaticus*, (G) *Auliscus caelatus* var. *strigillata*, (H) *Auliscus punctatus*, (I) *Coscinodiscus radiatus*, (J) *Shionodiscus oestrupii*, (K) *Psammodiscus nitidus*, (L) *Psammodiscus calceatus*, (M) *Cyclotella littoralis*, (N) *Aulacodiscus ehrenbergii*. Bars = 10  $\mu$ m.

to oxidation of the organic matter. This was done with a mixture of sample, commercial alcohol and nitric acid at a ratio of 1:3:5, varying the amount of the reagents according with the apparent amount of organic matter in each sample (Siqueiros-Beltrones, 2002). Later, the oxidized material was rinsed repeatedly with drinking water until it reached a pH  $\geq$  6. For each sample 2 permanent slides were mounted using the synthetic resin Pleurax (IR = 1.7).

The slides were examined under an optical microscope with phase contrast and planapochromatic optics. Species identification was based on regional literature: Hernández-Almeida and Siqueiros-Beltrones (2008, 2012), López-Fuerte et al. (2010), Moreno-Ruíz, Licea, and Santoyo (1996), Siqueiros-Beltrones (2002, 2006), Siqueiros-Beltrones and Hernández-Almeida (2006), Siqueiros-Beltrones, Argumedo-Hernández, Murillo-Jiménez, and Marmolejo-Rodríguez (2014), as well as on classic literature: Hendeby (1964), Hustedt (1959, 1966), Peragallo and

Peragallo (1908), Round, Crawford, and Mann (1990), Schmidt et al. (1959), Stidolph, Sterrenburg, Smith, and Kraberg (2012), Witkowski, Lange-Bertalot, and Metzeltin (2000). We mainly followed the classification system of Round et al. (1990). However, the taxonomic status of all taxa were updated according to the *Algaebase* website (<http://algaebase.org/search/species/>, Guiry & Guiry, 2015). To complement the floristic list, an iconographic catalog was constructed with micrographs taken with a CMOS Konus digital ocular lens microscope at 1000 $\times$ .

## Results

The diatom assemblages from the intertidal sediments of LGN comprised 232 taxa distributed within 74 genera, 42 centrics (>18%), and 190 pennates. Out of the total number of taxa, 24 could not be identified to species level (Table 1).

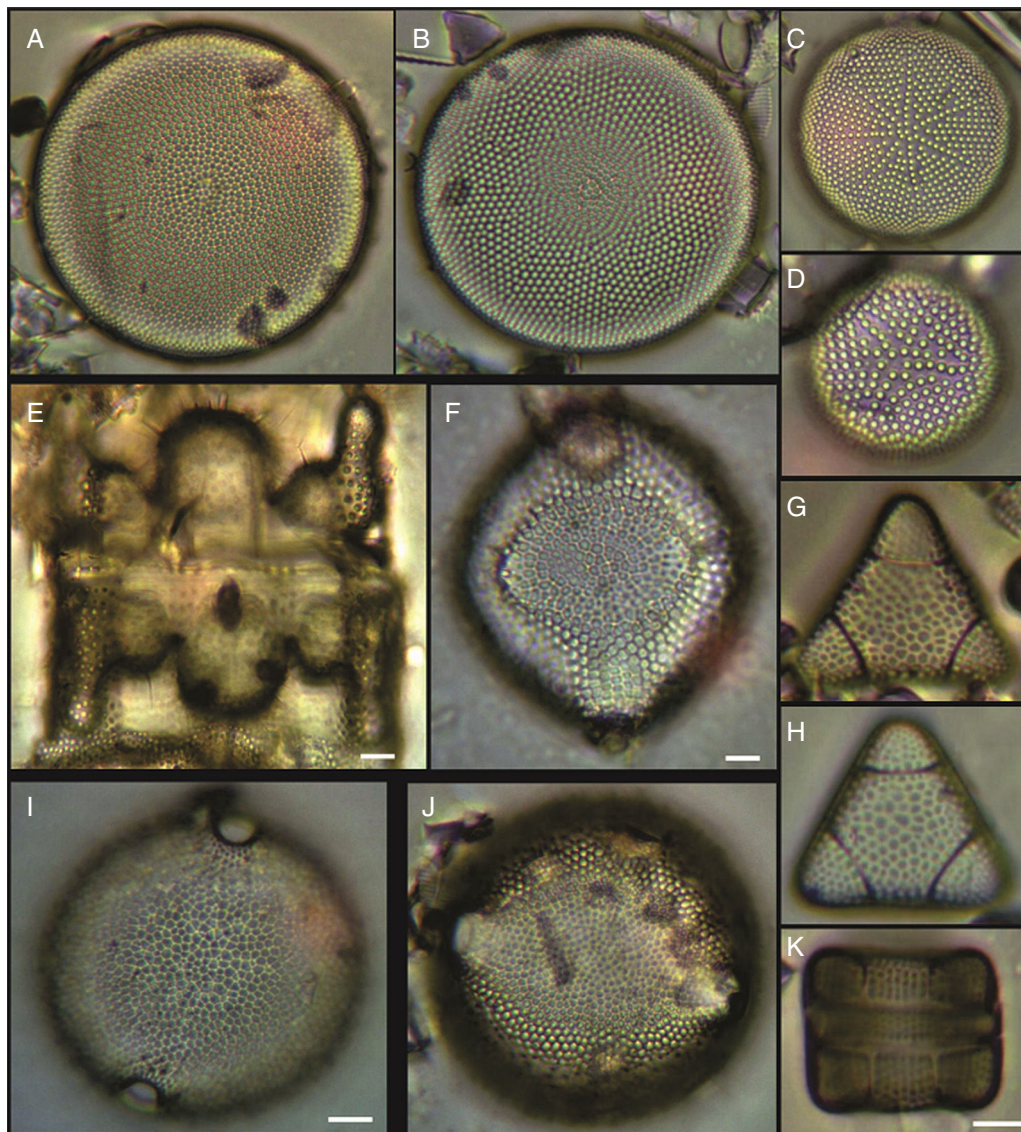


Figure 3. (A, B) *Actinocyclus curvatulus*, (C) *Actinocyclus octonarius* var. *tenellus*, (D) *Actinocyclus ralfsii* var. *minutae*, (E) *Biddulphia tuomeyi*, (F) *Biddulphia rhombus*, (I, J) *Cerataulus californicus*, (G, H, K) *Trigonium alternans*. Bars = 10  $\mu$ m.

An iconographic catalog with most of the observed taxa was constructed to complement the taxonomic analysis (Figs. 2–9).

The species list includes 14 new records (NR) for the Mexican Pacific (Table 1). The genus *Lyrella* I. Karayeva stands

out with the highest number of species and infra-specific taxa (21) and 6 NR, which were reviewed separately. Likewise, a high number of species of *Amphora* Ehrenberg (25, including 4 *Halamphora* (Cleve) Levkov) was recorded, and

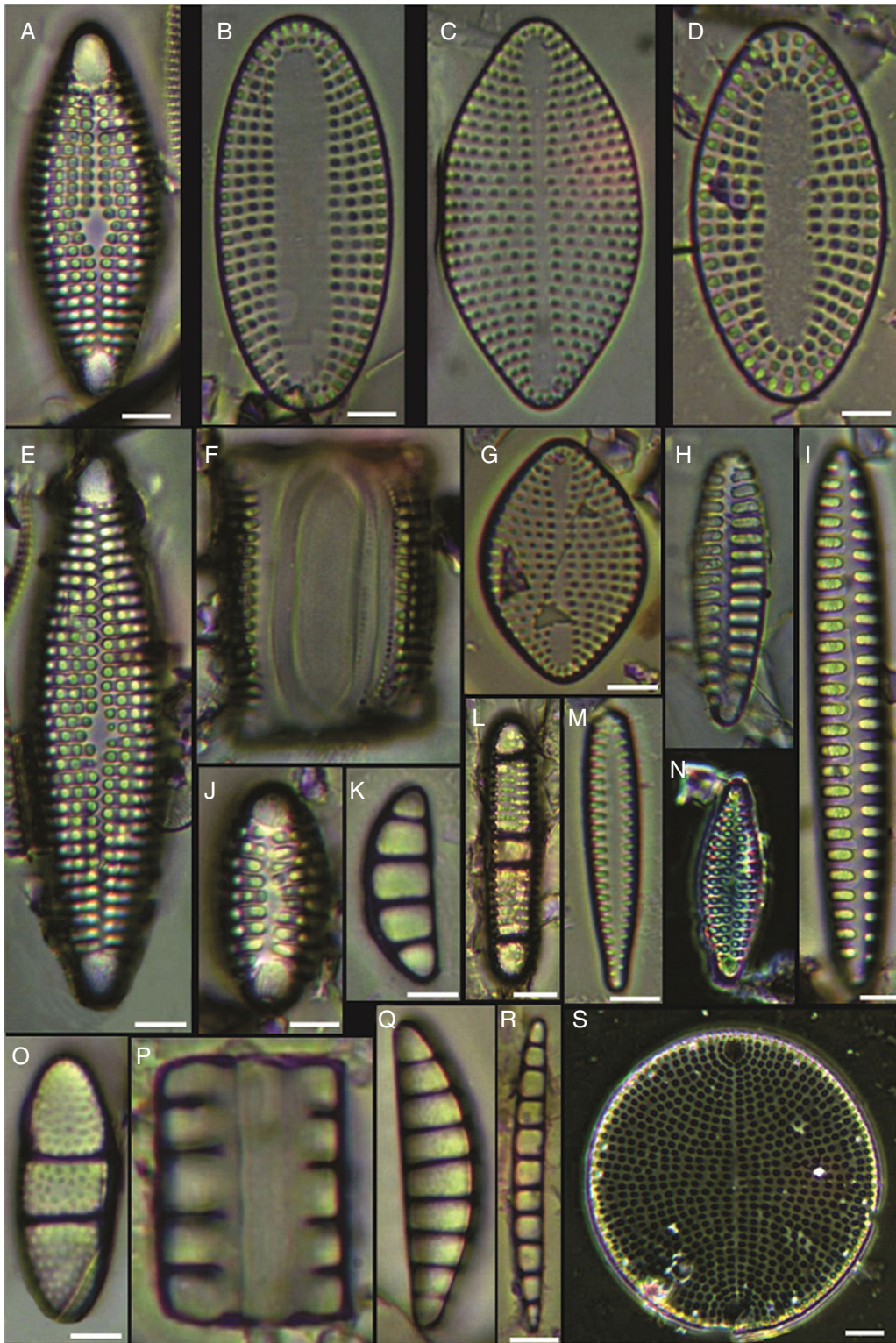


Figure 4. (A, E, F, J) *Dimeregramma minor* var. *minor*, (B, D) *Delphineis fasciola* var. *australis*, (C, G) *Delphineis surirella*, (H) *Opephora pacifica*, (I) *Opephora schwartzii*, (K, P, Q) *Eunotogramma laevis*, (L) *Plagiogramma wallichianum*, (M) *Opephora marina*, (N) *Dimeregramma* sp., (O) *Neohuttonia reichardtii*, (R) *Eunotogramma marinum*, (S) *Diplomenora cocconeiformis*. Bars = 10  $\mu$ m.

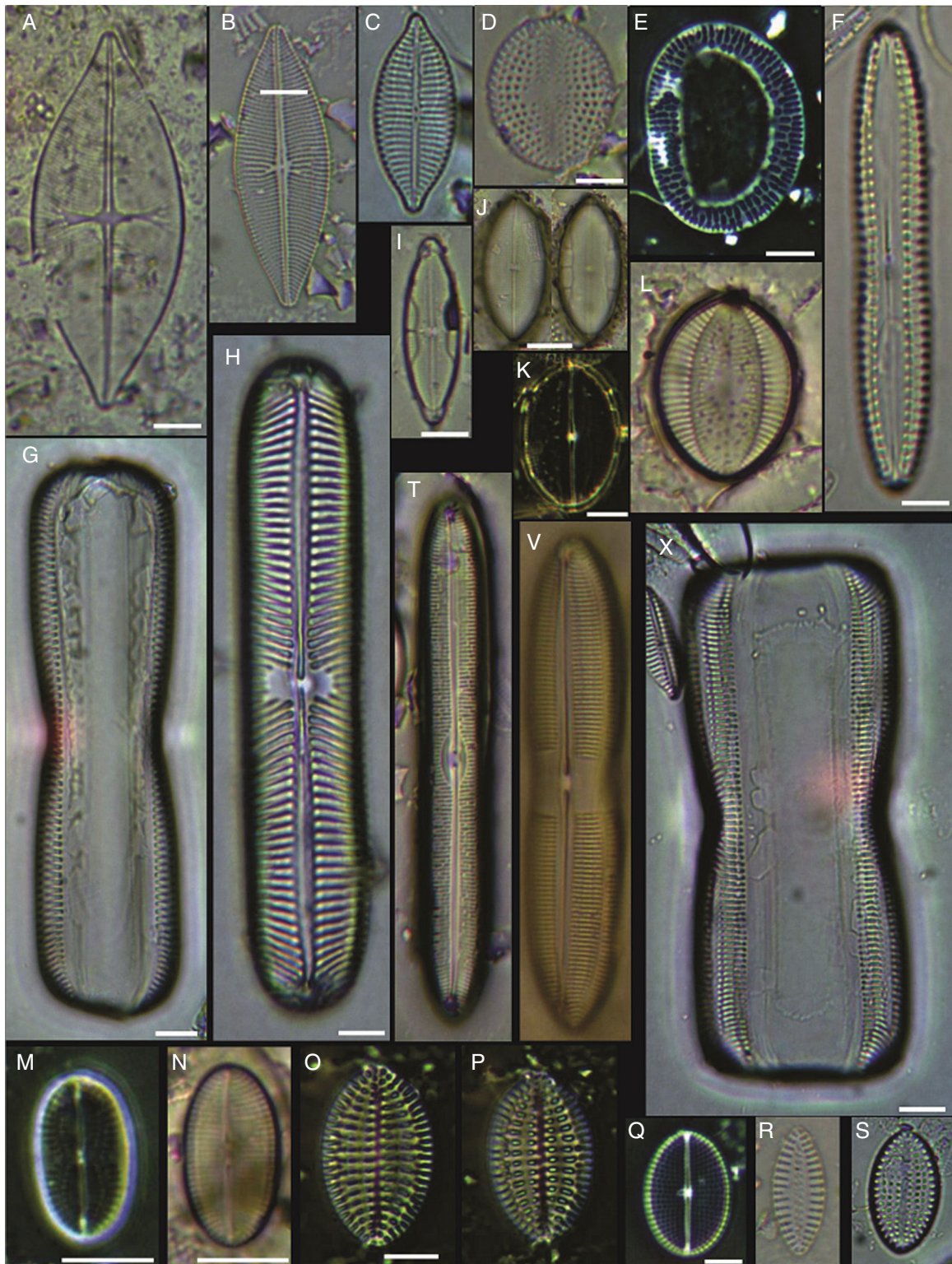


Figure 5. (A) *Achnanthes danica*, (B) *Achnanthes fimbriata*, (C) *Navicula diversistriata*, (D) *Anorthoneis eccentrica*, (E) *Anorthoneis hyalina*, (F) *Biremis* cf. *ridicula*, (G, H) *Pinnularia rectangularata*, (I) *Mastogloia gieskesii*, (J) *Mastogloia pusilla*, (K) *Fallacia* sp., (L) *Cocconeis latecostata*, (M) *Fallacia hummii*, (N) *Fallacia vittata*, (O, P) *Cocconeis californica* var. *keruelensis*, (Q) *Cocconeopsis patrickae*, (R) *Planothidium polaris*, (S) *Cocconeis distans*, (T) *Caloneis liber* var. *linearis*, (X) *Caloneis westii*, (V) *Caloneis* cf. *consimilis*. Bars = 10  $\mu$ m.

although no NR of this genus occurred, there were 2 unidentified taxa. Also, *Navicula* Bory included 16 species and 2 NR; 14 species of *Fallacia* Stickle et Mann, a genus that comprises mainly epipelagic forms. The genus *Cocconeis* Ehrenberg was represented by 14 species (1 NR); these are mainly

epilithic and epiphytic forms. The above contrasts with the few (6) species of *Nitzschia* Hassall (1 NR) and 5 *Mastogloia* Thwaites (1 NR). There is also included 1 new record of *Craspedopleura* M. Poulin and 2 of *Cosmioneis* Mann et Stickle.

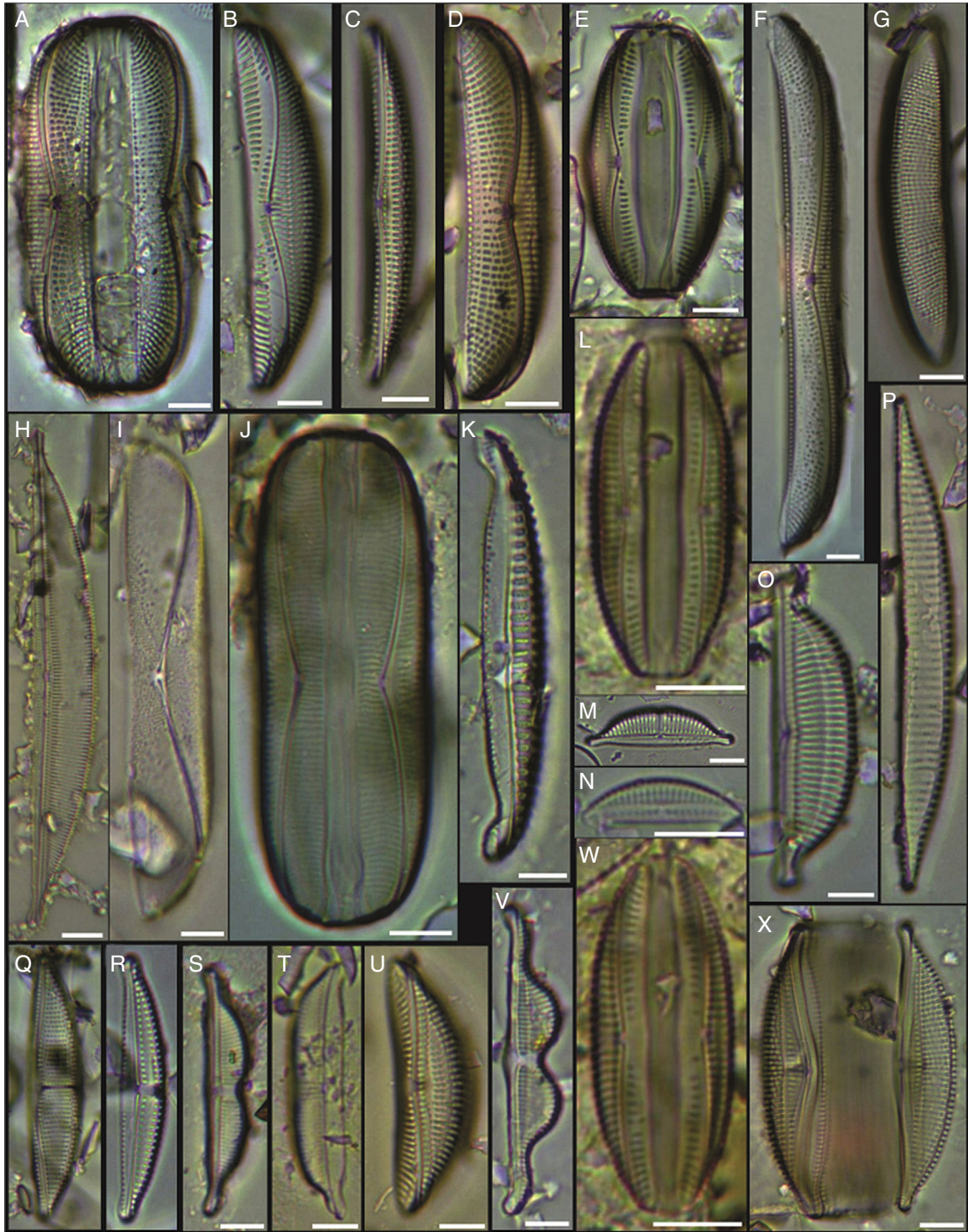


Figure 6. (A, D) *Amphora proteus* var. *kariana*, (B, E, U) *Amphora proteus*, (C) *Amphora proteus* var. *contigua*, (F) *Amphora arenicola*, (G) *Amphora* sp. 1, (H) *Halamphora terroris*, (I) *Amphora arenaria*, (J) *Amphora spectabilis*, (K) *Amphora crassa* var.? (L, W) *Amphora marina*, (M) *Amphora amoena*, (N) *Amphora exilitata*, (O) *Halamphora turgida*, (P) *Amphora elegantula*, (Q) *Amphora ostrearina*, (R) *Amphora malectracta* var. *constricta*, (S) *Amphora bigibba*, (T) *Amphora delicatissima*, (V) *Amphora binodis* v. *bigibba*, (X) *Amphora crassa*. Bars = 10  $\mu$ m.

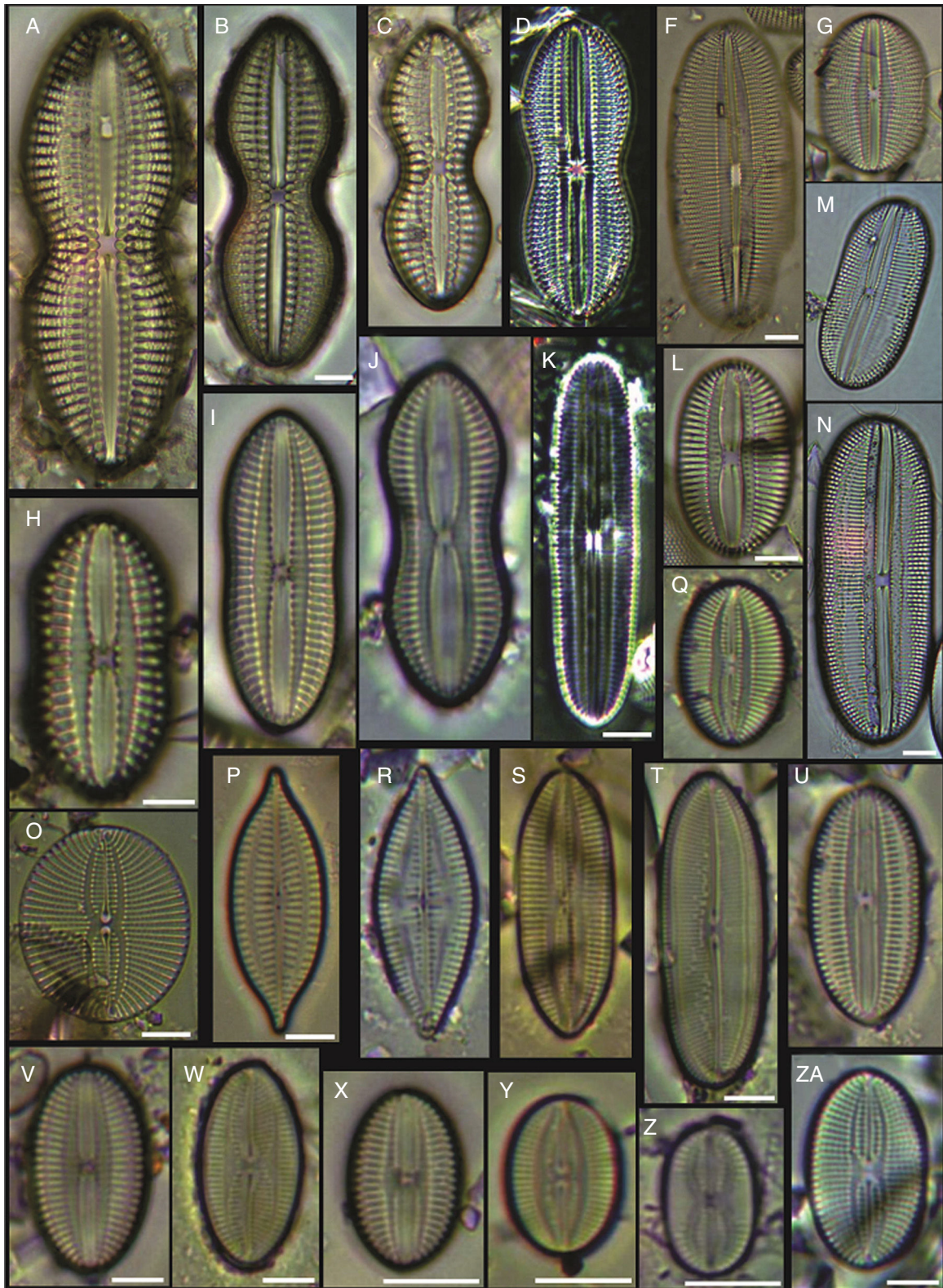


Figure 7. (A–C) *Diploneis crabro*, (D) *Diploneis splendida*, (F) *Diploneis litoralis*, (G) *Diploneis smithii*, (H, I, X) *Diploneis papula*, (J) *Diploneis papula* var. *constricta*, (K) *Diploneis litoralis* var. *clathrata*, (L) *Diploneis suborbicularis*, (M, N) *Diploneis obliqua*, (O) *Fallacia nummularia*, (P) *Fogedia finmarchica*, (Q, ZA) *Fallacia subforcipata*, (R) *Fogedia* cf. *geissleriana*, (S) *Fallacia forcipata*, (T) *Fallacia inscriptura*, (U, V) *Diploneis notabilis*, (W) *Fallacia shoemaniana*, (Y) *Fallacia oculiformis*, (Z) *Fallacia* cf. *tenera*. Bars = 10  $\mu$ m.



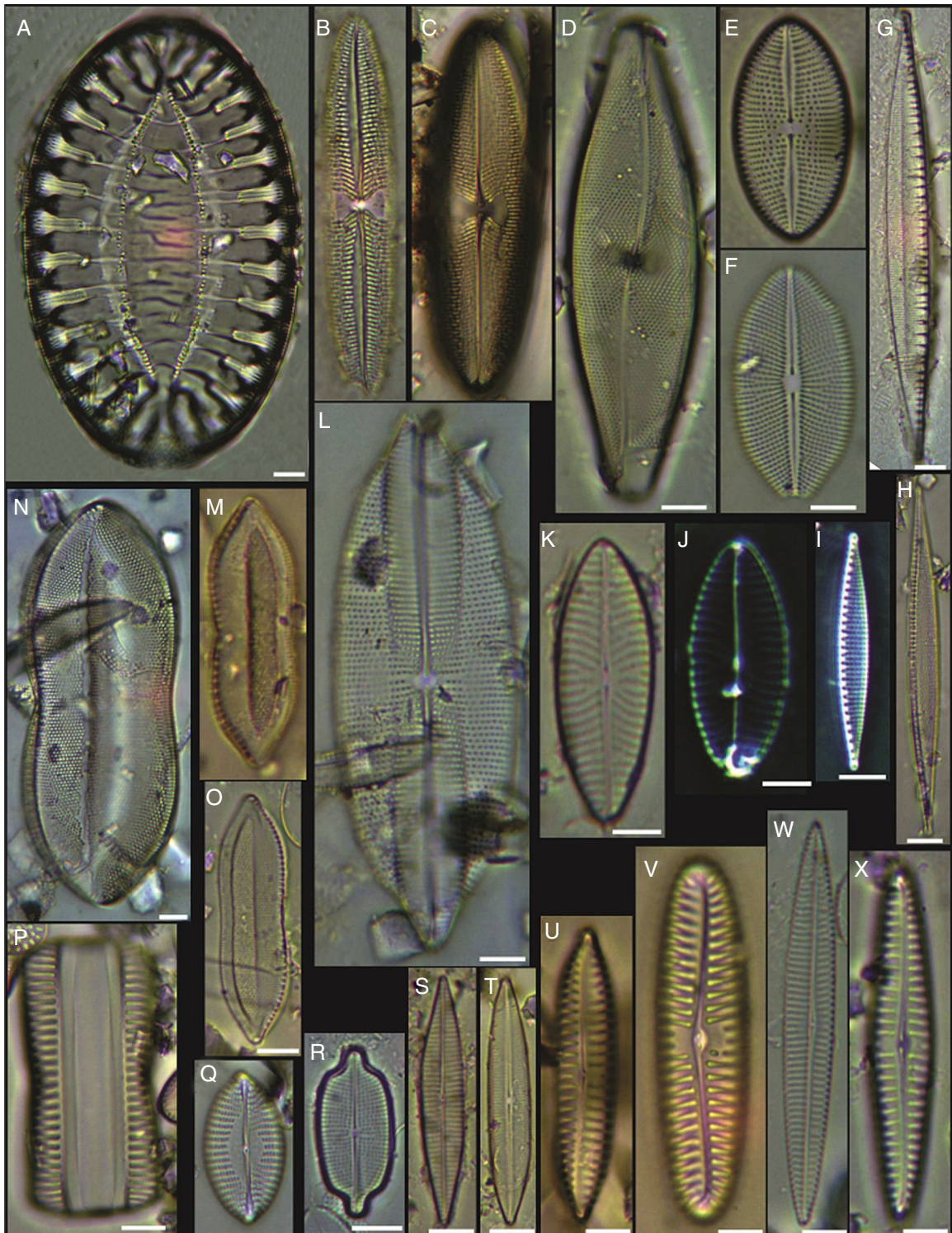


Figure 8. (A) *Suirella fastuosa*, (B) *Trachyneis aspera*, (C) *Trachyneis velata*, (D) *Pleurosigma naviculaceum*, (E) *Petroneis granulata*, (F) *Cosmioneis* sp. 2, (G) *Nitzschia fluminensis*, (H) *Nitzschia sigma*, (I) *Nitzschia grossestriata*, (J) *Navicula digitoradiata*, (K) *Navicula rolandii*, (L) *Navicula carinifera*, (M, O) *Psammodyctyon roridum*, (N) *Psammodyctyon panduriformis* var. *latum*, (P) *Navicula cancellata*, (Q) *Navicula torifera*, (R) *Navicula borneoensis*, (S) *Navicula* sp. 1, (T) *Parlibellus* sp. 1, (U) *Navicula* cf. *bipustulata*, (V) *Navicula distans*, (W) *Navicula directa*, (X) *Navicula longa*. Bars = 10  $\mu$ m.

## Discussion

The above results back up the proposed hypothesis that: a) the epipelagic diatoms from the intertidal of the Guerrero Negro Lagoon constitute assemblages with a high species diversity,

and b) the occurrence of 193 diatom taxa previously recorded hitherto in the region, i.e., 83%, reflects the wide biogeographical spectrum recorded in the neighboring subtropical transition zone to the south and the east coast of the Baja California Peninsula. Many of these taxa have been recorded previously

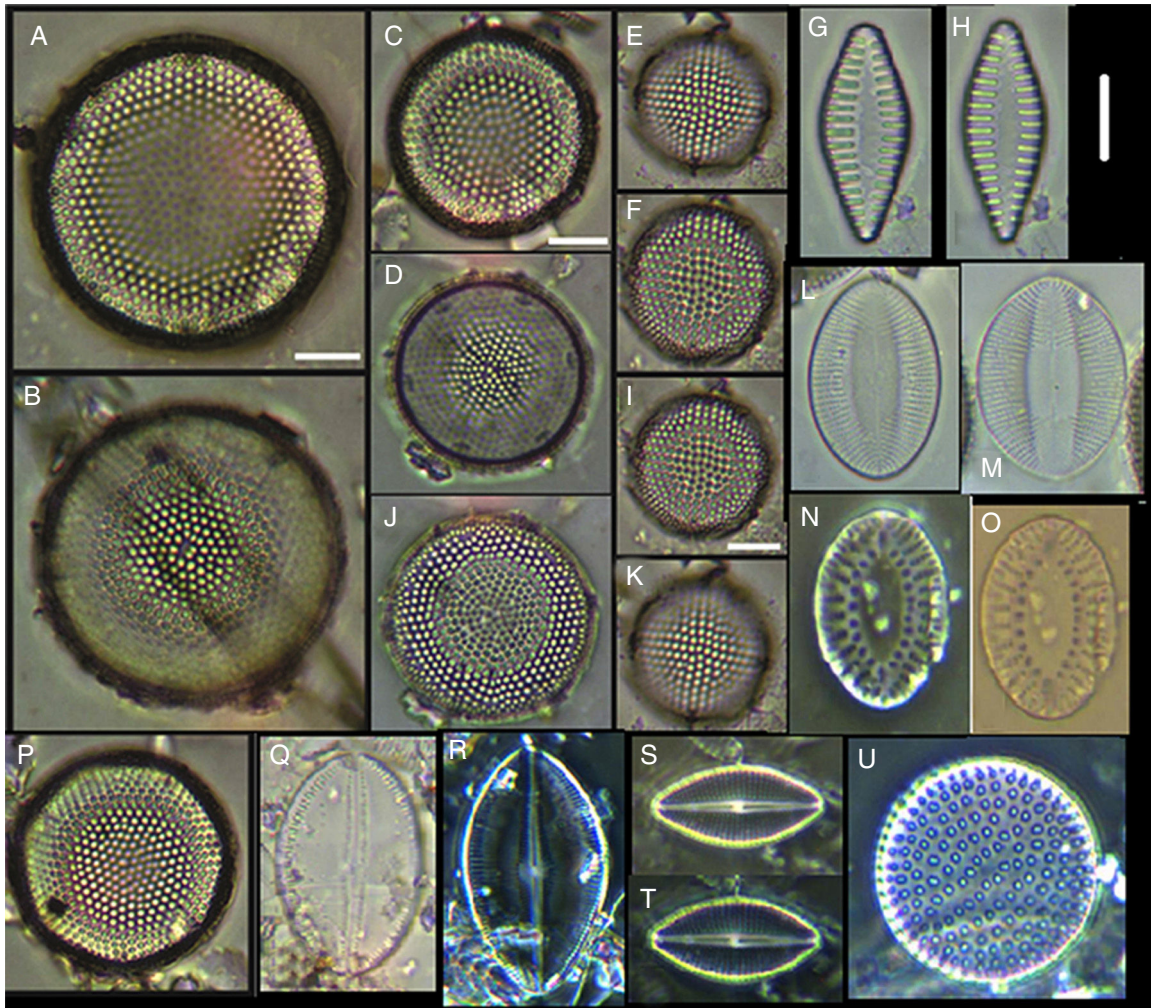


Figure 9. (A–F, I–K, P) *Aulacodiscus* sp., (G, H) *Opephora* sp., (L, M) *Cocconeis* cf. *pelta*, (N, O) *Surirella* sp., (Q) *Cocconeis californica* var. *keruelensis*, (R) *Craspedopleura* sp. (S, T) *Cosmioneis* sp. 1, U) *Neodetonula superba*. Bars = 10  $\mu$ m.

as tytoplankton, either in the Gulf of California (Moreno-Ruíz et al., 1996) e.g., species of *Auliscus* Ehrenberg and *Psammodiscus* Round et Mann or, as most of the taxa in our list, in benthic substrata from mangrove systems on both coasts of Baja California Sur (Hernández-Almeida & Siqueiros-Beltrones, 2012; López-Fuerte & Siqueiros-Beltrones, 2006; López-Fuerte et al., 2010; Siqueiros-Beltrones & Morzaria-Luna, 1999; Siqueiros-Beltrones & Sánchez-Castrejón, 1999; Siqueiros-Beltrones et al., 2014; Siqueiros-Beltrones, 2006).

In the most recent study on diatoms from sediments in the region (Siqueiros-Beltrones et al., 2014) a typical assemblage of diatoms was described with a species richness of 182 taxa, where only 13 were centrics (7%). However, few species of *Lyrella* (4) were observed. In contrast, in mangrove sediments from Magdalena Bay, out of 327 diatom taxa recorded, 15.5% (50) were centrics, and 15 of *Lyrella* (López-Fuerte, 2004). A suggestive similarity stands out, inasmuch in our species list, besides the 43 centrics, 21 species and infra-specific-taxa of *Lyrella* were identified, including 8 new records for the Mexican coasts and 11 for the NW of México (Siqueiros-Beltrones et al., in press).

The relatively high number of centric forms in the LGN, combined with the many representatives of *Lyrella*, could be reflecting particular conditions that distinguish it from the other environments in the west coast of BCS. The LGN is located farther north than the accepted latitudinal distribution for mangrove forests along the west coast of the Baja California Peninsula (González-Zamorano, Nava-Sánchez, León-de la Luz, & Díaz-Castro, 2011). However, it has been considered within a subtropical region due to the influence of a tropical water mass (Hernández-Rivas, Jiménez-Rosenberg, Funes-Rodríguez, & Saldierna-Martínez, 2000). However, the occurrence and effect of the California current and local upwelling events, typical of this area should be acknowledged. The low temperature of the water that these currents provide related to a certain type of characteristic biota – recorded by Eberhard (1966)–, is also found in San Quintín Bay and in the Punta Banda estuary farther north in Baja California. This defines a transitional region that has been observed in the phytoplankton assemblages of the Magdalena Bay lagoon complex (Gárate-Lizárraga & Siqueiros Beltrones, 1998). Furthermore, López-Fuerte et al. (2015) recently recorded a particular benthic diatom flora in

Table 1

List of species and infra-specific taxa of benthic diatoms found in subtidal sediments of Laguna Guerrero Negro, BC-BCS, Mexico. NR = new records for the Mexican NW region.

Class Coscinodiscophyceae Round et R. M. Crawford  
 Order: Anaulales Round et R. M. Crawford  
 Family: Anaulaceae (F. Schütt) Lemmermann  
*Eunotogramma* Weisse  
*Eunotogramma laevis* Grunow (Fig. 4K, P, Q)  
*Eunotogramma marinum* (W. Smith) H. Peragallo et M. Peragallo (Fig. 4R)  
 Order: Coscinodiscales Round et R. M. Crawford  
 Family: Heliopeltaceae W. Smith  
*Actinocyclus* Ehrenberg  
*Actinocyclus curvatus* Janisch (Fig. 3A and B)  
*Actinocyclus octonarius* var. *tenellus* (Brébisson) Hendey (Fig. 3C)  
*Actinocyclus ralfsii* f. *minutae* H. Peragallo et M. Peragallo NR  
*Actinoptychus* Ehrenberg  
*Actinoptychus adriaticus* Grunow (Fig. 2F)  
*Actinoptychus aster* J. J. Brun (Fig. 2A)  
*Actinoptychus openoorthi* T. Reinhold (Fig. 2C)  
*Actinoptychus senarius* (Ehrenberg) Ehrenberg (Fig. 2B)  
*Actinoptychus splendens* (Shadbolt) Ralfs  
*Plagiogrammopsis* Hasle, Stosch et Syvertsen  
*Plagiogrammopsis vanheurckii* (Grunow) Hasle, von Stosch et Syvertsen  
 Order: Melosirales R. M. Crawford  
 Family: Hyalodiscaceae R. M. Crawford  
*Hyalodiscus* Ehrenberg  
*Hyalodiscus punctatus* A. Schmidt  
 Order: Paraliales R. M. Crawford  
 Family: Paraliaceae R. M. Crawford  
*Paralia* Heib.  
*Paralia sulcata* var. *crenulata* Grunow  
 Family: Aulacodiscaceae (F. Schütt) Lemmermann  
*Aulacodiscus* Ehrenberg  
*Aulacodiscus ehrenbergii* C. Janisch (Fig. 2N)  
*Aulacodiscus* cf. *minimus* Hustedt  
*Aulacodiscus* sp. NR (Fig. 9A and P)  
 Family: Coscinodiscaceae Kütz.  
*Coscinodiscus* Ehrenberg  
*Coscinodiscus concinnus* W. Smith  
*Coscinodiscus radiatus* Ehrenberg (Fig. 2I)  
 Order: Cymatosirales Round et R. M. Crawford  
 Family: Cymatosiraceae Hasle, von Stosch et Syvertsen  
*Brockmanniella*  
*Brockmanniella brockmannii* (Hustedt) Hasle, Stosch et Syvertsen  
*Campylosira* Grunow  
*Campylosira cymbelliformis* (A. Schmidt) Grunow ex van Heurck  
 Order: Triceratiales Round et R. M. Crawford  
 Family: Triceratiaceae (F. Schütt) Lemmermann  
*Auliscus* Ehrenberg  
*Auliscus caelatus* var. *strigillata* A. W. F. Schmidt (Fig. 2G)  
*Auliscus punctatus* Bailey (Fig. 2H)  
*Cerataulus* Ehrenberg  
*Cerataulus californicus* A. Schmidt (Fig. 3I, J)  
*Triceratium* Ehrenberg  
*Triceratium favus* Ehrenberg  
 Family: Plagiogrammaceae De Toni  
*Glyphodesmis* Grev.  
*Glyphodesmis* sp.  
*Dimeregramma* Ralfs  
*Dimeregramma* cf. *maculatum* (Cleve) Frenguelli  
*Dimeregramma minor* var. *minor* (Gregory) Ralfs (Fig. 4A, E, F, J)  
*Dimeregramma* sp. (Fig. 4N)  
*Plagiogramma* Grevillei  
*Plagiogramma interruptum* (Gregory) Ralfs  
*Plagiogramma pulchellum* Greville

Table 1 (Continued)

*Plagiogramma* sp.  
*Plagiogramma wallichianum* Greville (Fig. 4L)  
 Family: Biddulphiaceae Kützing  
*Biddulphia* Gray  
*Biddulphia tuomeyi* (J. W. Bailey) Roper (Fig. 3E)  
*Biddulphia rhombus* (Ehrenberg) W. Smith (Fig. 3F)  
*Neohuttonia* Kuntze  
*Neohuttonia reichardtii* (Grunow) Hustedt (Fig. 4O)  
*Terpsinoë* Ehrenberg  
*Terpsinoë americana* (Bailey) Grunow  
*Trigonium* Cleve  
*Trigonium alternans* (Bailey) A. Mann  
 Order: Thalassiosirales Glezer et Makarova  
 Family: Stephanodiscaceae Glezer et Makarova  
*Cyclotella* (Kützing) Brébisson  
*Cyclotella litoralis* Lange et Syvertsen (Fig. 2M)  
*Cyclotella striata* (Kützing) Grunow  
 Family: Thalassiosiraceae M. Lebour  
*Ehrenbergiulva* Witkowski, Lange-Bertalot et Metzeltin  
*Ehrenbergiulva granulosa* (Grunow) Witkowski, Lange-Bertalot et Metzeltin (Fig. 2D and E)  
*Ehrenbergiulva haucki* (Grunow) Witkowski, Lange-Bertalot et Metzeltin  
*Thalassiosira* Cleve  
*Shionodiscus* A. J. Alverson, S. H. Kang et E. C. Theriot  
*Shionodiscus oestrupii* (Ostenfeld) A. J. Alverson, S. H. Kang et E. C. Theriot (Fig. 2J)  
 Class Fragilariophyceae Round  
 Family: Psammodiscaceae Round et D. G. Mann  
 Family: Rhaphoneidaceae Forti  
*Delphineis* G. W. Andrews  
*Delphineis surirella* (Ehrenberg) G. W. Andrews (Fig. 4C, G)  
*Delphineis fasciola* var. *australis* (P. Petit) P. M. Tsarenko (Fig. 4B, D)  
*Diplomenora* K. L. Blazé  
*Diplomenora cocconeiformis* (A. Schmidt) K. L. Blazé (Fig. 4S)  
*Neodelphineis* Takano  
*Neodelphineis* sp.  
*Rhaphoneis* Ehrenberg  
*Rhaphoneis nitida* (W. Gregory) Grunow  
*Rhaphoneis* sp. 1  
*Rhaphoneis surirella* var. *ceylanica* (Cleve) Foged  
*Psammodiscus* Round et D. G. Mann  
*Psammodiscus calceatus* T. Watanabe, T. Nagumo et J. Tanaka NR (Fig. 2L)  
*Psammodiscus nitidus* (W. Gregory) Round et D. G. Mann (Fig. 2K)  
*Grammatophora* Ehrenberg  
*Grammatophora hamulifera* Kützing  
 Order: Thalassionematales Round  
 Family: Thalassionemataceae Round  
*Thalassionema* Grunow  
*Thalassionema nützschoides* (Grunow) Mereschkowsky  
 Order: Climacospheniales Round  
 Family: Climacospheniaceae Round  
*Climacosphenia* Ehrenberg  
*Climacosphenia monilligera* Ehrenberg  
 Family: Fragilariaceae Grev.  
*Opephora* Petit  
*Opephora marina* (W. Gregory) Petit  
*Opephora marina* (W. Gregory) Petit var.? (Fig. 4M)  
*Opephora pacifica* (Grunow) Petit (Fig. 4H)  
*Opephora schwartzii* (Grunow) Petit ex Pelletan (Fig. 4I)  
*Opephora* sp. 1 NR (Fig. 9G, H)  
*Podocystis* J. W. Bailey  
*Podocystis adriatica* (Kützing) Ralfs  
*Staurosirella* D. M. Williams et Round  
*Staurosirella pinnata* (Ehrenberg) D. M. Williams et Round  
*Trachysphenia* P. Petit

Table 1 (Continued)

*Trachysphenia australis* P. Petit  
*Trachysphenia australis* var. *rostellata* Hustedt  
 Class Bacillariophyceae Haeckel  
 Order: Achnanthales Silva  
 Family: Achnanthaceae Kützing  
*Achnanthes* Bory  
*Achnanthes danica* (Flögel) Grunow (Fig. 5A)  
*Achnanthes fimbriata* (Grunow) Ross (Fig. 5B)  
*Achnanthes tenera* Hustedt  
 Family: Achnanthidiaceae D. G. Mann  
*Achnanthidium* Kützing  
*Achnanthidium* sp. 1  
*Planothidium* Round et Bukhtiyarova  
*Planothidium delicatulum* (Kützing) Round et Bukhtiyarova  
*Planothidium hauckianum* (Grunow) Round et Bukhtiyarova  
*Planothidium lilljeborgei* (Grunow) Witkowski  
*Planothidium polaris* (Østrup) Witkowski, Lange Bertalot et Metzeltin (Fig. 5R)  
 Family: Cocconeidaceae Kützing  
*Amphicoconeis*  
*Amphicoconeis disculoides* (Hustedt) Stefano et Marino  
*Anorthoneis* Grunow  
*Anorthoneis eurystoma* Cleve (Fig. 5D)  
*Anorthoneis excentrica* (Donkin) Grunow (Fig. 5D)  
*Anorthoneis hyalina* Hustedt (Fig. 5E)  
*Cocconeis* Ehrenberg  
*Cocconeis californica* var. *kerquelenensis* Heiden (Fig. 9Q)  
*Cocconeis* cf. *nugalis* M. H. Hohn et J. Hellerman  
*Cocconeis* cf. *pelta* A. Schmidt NR (Fig. 9L, M)  
*Cocconeis discrepans* A. W. F. Schmidt  
*Cocconeis distans* W. Gregory (Fig. 5S)  
*Cocconeis guttata* Hustedt et Aleem (Fig. 5O, P)  
*Cocconeis latecostata* Hustedt (Fig. 5L)  
*Cocconeis neodiminuta* Krammer  
*Cocconeis peltoidea* Hustedt  
*Cocconeis pinnata* W. Gregory ex Greville  
*Cocconeis placentula* var. *euglypta* (Ehrenberg) P.T. Cleve  
*Cocconeis pseudomarginata* Gregory  
*Cocconeis* sp.1  
*Cocconeopsis* Witkowski, Lange-Bertalot et Metzeltin  
*Cocconeopsis* cf. *kantsinensis* (Giffen) Witkowski  
*Cocconeopsis patrickae* (Hustedt) A. Witkowski, Lange-Bertalot et Metzeltin (Fig. 5Q)  
*Cocconeopsis regularis* (Hustedt) Witkowski  
 Order: Bacillariales Hendey  
 Family: Bacillariaceae Ehrenberg  
*Fragilariopsis* Hustedt  
*Fragilariopsis doliolus* (Wallich) Medlin et P. A. Sims  
*Hantzschia* Grunow  
*Hantzschia virgata* (Roper) Grunow  
*Nitzschia* Hassall  
*Nitzschia dissipata* (Kützing) Rabenhorst  
*Nitzschia distans* Gregory  
*Nitzschia fluminensis* Grunow (Fig. 8G)  
*Nitzschia grossestriata* Hustedt (Fig. 8I)  
*Nitzschia sigma* (Kützing) W. Smith (Fig. 8H)  
*Tryblionella*  
*Tryblionella* cf. *coarctata* (Grunow) D. G. Mann  
 Family: Anomoeoneidaceae D. G. Mann  
 Staurophora Mereschkowsky  
*Staurophora* cf. *salina* (W. Smith) Mereschkowsky  
*Staurophora* sp.  
 Order: Lyrellales D. G. Mann  
 Family: Lyrellaceae D. G. Mann  
*Lyrella* Karayeva  
*Lyrella abrupta* (Gregory) D. G. Mann  
*Lyrella approximatoidea* (Hustedt) D. G. Mann

Table 1 (Continued)

*Lyrella atlantica* (A. Schmidt) D. G. Mann  
*Lyrella clavata* var. *caribaea* (Cleve) Siqueiros Beltrones  
*Lyrella clavata* var. *elongata* (H. Peragallo) Siqueiros Beltrones  
*Lyrella clavata* var. *indica* (Greville) Moreno  
*Lyrella excavata* (Greville) D. G. Mann  
*Lyrella exsul* (A. Schmidt) D. G. Mann  
*Lyrella fogedii* Witkowski, Lange-Bertalot et Metzeltin  
*Lyrella fundata* (Hustedt) Siqueiros Beltrones  
*Lyrella granulata* (Grunow) E. Nevrova, A. Witkowski, M. Kulikovskiy et Lange-Bertalot  
*Lyrella hennedyi* var. *crassa* (Peragallo) Siqueiros Beltrones  
*Lyrella hennedyi* var. *furcata* (Peragallo et Peragallo) Siqueiros Beltrones  
*Lyrella impercepta* (Hustedt) J. L. Moreno  
*Lyrella implana* (Hustedt) J. L. Moreno  
*Lyrella irrorata* (Greville) D. G. Mann  
*Lyrella lyra* (Ehrenberg) Karayeva  
*Lyrella lyra* var. *constricta* (Peragallo) Siqueiros Beltrones  
*Lyrella lyra* var. *subtypica* (Hustedt) Siqueiros Beltrones  
*Lyrella spectabilis* (Gregory) D. G. Mann  
*Lyrella* sp. 2 cf. *spectabilis* (Gregory) D. G. Mann  
*Petroneis* Stickle et D. G. Mann  
*Petroneis granulata* (J. W. Bailey) D. G. Mann (Fig. 8E)  
 Order: Mastogloiales D. G. Mann  
 Family: Mastogloiaceae Mereschkowsky  
*Mastogloia* G. H. K. Thwaites ex W. Smith  
*Mastogloia binotata* (Grunow) Cleve  
*Mastogloia crucicula* (Grunow) Cleve v. *crucicula*  
*Mastogloia pusilla* Grunow (Fig. 5J)  
*Mastogloia gieskesii* Cholnoky NR (Fig. 5I)  
*Mastogloia* sp.  
 Order: Naviculales Bessey  
 Family: Amphipleuraceae Grunow  
*Frustulia* Rabenhorst  
*Frustulia* sp. 1  
*Halamphora* (Cleve) Levkov  
*Halamphora subangularis* (Hustedt) Levkov  
*Halamphora terroris* (Ehrenberg) P. Wang  
*Halamphora turgida* (Gregory) Levkov (Fig. 6O)  
*Halamphora wisei* (M. M. Salah) I. Álvarez-Blanco et S. Blanco  
*Parlibellus* Cox  
*Parlibellus* sp. 1  
*Parlibellus* sp. 2  
 Family: Diadesmidaceae D. G. Mann  
*Caloneis* Cleve  
*Caloneis* cf. *consimilis* (A. Schmidt) Cleve NR (Fig. 5A)  
*Caloneis liber* (W. Smith) Cleve  
*Caloneis liber* var. *linearis* Cleve (Fig. 5T)  
*Caloneis westii* (W. Smith) Hendey (Fig. 5X)  
 Family: Cosmioneidaceae D. G. Mann  
*Cosmioneis* D. G. Mann et Stickle  
*Cosmioneis* sp. 1 NR (Fig. 9S, T)  
*Cosmioneis* sp. 2 NR (Fig. 8F)  
 Family: Scoliotropidaceae Mereschkowsky  
*Biremis* D. G. Mann et E. J. COX  
*Biremis* cf. *ridicula* (M. H. Giffen) D. G. Mann (Fig. 5F)  
*Fogedia* Witkowski, Lange-Bertalot, Metzeltin et Bafana  
*Fogedia finmarchica* (Cleve and Grunow) A. Witkowski, Metzeltin et Lange-Bertalot (Fig. 7P)  
*Fogedia geisslerae* A. Witkowski, Metzeltin et Lange-Bertalot (Fig. 7R)  
*Diploneis* Ehrenberg  
*Diploneis crabro* (Ehrenberg) Ehrenberg (Fig. 7A–C)  
*Diploneis litoralis* (Donkin) Cleve (Fig. 7F)  
*Diploneis litoralis* var. *clathrata* (Østrup) Cleve (Fig. 7K)  
*Diploneis notabilis* (Greville) Cleve (Fig. 7U, V)  
*Diploneis obliqua* (J.-J. Brun) Hustedt (Fig. 7M, N)

Table 1 (Continued)

*Diploneis papula* (A. W. F. Schmidt) Cleve (Fig. 7H, I, X)  
*Diploneis papula* var. *constricta* Hustedt (Fig. 7J)  
*Diploneis smithii* (Brébisson) Cleve (Fig. 7G)  
*Diploneis splendida* (W. Gregory) Cleve (Fig. 7D)  
*Diploneis suborbicularis* (W. Gregory) Cleve (Fig. 7L)  
 Family: Naviculaceae Kütz.  
*Navicula* Bory  
*Navicula bipustulata* A. Mann  
*Navicula borneoensis* Hustedt NR (Fig. 8R)  
*Navicula cancellata* Donkin (Fig. 8P)  
*Navicula carinifera* Grunow (Fig. 8L)  
*Navicula* cf. *arenaria* var. *rostellata* Lange-Bertalot  
*Navicula* cf. *bipustulata* A. Mann (Fig. 8U)  
*Navicula* cf. *parva* (Ehrenberg) Ralfs  
*Navicula* cf. *diserta* Hustedt  
*Navicula digitoradiata* (W. Gregory) Ralfs (Fig. 8J)  
*Navicula directa* (W. Smith) Ralfs (Fig. 8W)  
*Navicula distans* (W. Smith) Ralfs (Fig. 8V)  
*Navicula diversistriata* Hustedt (Fig. 5C)  
*Navicula longa* (W. Gregory) Ralfs (Fig. 8X)  
*Navicula parva* (Ehrenberg) Ralfs  
*Navicula pennata* A. Schmidt  
*Navicula rolandii* W. Wunsam, A. Witkowski et Lange-Bertalot (Fig. 8K)  
*Navicula* sp. 1 (Fig. 8S)  
*Navicula torifera* Hustedt NR (Fig. 8Q)  
*Trachyneis* Cleve  
*Trachyneis aspera* (Ehrenberg) Cleve (Fig. 8B)  
*Trachyneis velata* A. Schmidt (Fig. 8C)  
 Family: Pinnulariaceae D. G. Mann  
*Craspedopleura* M. Poulin  
*Craspedopleura* cf. *kryophila* (Cleve) M. Poulin NR (Fig. 9Q)  
*Craspedopleura* sp. NR (Fig. 9R)  
*Oestrupia* Heiden  
*Oestrupia powelli* (Lewis) Heiden  
*Pinnularia* Ehrenb.  
*Pinnularia rectangulata* (W. Gregory) Rabenhorst (Fig. 5G, H)  
*Pinnularia* cf. *cruciformis* (Donkin) Cleve  
*Pinnularia* cf. *trevelyana* (Donkin) Rabenhorst  
 Family: Pleurosigmataceae Mereschowsky  
*Gyrosigma* Hassall  
*Gyrosigma simile* (Grunow) Boyer  
*Pleurosigma* W. Smith  
*Pleurosigma angulatum* var. *genuinum* (Queckett) W. Smith  
*Pleurosigma inflatum* Shadbolt  
*Pleurosigma naviculaceum* Brébisson (Fig. 8D)  
 Family: Scolioneidae D. G. Mann  
*Scolioneis* D. G. Mann  
*Scolioneis brunkseiensis* (Hendey) D. G. Mann  
 Family: Scoliotropidaceae Mereschowsky  
*Progonioia* H.-J. Schrader  
*Progonioia musca* (Gregory) Schrader  
 Family: Sellaphoraceae Mereschowsky  
*Fallacia* Stickle et D. G. Mann  
*Fallacia* cf. *tenera* (Hustedt) D. G. Mann (Fig. 7Z)  
*Fallacia forcipata* (Greville) Stickle et D. G. Mann (Fig. 7S)  
*Fallacia hummii* (Hustedt) D. G. Mann (Fig. 5M)  
*Fallacia inscriptura* (Hendey) Witkowski, Lange-Bertalot et Metzeltin (Fig. 7T)  
*Fallacia litoricola* (Hustedt) D. G. Mann  
*Fallacia nummularia* (Greville) D. G. Mann (Fig. 7O)  
*Fallacia nyella* (Hustedt) D.G. Mann  
*Fallacia oculiformis* (Hustedt) D. G. Mann (Fig. 7Y)  
*Fallacia* sp. 1 (Fig. 5K)  
*Fallacia pseudoforcipata* (Hustedt) D. G. Mann  
*Fallacia schoemania* (Foged) Witkowski (Fig. 7W)  
*Fallacia subforcipata* (Hustedt) D. G. Mann (Fig. 7Q, ZA)

Table 1 (Continued)

*Fallacia versicolor* (Grunow) D. G. Mann  
*Fallacia vittata* (Cleve) D. G. Mann (Fig. 5N)  
 Stauroneis Ehrenberg  
*Stauroneis tackei* (Hustedt) Krammer et Lange-Bertalot  
 Order: Rhopalodiales D. G. Mann  
 Family: Rhopalodiaceae (Karsten) Topachevs'kyj et Oksiyuk  
*Rhopalodia pacifica* Krammer  
 Order: Surirellales D. G. Mann  
 Family: Surirellaceae Kützing  
*Psammodictyon* D. G. Mann  
*Psammodictyon panduriforme* var. *abruptum* (Peragallo) D. G. Mann  
*Psammodictyon panduriforme* var. *latum* (Wittrock) D. G. Mann (Fig. 8N)  
*Psammodictyon roridum* (M. H. Giffen) D. G. Mann (Fig. 8M, O)  
*Psammodictyon* sp. 1  
*Surirella* Turpin  
*Surirella fastuosa* Ehrenberg (Fig. 8A)  
*Surirella fastuosa* var. *recedens* (A. Schmidt) Cleve  
*Surirella* sp. NR (Fig. 9N, O)  
 Order: Thalassiophysales D. G. Mann  
 Family: Catenulaceae Mereschowsky  
*Amphora* Ehrenberg  
*Amphora amoena* Hustedt (Fig. 6M)  
*Amphora arenaria* Donkin (Fig. 6I)  
*Amphora arenicola* Grunow (Fig. 6F)  
*Amphora beaufortiana* Hustedt  
*Amphora biggiba* Grunow (Fig. 6S)  
*Amphora binodis* v. *biggiba* Grunow (Fig. 6V)  
*Amphora contracta* Grunow  
*Amphora crassa* W. Gregory (Fig. 6X)  
*Amphora crassa* W. Gregory var. (?) (Fig. 6K)  
*Amphora delicatissima* Krasske (Fig. 6T)  
*Amphora elegantula* Hustedt (Fig. 6P)  
*Amphora exilitata* Giffen (Fig. 6N)  
*Amphora malectra* var. *constricta* (H. Heiden) Simonsen (Fig. 6R)  
*Amphora marina* W. Smith (Fig. 6L, W)  
*Amphora ostrearia* Brébisson ex Kützing (Fig. 6Q)  
*Amphora pediculus* (Kützing) Grunow ex A. Schmidt  
*Amphora proteus* W. Gregory (Fig. 6B, E, U)  
*Amphora proteus* var. *contigua* Cleve (Fig. 6C)  
*Amphora proteus* var. *kariana* Grunow (Fig. 6A, D)  
*Amphora* sp. 1 (Fig. 6G)  
*Amphora* sp. 2  
*Amphora spectabilis* Gregory (Fig. 6J)  
*Catenula* Mereschowsky  
*Catenula adhaerens* (Mereschkowsky) Mereschowsky  
 Class: Bacillariophyta *incertae sedis*  
 Order: Bacillariophyta *incertae sedis*  
 Family: Bacillariophyta *incertae sedis*  
*Neodetonia*  
*Neodetonia superba* (C. Janisch) S. Blanco NR

the coast of Guadalupe Island located farther north, off the coast of Baja California, for which no particular biogeographical affinity could be determined. There, many tropical forms were observed, v.gr. *Mastogloia* spp., including recent records from the Mexican Caribbean (López-Fuerte, Siqueiros-Beltrones, & Hernández-Almeida, 2013).

According to the above, the recorded species of the epipelagic diatom assemblage in the LGN reflect the transitional biogeographical nature of the region. Likewise, the high species richness of benthic forms in the lagoon is evidenced, considering that only 1 type of substratum was analyzed. Moreover, the

24 still unidentified species also show that much exploration is required for this region on benthic diatoms

In view of the potential regarding this floristic reference for further ecological and biogeographical studies which are necessary for managing protected areas, the scenario calls for estimating ecological parameters of the benthic diatom assemblages comprising other substrates and seasons.

## Acknowledgements

This study was partially financed by Project SIP-20150537 of the IPN where DASB is Comisión de Operación y Fomento de Actividades Académicas (COFAA) and Estímulos al Desempeño de los Investigadores (EDI) fellow. FOLF currently holds a postdoctoral research grant from the Conacyt. The reviews by 2 anonymous referees helped to improve this manuscript.

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