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Taxonomy and systematics

Diversity of benthic diatoms in the Guerrero Negro Lagoon (El Vizcaíno Biosfere 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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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 epipelic 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 epipelic diatoms from the LGN subtidal constitute assemblages with a high species richness and numerous taxa characteristic of subtropical regions.

Keywords: Bacillariophyta; Biogeography; Biosfere 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 esperaría 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 epipélicas mediante microscopia 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 epipélicas en el submareal de LGN conforman taxocenosis con elevadas riquezas de especies, conformadas por numerosos taxones característicos de regiones subtropicales.

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

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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 epipelic 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 epipelic 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 epipelic 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

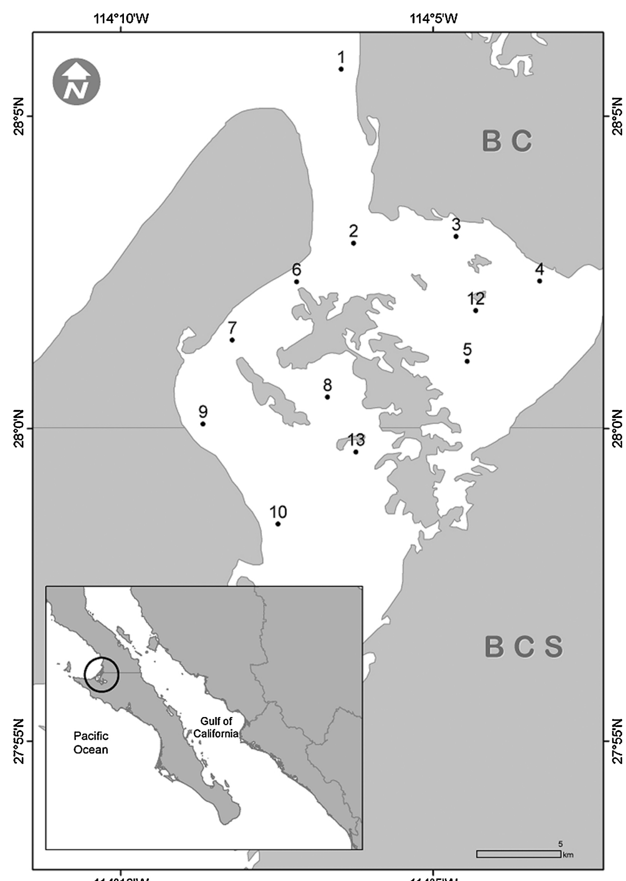

Figure 1. Location of the 12 sampling sites in Laguna Guerrero Negro, BC-BCS, Mexico.

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 where 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

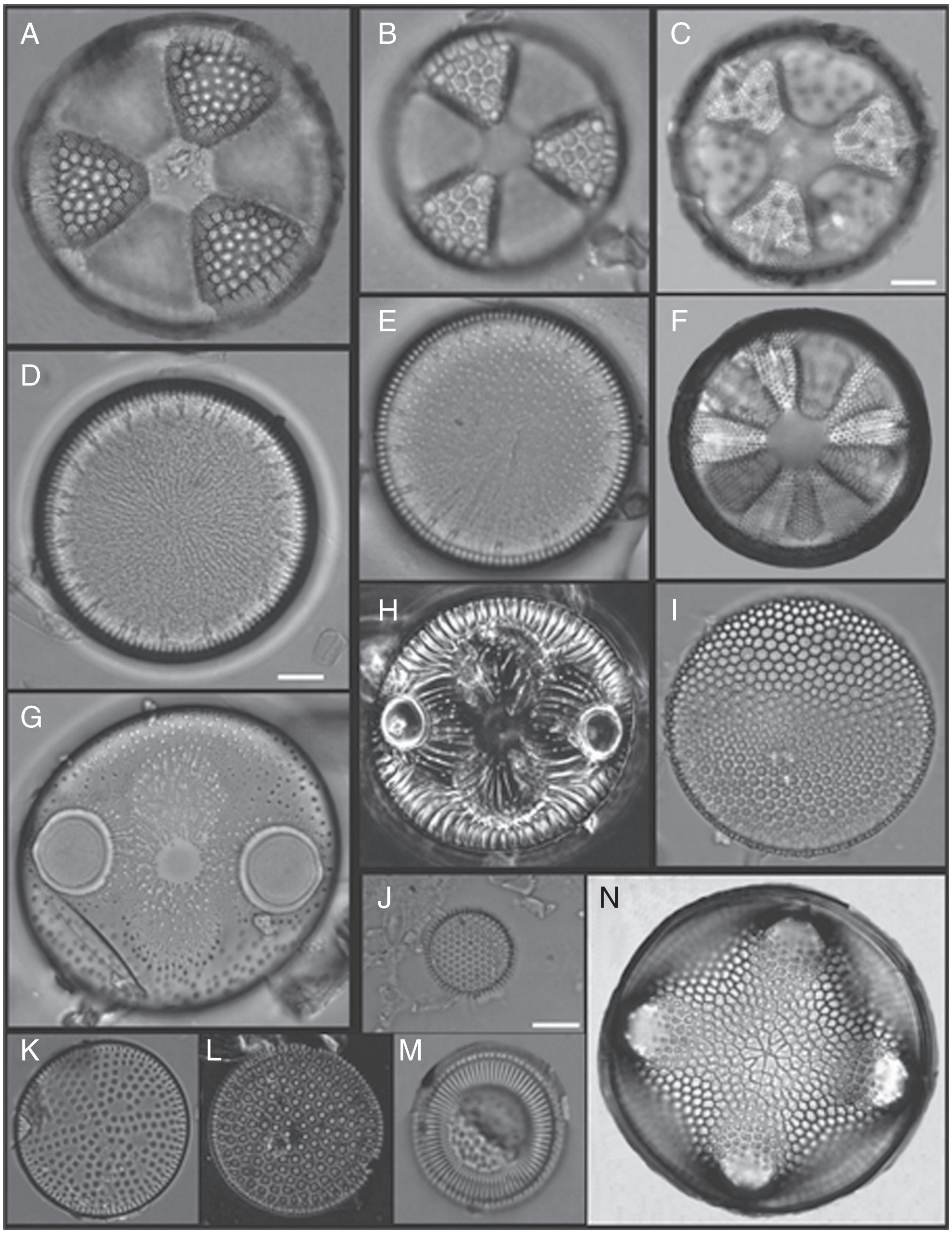

Figure 2. (A) *Actinoptychus aster*, (B) *Actinoptychus senarius*, (C) *Actinoptychus oppenoorthi*, (D, E) *Ehrenbergiulva granulosa*, (F) *Actinoptychus adriaticus*, (G) *Auliscus caelatus* var. *strigillata*, (H) *Auliscus punctatus*, (I) *Coscinodiscus radiatus*, (J) *Shionodiscus oestrupii*, (K)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

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 ≥ 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: Hendey (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 *Algaease* 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×.

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).

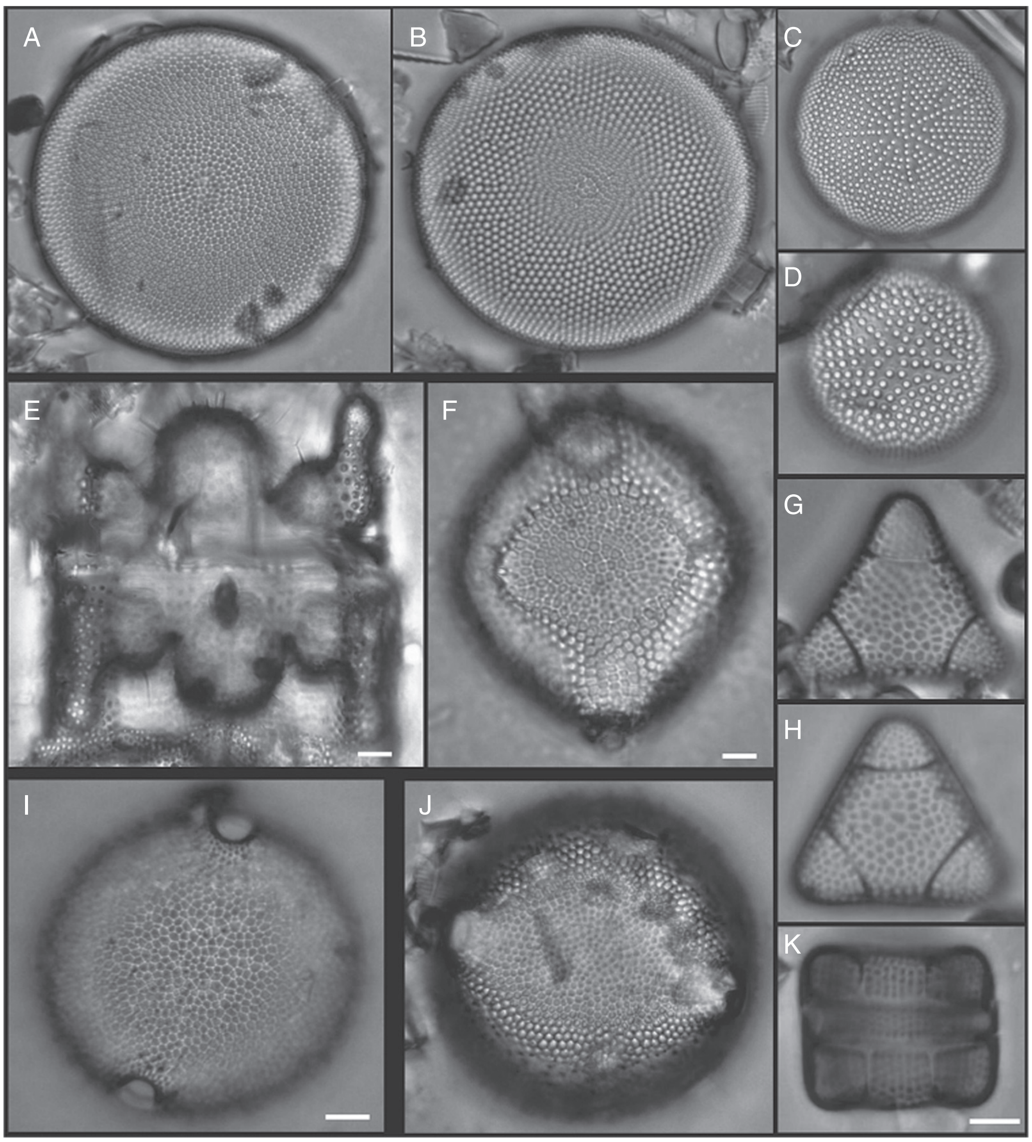

Figure 3. (A, B) *Actinocyclus curvatulus*, (C) *Actinocyclus octonarius* var. *tenellus*, (D) *Actinocyclus ralfsii* var. *minutae*, (E) *Biddulphia tuomeyi*, (F) *Biddulphia rhombus*, (I, J) *Cerataulus californicus*, (G, H, K) *Trigonium alternans*. Bars = 10 μm.

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

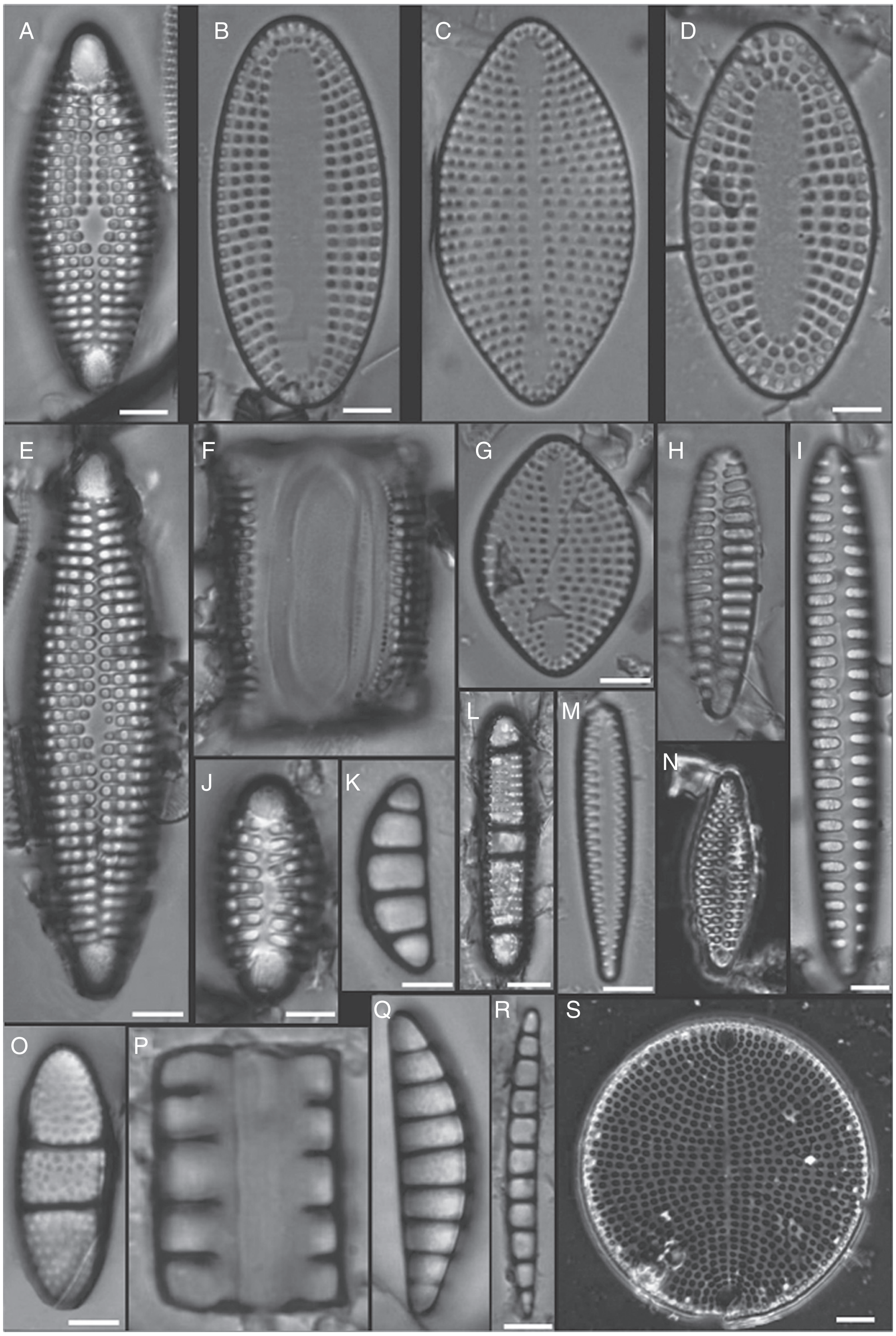

Figure 4. (A, E, F, J) *Dimeregramma minor* var. *minor*, (B, D) *Delphineis fasciola* var. *australis*, (C, G) *Delphineis surirella*, (H) *Opephora pacifica*, (I) *Opephora schwartzii*, (K, P, Q) *Eunotogramma laevis*, (L) *Plagiogramma wallichianum*, (M) *Opephora marina*, (N) *Dimeregramma* sp.,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

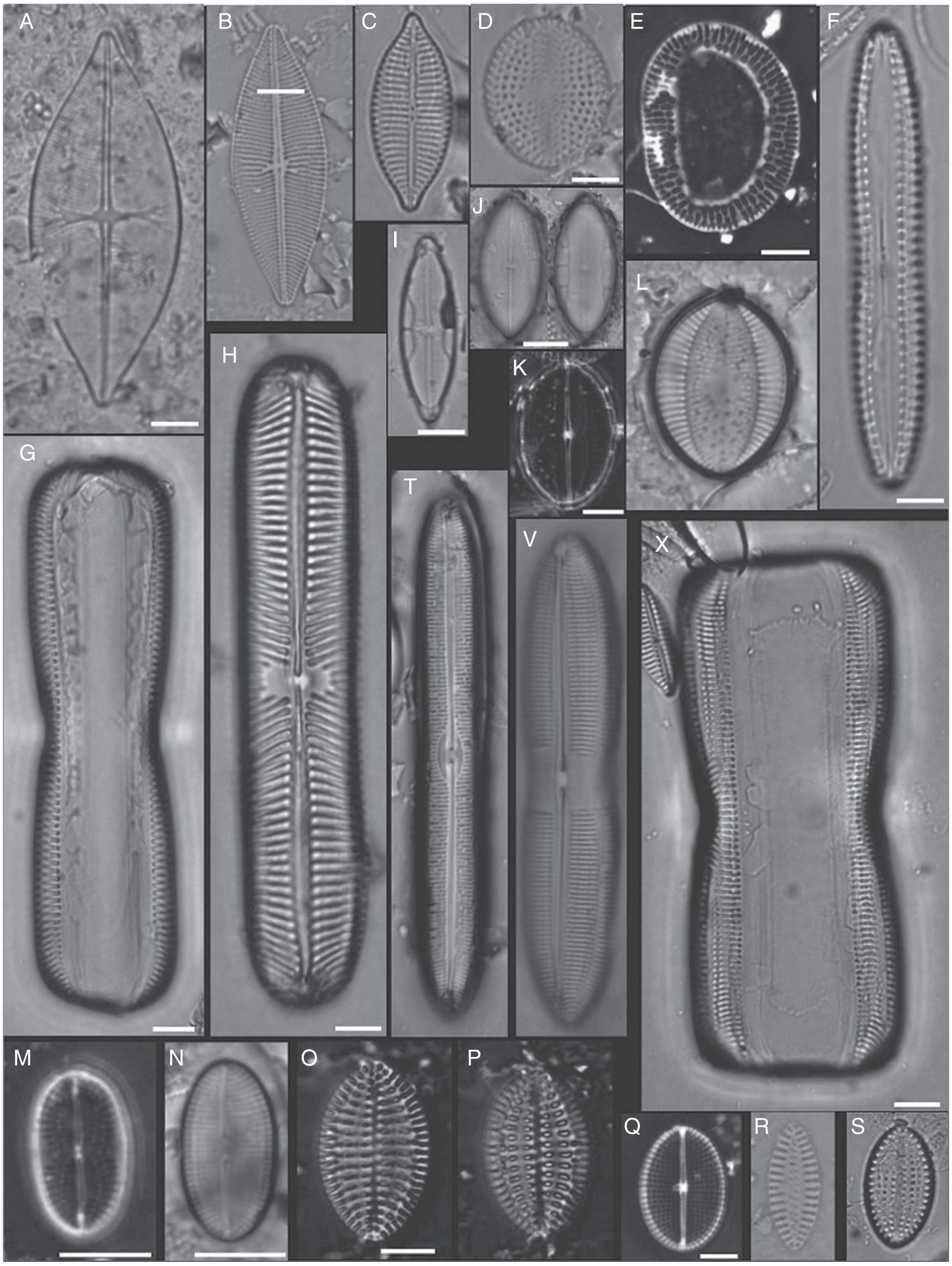

Figure 5. (A) *Achnanthes danica*, (B) *Achnanthes fimbriata*, (C) *Navicula diversistriata*, (D) *Anorthoneis eccentrica*, (E) *Anorthoneis hyalina*, (F) *Biremis* cf. *ridicula*, (G, H) *Pinnularia rectangulata*, (I) *Mastogloia gieskesii*, (J) *Mastogloia pusilla*, (K) *Fallacia* sp., (L) *Cocconeis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

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 epipelic 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.

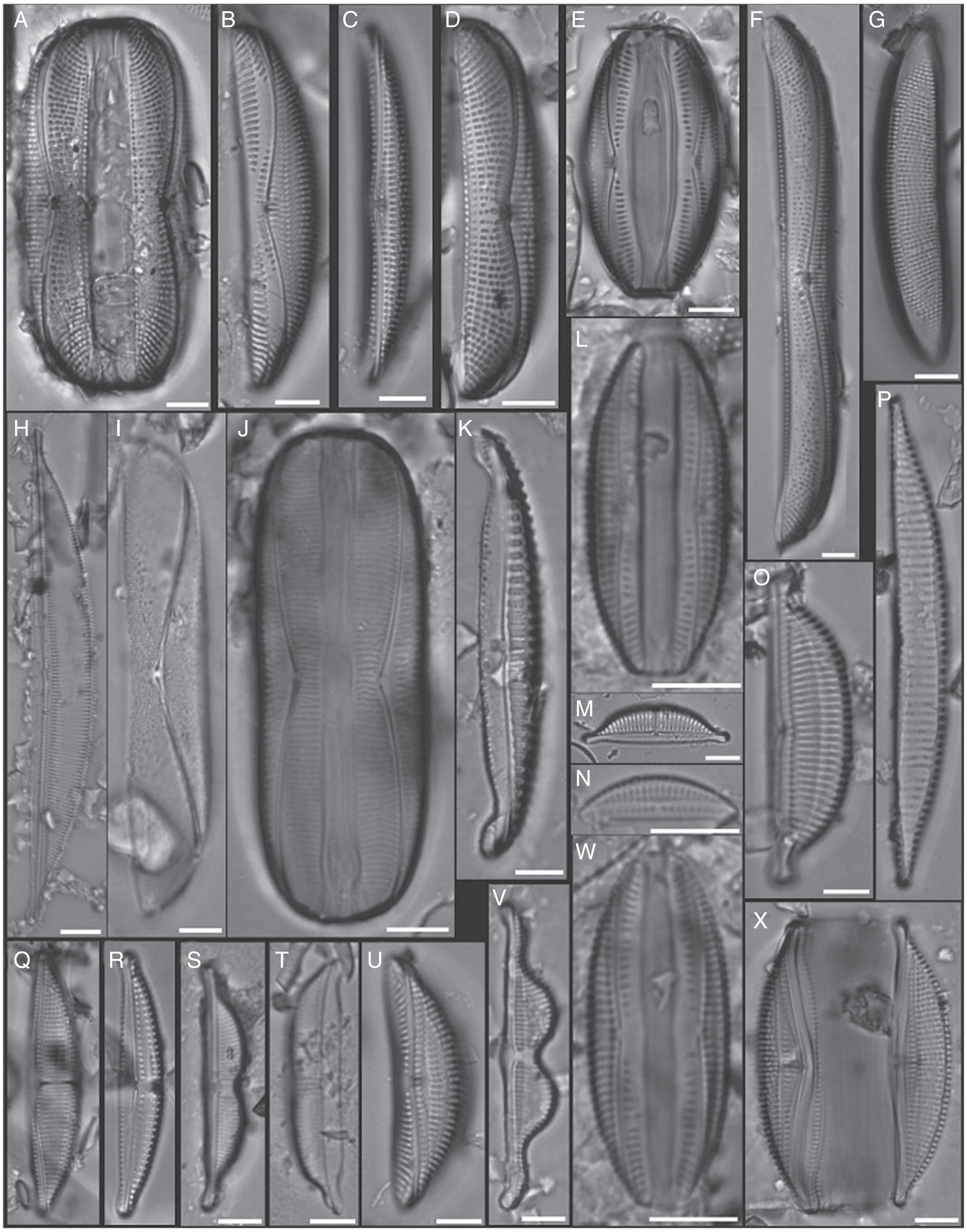

Figure 6. (A, D) *Amphora proteus* var. *kariana*, (B, E, U) *Amphora proteus*, (C) *Amphora proteus* var. *contigua*, (F) *Amphora arenicola*, (G) *Amphora* sp. 1, (H) *Halamphora terroris*, (I) *Amphora arenaria*, (J) *Amphora spectabilis*, (K) *Amphora crassa* var.? (L, W) *Amphora marina*, (M) *Amphora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

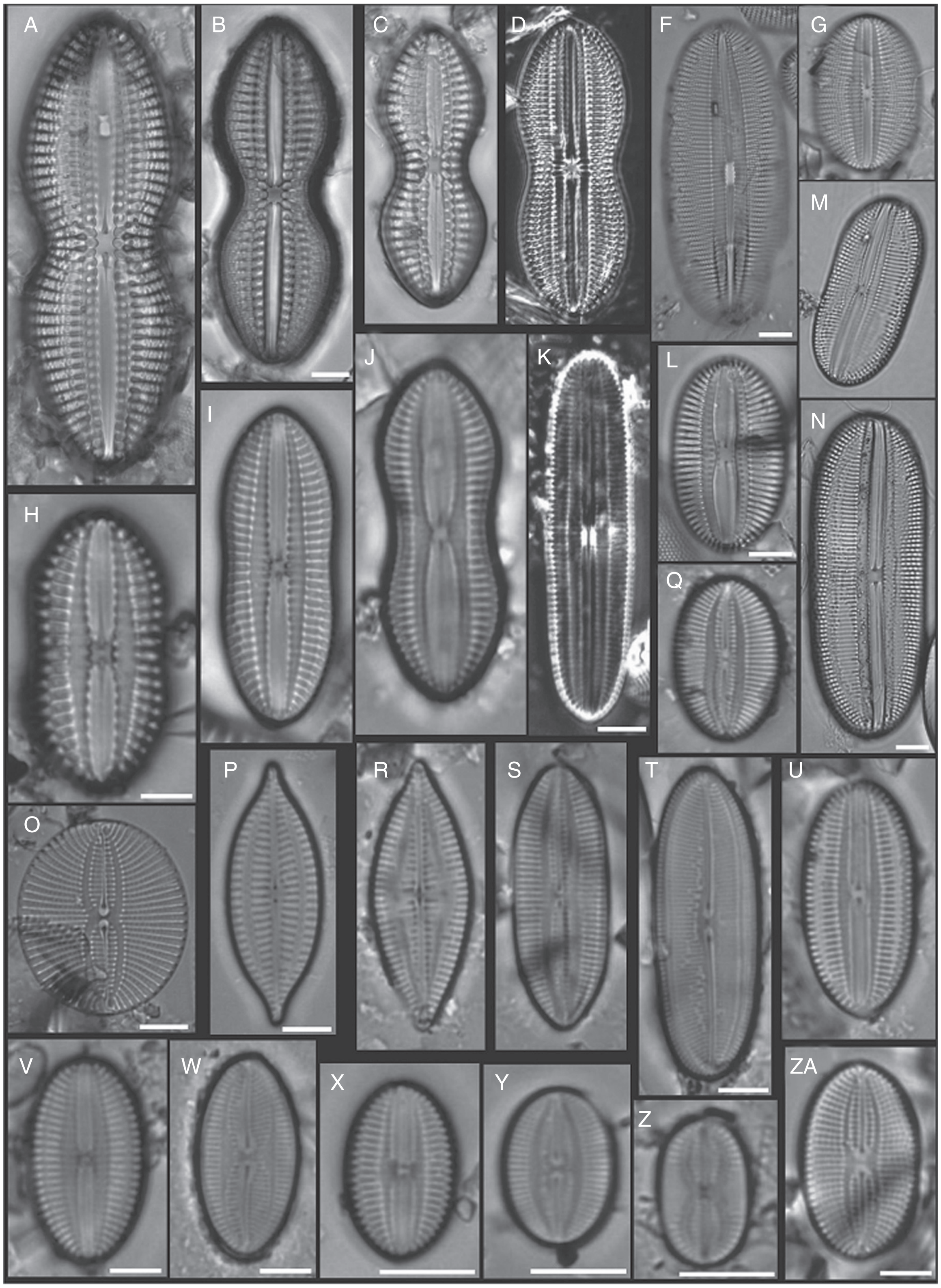

Figure 7. (A–C) *Diploneis crabro*, (D) *Diploneis splendida*, (F) *Diploneis litoralis*, (G) *Diploneis smithii*, (H, I, X) *Diploneis papula*, (J) *Diploneis papula* var. *constricta*, (K) *Diploneis litoralis* var. *clathrata*, (L) *Diploneis suborbicularis*, (M, N) *Diploneis obliqua*, (O) *Fallacia 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 μm.

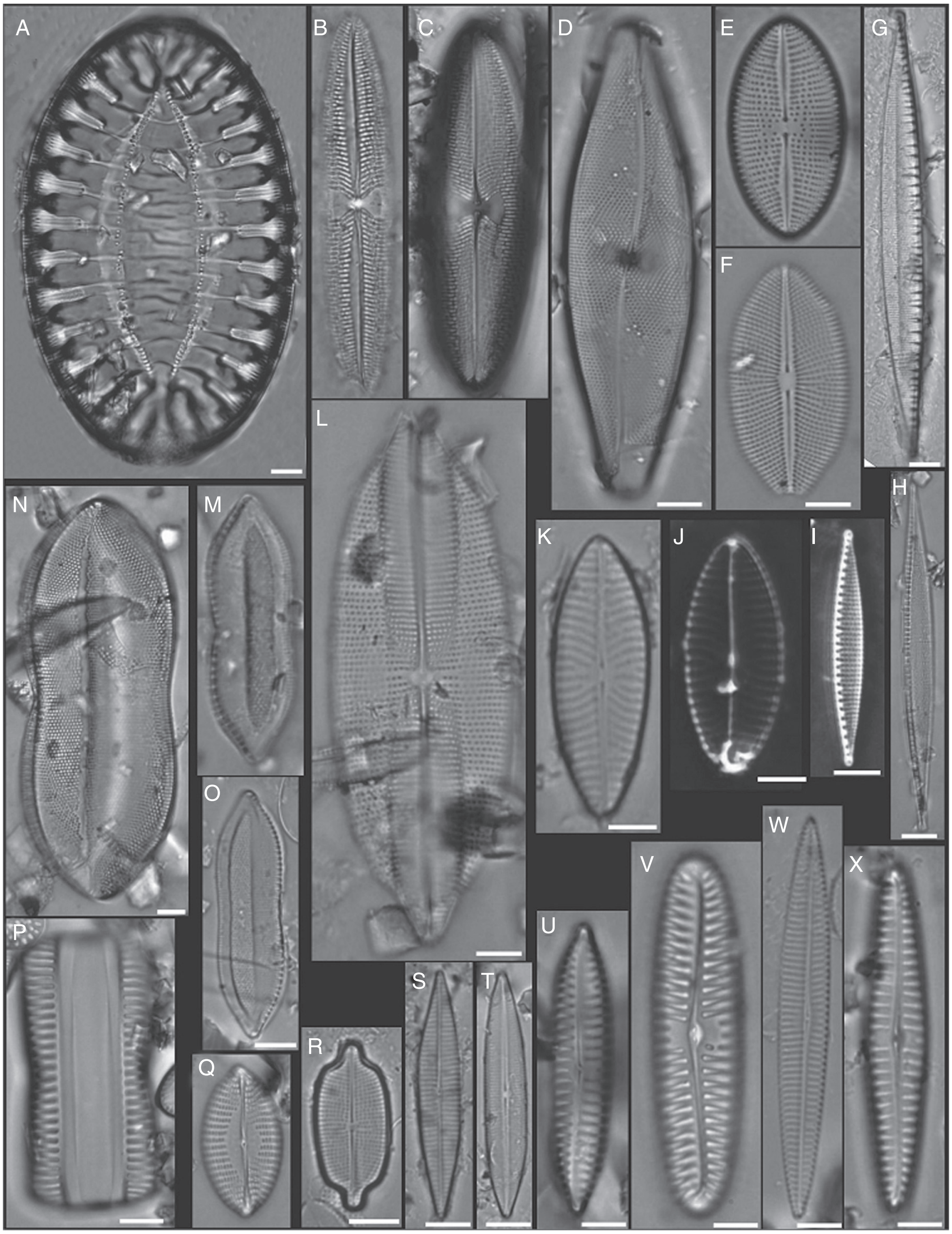

Figure 8. (A) *Surirella fastuosa*, (B) *Trachyneis aspera*, (C) *Trachyneis velata*, (D) *Pleurosigma naviculaceum*, (E) *Petroneis granulata*, (F) *Cosmioneis* sp. 2, (G) *Nitzschia fluminensis*, (H) *Nitzschia sigma*, (I) *Nitzschia grossestriata*, (J) *Navicula digitoradiata*, (K) *Navicula rolandii*, (L) *Navicula carinifera*, (M, O) *Psammodictyon roridum*, (N) *Psammodyction 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 µm.

Discussion

The above results back up the proposed hypothesis that: a) the epipelic 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

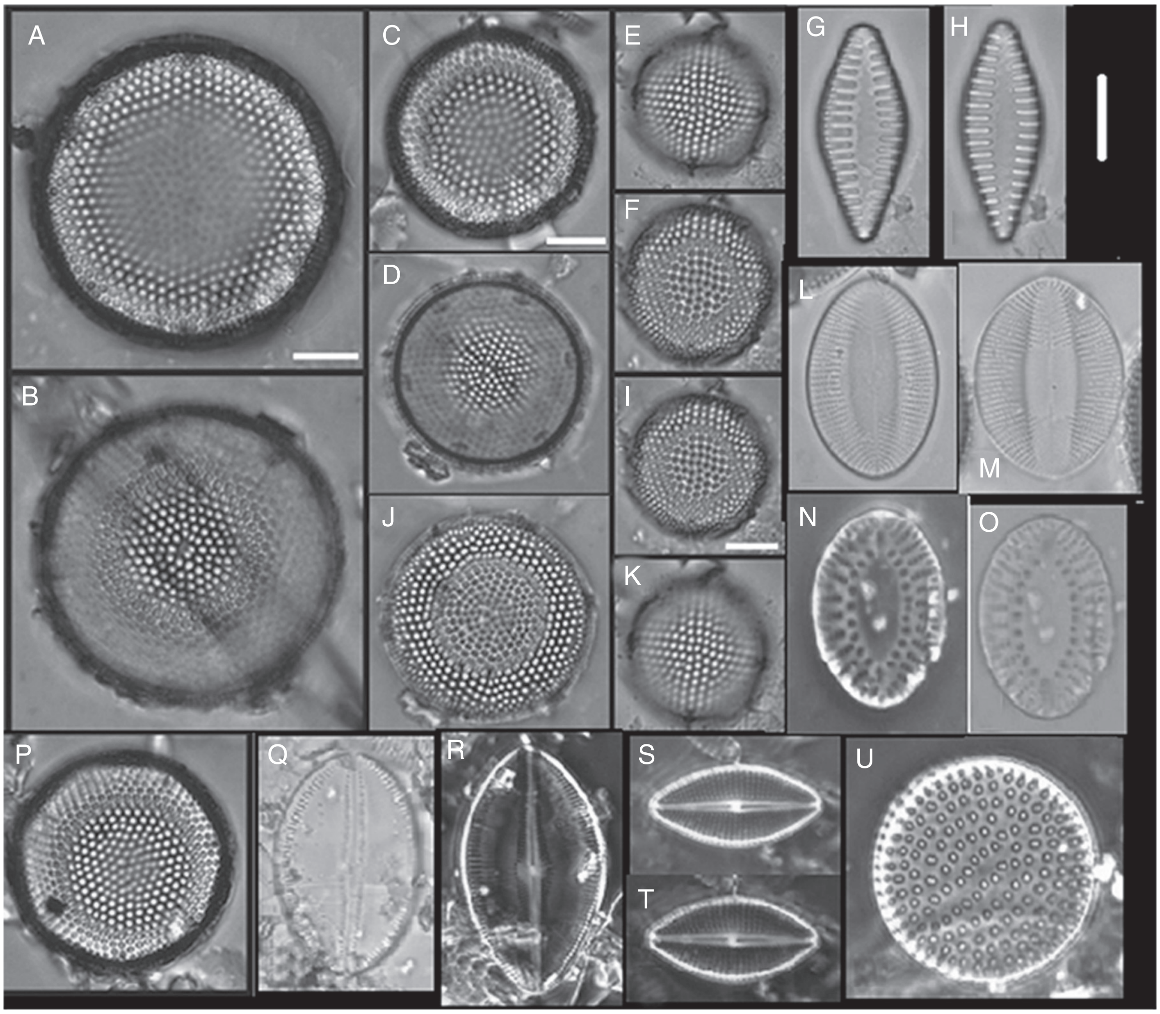

Figure 9. (A–F, I–K, P) *Aulacodiscus* sp., (G, H) *Opephora* sp., (L, M) *Cocconeis* cf. *pelta*, (N, O) *Surirella* sp., (Q) *Cocconeis californica* var. *kerguelensis*, (R) *Craspedopleura* sp, (S, T) *Cosmioneis* sp. 1, U) *Neodetonula superba*. Bars = 10 μm.

as tychoplankton, either in the Gulf of California (Moreno-Ruíz et al., 1996) e.gr., 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 curvatulus 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 oppenoorthi 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) Brébison
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 nitzschioides (Grunow) Mereschkowsky
Order: Climacospheniales Round
Family: Climacospheniaceae Round
Climacosphenia Ehrenberg
Climacosphenia moniligera 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 Buktiyarova
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
Amphicocconeis
Amphicocconeis 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. *kerguelensis* Heiden (Fig. 9Q)
Cocconeis cf. *nugalas* 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 peltoides Hustedt
Cocconeis pinnata W. Gregory ex Greville
Cocconeis placentula var. *euglypta* (Ehrenberg) P.T. Cleve
Cocconeis pseudomarginata Gregory
Cocconeis sp.1
Cocconeiopsis Witkowski, Lange-Bertalot et Metzeltin
Cocconeiopsis cf. *kantsinensis* (Giffen) Witkowski
Cocconeiopsis patrickae (Hustedt) A. Witkowski, Lange-Bertalot et Metzeltin (Fig. 5Q)
Cocconeiopsis 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 approximatoides (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* Hiustedt (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: Scolioneidaceae D. G. Mann
Scolioneis D. G. Mann
Scolioneis brunkseiensis (Hendey) D. G. Mann
Family: Scoliotropidaceae Mereschkowsky
Progonoia H.-J. Schrader
Progonoia musca (Gregory) Schrader
Family: Sellaphoraceae Mereschkowsky
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 schoemaniana (Foged) Witkowski (Fig. 7W)
Fallacia subforcipata (Hustedt) D. G. Mann (Fig. 7Q, ZA)
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 Mereschkowsky
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. *bigibba* 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 maletracta 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 Mereschkowsky
Catenula adhaerens (Mereschkowsky) Mereschkowsky
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 epipelic 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.

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