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Article

# First Account of Epibiotic Diatoms Taxa from the Shells of Green Swimming Crabs *Callinectes bellicosus* (Stimpson 1859) (Decapoda, Portunidae)

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**Abstract:** Diatoms are among the most common epibionts and have been recorded on the surfaces of various living substrates, either plants or animals. However, said studies are still scarce in view of the many substrata available. In this study, epibiotic diatoms living on *Callinectes bellicosus* were identified for the first time from a subtropical coastal lagoon in northwest Mexico. We tested the null hypothesis that the diatom flora living on the shells of *C. bellicosus* would not be similar to that recorded for mangrove sediments, its typical habitat. The epibiotic diatoms were brushed off from the carapaces of two specimens, acid-cleaned, mounted in synthetic resin, and identified based on frustule morphology. In this way, 106 taxa from 45 genera were recorded, including 24 singletons, and six new records for the Mexican northwest region. The best-represented genera were *Nitzschia* (10 taxa), *Mastogloia* (9), *Diploneis* (7), *Navicula* (7), *Amphora* (5), *Cocconeis* (5), *Tryblionella* (4), and *Gyrosigma* (4). Species composition included 93% of local taxa, thus refuting the proposed hypothesis and supporting the alternate one. Although the estimated species richness was lower than in sediments, it deems the green crab carapace a favorable substrate for the growth of benthic diatoms.

**Keywords:** benthic diatoms; coastal lagoon; crustaceans; epibiosis; Mexico

## 1. Introduction

The interaction between an organism (basibiont) and those that live on it (epibionts) is known as epibiosis. This type of relationship has been documented as a common phenomenon in aquatic ecosystems, especially in marine environments [1], and the phenomenon of adhesion of microalgae (including diatoms) to living substrata is well studied [2]. Diatoms represent a principal constituent of microphytobenthos, and a common habitat of theirs are living substrata, sometimes plants and algae (epiphytic diatoms) and other times animals (epizoic diatoms) [2,3]. In this vein, the importance of epizoic growth of diatoms has been described for many types of hosts including insects, turtles, diving birds, marine mammals [4–9], and crustaceans such as amphipoda, cladocerans, copepods, decapods, and hoplocarids [10–14]. Studies on crabs' epibiota have focused on the macro-epibionts, seeking to elucidate their masking behavior [1,15]. In the Gulf of California, the type and quantity of pieces used by decorator crabs (Majidae) was studied [16], observing the dominance of macroalgae and sponges. Others have focused on the adherence capability of epibionts such as diatoms. However, little was hitherto known of the species composition, seasonality, or the types of habitats in which epizoic diatoms occur on green swimming crabs in any area. Moreover, further ecological research on the interactive relations between epibiotic diatoms and their basibionts requires basic

floristic information in order to carry out formal biodiversity or ecological studies related to the consequences of using animal surfaces as substrate by benthic diatoms. Given the challenge that this presents, in general, there is scarce information on diatom epibiosis with crabs [17,18] inasmuch the species composition and richness of the epibiotic diatoms has received very little attention.

The green swimming crab *Callinectes bellicosus* Stimpson 1859 (Decapoda: Portunidae) is distributed along the Eastern Pacific, ranging from California, USA, to the Tehuantepec Gulf, Oaxaca, Mexico. It inhabits estuaries, coastal lagoons, and soft bottoms up to 90 m deep [19,20], and adults can live for 3–4 years [19,21]. The species is omnivorous, as well as an opportunistic predator, often burrowing down superficially in the sediments to wait for its prey [22]. This behavior makes green swimming crabs not only accessible but suitable as a substrate for a variety of small marine biota, which they may carry on their carapaces, such as various algal forms [23,24], including benthic diatoms. However, up to now, the species composition of epibiotic diatoms of green swimming crabs had remained unexplored. Thus, it is unknown how many diatom species or forms may be found that are either truly epizoic or just opportunistic, and the differential benefits that these may have in terms of survival, reproduction, or dispersal. The basic floristics of epibiotic diatoms will surely provide a reliable platform to undertake further ecological studies between them and this basibiont.

According to the above, in the present study the epibiotic diatom flora living on carapaces of *C. bellicosus* from the subtropical coastal lagoon of La Paz, BCS, Mexico was investigated. The related background on this shows that benthic diatom flora from the northwest region of Mexico has been previously studied in several localities including mangrove environments [25]. In these and later investigations around 1500 benthic diatom taxa have been recorded, which provide a reliable reference for our work. Moreover, the structure of the benthic diatom assemblages has been described based on the characteristic taxa in a way that a typical benthic diatom flora can be recognized for the region. So, considering the observed distribution of the benthic diatom taxa on the various substrates inspected in said works we asked if the diatom flora living on the shells of green swimming crabs would be similar to that recorded for mangrove sediments, its typical habitat in the northwest region of Mexico. Thus, we tested the null hypothesis that the diatom flora living on the carapaces of green swimming crabs would not be similar to that recorded historically for the mangrove sediments in the southern Baja California Peninsula (northwest region of Mexico). This abduction ( $H_0$ ) responds to the influence that mobility of the basibiont and constant exposure of the colonized surface, plus the discrete temporal sampling that could exhibit a seasonal variation in species composition of the colonizing diatoms, that may result in a difference in species composition between the typical diatom flora and that living on the inspected green crab specimens.

## 2. Materials and Methods

The La Paz coastal lagoon forms part of Bahía de La Paz, a shallow-bottom water body that reaches 10 m deep with a dominant soft bottom. In the northwest part of the lagoon the mangrove swamp of Zacatecas Estuary is located (24°10'27" N, 110° 26' 06" W) (Figure 1). There, in September 2022, two male specimens of *C. bellicosus* (Figure 2) were captured using a hand net and identified according to [20].

Diatoms were separated from the cephalothoraxes and chelae of the swimming crabs using a toothbrush to generate a compound sample of the two specimens. The brushed-off material was placed in a 250 mL flask and preserved in commercial 70% ethanol. Afterward, to eliminate organic matter that would obstruct visibility of the diatom frustules, the compound sample was oxidized by adding 3 mL of 70% nitric acid to 2 mL of sample and then heating with a burner to the boiling point, where it was held until the emission of gas subsided, indicating the end of the reaction (ca. 3 min). The oxidized sample was rinsed repeatedly with deionized water until reaching a circumneutral pH. Then, six mounted slides were inspected under a Zeiss® Axio Lab A1 (Zeiss, Germany) compound microscope equipped with phase contrast and a Canon 5D Mark II camera (Canon, Japan). Diatoms were identified based on frustule morphology using classic and recent references: [26–45].

A systematic list of the diatom taxa was constructed following practical formats [46–49]. Nomenclatural updates for the identified taxa were performed based on [www.algaebase.org](http://www.algaebase.org) [50] and

www.marinespecies.org [51]. This is complemented by an iconographic catalog of all the recorded taxa (Table 1).

### 3. Results

The inspection of the brushed-off material from the green-crab's shell yielded 106 diatom taxa belonging to 46 genera (Table 1; Figures 3–18). At class level, 91% (97 taxa) were Bacillariophyceae, 5% (5) Coscinodiscophyceae, and 4% (4) Mediophyceae. The taxonomic families with most species were Bacillariaceae (with 17), Mastogloioaceae (9), Naviculaceae (9), and Diploneidaceae (8). Meanwhile, the highest-represented genera in terms of the number of species were *Nitzschia* (10), *Mastogloia* (9), *Diploneis* (7), *Navicula* (7), *Amphora* (5), *Cocconeis* (5), *Tryblionella* (4) and *Gyrosigma* (4), which accounted for 49% of all taxa. We found that 24 genera were singletons, i.e., they included a single taxon, representing 23% of all the records (Table 1). The most frequent species were *Navicula normaloides* (Figure 13E) and *N. platyventris* (Figure 13H–K). Meanwhile, *Biddulphia californica* (Figure 3A,B), *Campylodiscus subangularis* (Figure 18L,O), *Melosira westii* var. *quadrata* (Figure 3H,I), *Nitzschia ligowskii* (Figure 17M,N), *Petronis besarensis* (Figure 9E–G) and *Tryblionella pararostrata* (Figure 16N) are new records for the study area and the northwestern Mexican region. This means that 93 % of the diatom taxa that we found on the shell of the green crabs are also characteristic or typical of the local epipelagic diatom flora recorded for mangrove sediments in the region. This constitutes evidence that refutes the posed null hypothesis, thus supporting an alternate hypothesis.

**Table 1.** Systematic list of epibiotic diatom taxa found on carapaces of green swimming crabs (*Callinectes bellicosus*) from La Paz lagoon, Mexico. NR=new recor for the Mexican northwestern, SG=singleton (genus).

#### **Division Bacillariophyta** Silva

##### **Subdivision Bacillariophytina** Medlin & Kaczmarska

##### **Class Coscinodiscophyceae** Round et Crawford in Round et al. emend. Medlin & Kaczmarska

Order Coscinodiscales Round & Crawford in Round et al.

Family Heliopeltaceae Smith

Genus *Actinoptychus* Ehrenberg

##### ***Actinoptychus senarius* (Ehrenberg) Ehrenberg** (Figure 3E,F; SG)

Order Melosirales Crawford in Round et al.

Family Melosiraceae Kützing emend. Crawford in Round et al.

Genus *Melosira* Agardh

##### ***Melosira distans* var. *lyrata* (Ehrenberg) Müller** (Figure 3G)

##### ***Melosira nummuloides* Agardh** (Figure 3J)

##### ***Melosira westii* var. *quadrata* Jurilj** (Figure 3H,I; NR)

Order Paraliales Crawford

Family Paraliaceae Crawford

Genus *Paralia* Heiberg

##### ***Paralia sulcata* (Ehrenberg) Cleve** (Figure 3K,L; SG)

**Class Mediophyceae** (Jousé & Proshkina-Lavrenko) Medlin & Kaczmarska

Order Biddulphiales Krieger

Family Biddulphiaceae Kützing

Genus *Biddulphia* Gray

##### ***Biddulphia californica* (Schmidt) Wolle** (Figure 3A,B; SG; NR)

Order Anaulales Round & Crawford

Family Anaulaceae (Schütt) Lemmermann

Genus *Eunotogramma* Weisse

##### ***Eunotogramma litorale* Amspoker** (Figure 4U,V; SG)

Order Eupodiscales Nikolaev & Harwood

Family Odontellaceae Sims, Williams & Ashworth

Genus *Odontella* Agardh

##### ***Odontella aurita* (Lyngbye) Agardh** (Figure 3D; SG)

- Class Bacillariophyceae** Haeckel emend. Medlin & Kaczmarska  
 Order Achnanthales Silva  
 Family Achnanthaceae Kützing  
 Genus *Achnanthes* Bory
- Achnanthes angustata* Bory (Figure 5P)  
*Achnanthes pseudogroenlandica* Hendey (Figure 5E–O)  
*Achnanthes yaquiniensis* McIntire & Reimer (Figure 5A–D)  
*Achnanthes pyrenaica* Hustedt (Figure 5Z)  
 Genus *Planothidium* Round & Bukhtiyarova  
*Planothidium delicatulum* (Kützing) Round & Bukhtiyarova (Figure 5T–Y)  
*Planothidium hauckianum* (Grunow) Bukhtiyarova (Figure 5Q–S)  
 Family Cocconeidaceae Kützing  
 Genus *Cocconeis* Ehrenberg
- Cocconeis neodiminuta* Krammer (Figure 6P,Q)  
*Cocconeis lineata* Ehrenberg (Figure 6G–K)  
*Cocconeis pseudodiruptoides* Foged (Figure 6R,S)  
*Cocconeis pseudomarginata* Gregory (Figure 6L,O)  
*Cocconeis scutellum* Ehrenberg (Figure 6A–F)  
 Order Bacillariales Hendey emend. Mann in Round et al.  
 Family Bacillariaceae Ehrenberg  
 Genus *Homoeocladia* Agardh, nom. rejic.
- Homoeocladia distans* (Gregory) Kuntze (Figure 17D,E)  
 Genus *Nitzschia* Hassall
- Nitzschia carnicobarica* Desikachary & Prema (Figure 17O–R)  
*Nitzschia frustulum* (Kützing) Grunow (Figure 17T–W)  
*Nitzschia fusoides* Ehrlich (Figure 4Y,Z)  
*Nitzschia ligowskii* Witkowski, Lange-Bertalot, Kociolek & Brzezinska (Figure 17M,N; NR)  
*Nitzschia persuadens* Cholnoky (Figure 17K,L)  
*Nitzschia longissima* (Brébisson ex Kützing) Grunow (Figure 17Y,Z)  
*Nitzschia scalpelliformis* Grunow (Figure 17S)  
*Nitzschia sigma* (Kützing) Smith (Figure 17B,C)  
*Nitzschia subconstricta* Desikachary & Prema (Figure 17I,J)  
*Nitzschia vidovichii* (Grunow) Grunow (Figure 17A)  
 Genus *Psammodictyon* Mann
- Psammodictyon constrictum* (Gregory) Mann (Figure 16D,E)  
*Psammodictyon panduriforme* (Gregory) Mann (Figure 16A–C)  
 Genus *Tryblionella* Smith
- Tryblionella coarctata* (Grunow) Mann (Figure 16F–L)  
*Tryblionella hungarica* (Grunow) Frenguelli (Figure 16O,P)  
*Tryblionella hyalina* (Amossé) Ohtsuka (Figure 16M)  
*Tryblionella pararostrata* (Lange-Bertalot) Clavero & Hernández-Mariné (Figure 16N; NR)  
 Order Cymbellales Mann in Round et al.  
 Family Cymbellaceae Greville  
 Genus *Navicymbula* Krammer
- Navicymbula pusilla* var. *lata* Krammer (Figure 14L; SG)  
 Family Rhoicospheniaceae Chen & Zhu  
 Genus *Gomphoseptatum* Medlin
- Gomphoseptatum aestuarii* (Cleve) Medlin (Figure 17X; SG)  
 Order Lyrellales Mann  
 Family Lyrellaceae Mann  
 Genus *Lyrella* Karayeva
- Lyrella exsul* (Schmidt) Mann (Figure 9A,B; SG)  
 Genus *Petroneis* Stickle & Mann
- Petroneis besarensis* (Giffin) Witkowski, Lange-Bertalot & Witkowski (Figure 9E–G; NR)  
*Petroneis granulata* Mann, nom. illeg. (Figure 9C,D)

- Order Mastogloiales Mann  
 Family Mastogloiaceae Mereschkowsky  
 Genus *Mastogloia* Thwaites ex Smith  
*Mastogloia acutiuscula* var. *elliptica* Hustedt (Figure 12M,N)  
*Mastogloia angulata* Lewis (Figure 12A,B)  
*Mastogloia apiculata* Smith (Figure 12G,H)  
*Mastogloia binotata* (Grunow) Cleve (Figure 12C,D)  
*Mastogloia exigua* Lewis (Figure 12E,F)  
*Mastogloia gieskesii* Cholnoky (Figure 12P)  
*Mastogloia braunii* Grunow (Figure 12J,O)  
*Mastogloia robusta* Hustedt (Figure 12K,L)  
*Mastogloia pisciculus* Cleve (Figure 12I)  
 Order Naviculales Bessey emend. Mann in Round et al.  
 Family Diploneidaceae Mann in Round et al.  
 Genus *Diploneis* (Ehrenberg) Cleve  
*Diploneis coffeiformis* (Schmidt) Cleve (Figure 8I)  
*Diploneis gruendleri* (Schmidt) Cleve (Figure 8A,F)  
*Diploneis gravelleana* Hagelstein (Figure 8B–E)  
*Diploneis incurvata* (Gregory) Cleve (Figure 8J)  
*Diploneis nitescens* (Gregory) Cleve (Figure 8P)  
*Diploneis obliqua* (Brun) Hustedt (Figure 8G,H)  
*Diploneis smithii* (Brébisson) Cleve (Figure 8K–O)  
 Family Naviculaceae Kützing emend. Mann in Round et al.  
 Genus *Navicula* Bory  
*Navicula abunda* Hustedt (Figure 13G)  
*Navicula cancellata* Donkin (Figure 13A,B)  
*Navicula cincta* Pantocsek, nom. illeg. (Figure 13F)  
*Navicula longa* var. *irregularis* Hustedt (Figure 13C)  
*Navicula normaloides* Cholnoky (Figure 13E)  
*Navicula pennata* Schmidt (Figure 13D)  
*Navicula platyventris* Meister (Figure 13H–K)  
 Genus *Trachyneis* Cleve  
*Trachyneis aspera* (Ehrenberg) Cleve (Figure 15D,E)  
*Trachyneis velata* (Schmidt) Cleve (Figure 15B,C)  
 Family Naviculaceae Kützing  
 Genus *Seminavis* Mann  
*Seminavis robusta* Danielidis & Mann (Figure 7D–G; SG)  
 Family Plagiotropidaceae Mann  
 Genus *Plagiotropis* Pfitzer nom. illeg.  
*Plagiotropis pusilla* (Gregory) Kuntze (Figure 15A; SG)  
 Family Pleurosigmataceae Mereschkowsky  
 Genus *Gyrosigma* Hassall  
*Gyrosigma balticum* (Ehrenberg) Rabenhorst (Figure 11A)  
*Gyrosigma eximium* (Thwaites) Boyer (Figure 11F–H)  
*Gyrosigma peisonis* (Grunow) Hustedt (Figure 11D)  
*Gyrosigma variistriatum* Hagelstein (Figure 11B)  
 Genus *Pleurosigma* Smith nom. et typ. cons  
*Pleurosigma diversetriatum* Meister (Figure 11E)  
*Pleurosigma salinarum* (Grunow) Grunow (Figure 11C)  
 Family Berkeleyaceae Mann  
 Genus *Parlibellus* Cox  
*Parlibellus rhombicula* (Hustedt) Witkowski, Lange-Bertalot & Metzeltin (Figure 7H; SG)  
 Family Brachysiraceae Mann in Round et al.  
 Genus *Brachysira* Kützing  
*Brachysira* cf. *estoniarum* Witkowski, Lange-Bertalot & Metzeltin

- (Figure 13N,O; SG)  
 Family Diadesmidaceae Mann in Round et al.  
 Genus *Caloneis* Cleve
- Caloneis linearis* (Cleve) Boyer** (Figure 7A–C; SG)  
 Family Scoliotropidaceae Mereschkowsky  
 Genus *Biremis* Mann & Cox
- Biremis ridicula* (Giffen) Mann** (Figure 13L,M; SG)  
 Order Rhopalodiales Mann in Round et al.  
 Family Rhopalodiaceae (Karsten) Topachevskiy & Oksiyuk  
 Genus *Rhopalodia* Müller
- Rhopalodia acuminata* Krammer** (Figure 18B)  
***Rhopalodia gibberula* (Ehrenberg) Müller** (Figure 18A)  
***Rhopalodia musculus* (Kützing) Müller** (Figure 18C)  
 Order Surirellales Mann in Round et al.  
 Family Entomoneidaceae Reimer  
 Genus *Entomoneis* Ehrenberg
- Entomoneis paludosa* (Smith) Reimer** (Figure 15F,G; SG)  
 Family Surirellaceae Kützing  
 Genus *Campylodiscus* Ehrenberg ex Kützing
- Campylodiscus subangularis* Cleve & Möller** (Figure 18L–O, S; NR)  
 Genus *Coronia* (Ehrenberg ex Grunow) Ehrenberg
- Coronia ambigua* (Greville) Ruck & Guiry** (Figure 18D–K; SG)  
 Order Thalassiophysales Mann in Round et al.  
 Family Catenulaceae Mereschkowsky  
 Genus *Amphora* Ehrenberg ex Kützing
- Amphora cingulata* Cleve** (Figure 14G)  
***Amphora holsaticoides* Nagumo & Kobayasi** (Figure 14F)  
***Amphora marina* Smith** (Figure 14D,E)  
***Amphora proteus* var. *contigua* Cleve** (Figure 14C)  
***Amphora proteus* var. *proteus* Gregory** (Figure 14A,B)  
 Genus *Halamphora* (Cleve) Levkov
- Halamphora acutiuscula* (Kützing) Levkov** (Figure 14K)  
***Halamphora coffeiformis* (Agardh) Mereschkowsky** (Figure 14I,J)  
***Halamphora holsatica* (Hustedt) Levkov** (Figure 14H)  
 Family Sellaphoraceae Mereschkowsky  
 Genus *Fallacia* Stickle & Mann
- Fallacia litoricola* (Hustedt) Mann** (Figure 10F,G)  
***Fallacia nummularia* (Greville) Mann** (Figure 10A–E)  
 Order Fragilariales Silva emend. Round in Round et al.  
 Family Staurosiraceae Medlin  
 Genus *Opephora* Petit
- Opephora mutabilis* Sabbe & Wyverman, nom. inval.** (Figure 4L)  
***Opephora pacifica* (Grunow) Petit** (Figure 4M)  
 Genus *Staurosirella* Williams & Round
- Staurosirella martyi* (Héribaude) Morales & Manoylov** (Figure 4N; SG)  
 Order Licmophorales Round in Round et al.  
 Family Ulnariaceae Cox  
 Genus *Tabularia* Williams & Round
- Tabularia fasciculata* (Agardh) Williams & Round** (Figure 4Q–S)  
***Tabularia tabulata* (Agardh) Snoeijs** (Figure 4T)  
 Order Rhabdonematales Round & Crawford  
 Family Grammatophoraceae Lobban & Ashworth  
 Genus *Grammatophora* Ehrenberg
- Grammatophora oceanica* Ehrenberg** (Figure 4P; SG)  
 Order Plagiogrammales Cox

Family Plagiogrammaceae De Toni

Genus *Dimeregramma* Ralfs

***Dimeregramma maculatum* (Cleve) Frenguelli** (Figure 4J,K; SG)

Genus *Plagiogramma* Greville

***Plagiogramma minus* (Gregory) Li, Ashworth & Witkowski** (Figure 4A–E)

***Plagiogramma tenuistriatum* Cleve** (Figure 4F–I)

Order Rhaphoneidales Round

Family Rhaphoneidaceae Forti

Genus *Delphineis* Ehrenberg

***Delphineis minutissima* (Hustedt) Simonsen** (Figure 4O; SG)

Genus *Rhaphoneis* Ehrenberg

***Rhaphoneis castracanei* Grunow** (Figure 4W,X; SG)

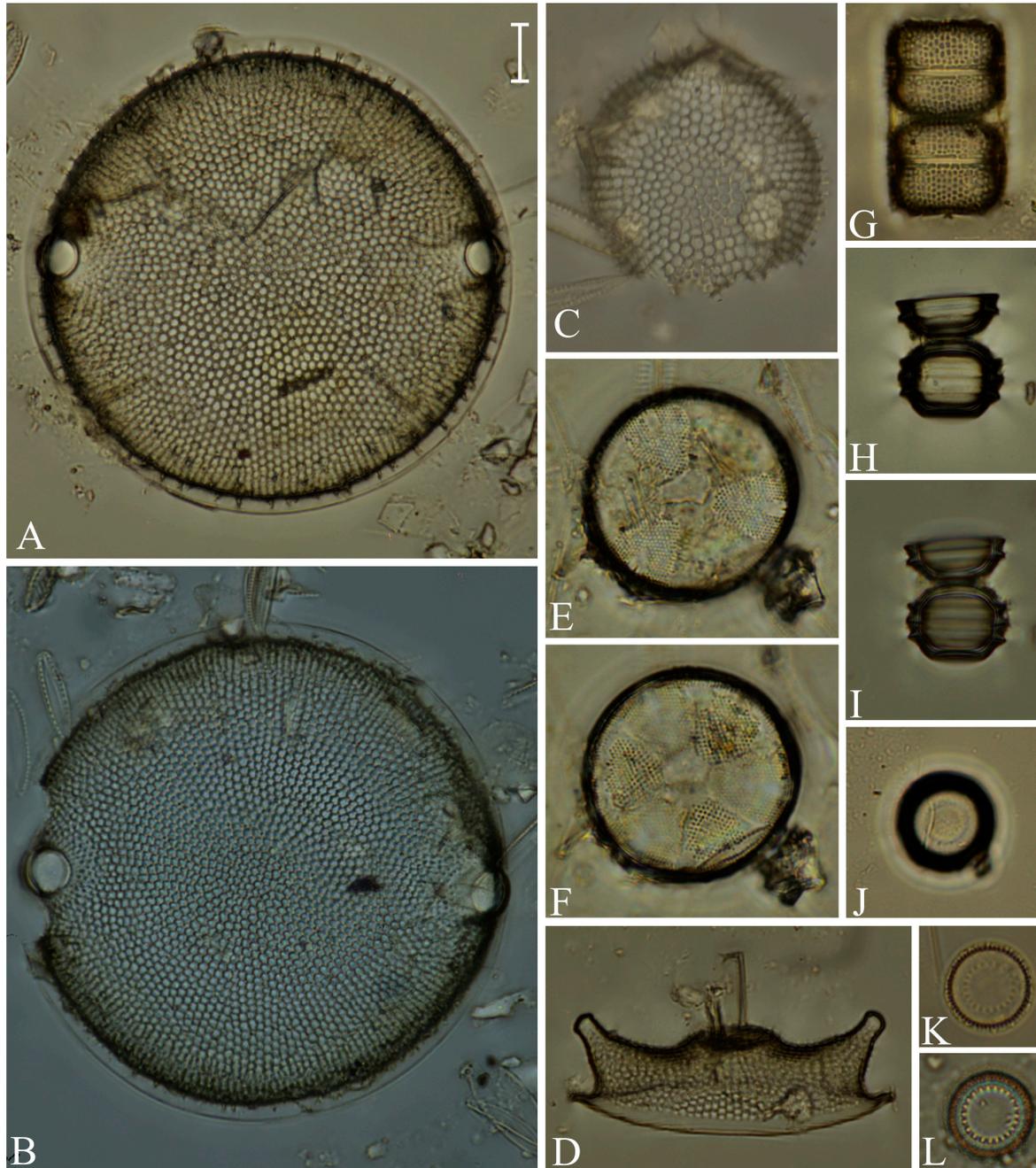
**Class Bacillariophyceae** incertae sedis

Order Bacillariophyceae ordo incertae sedis

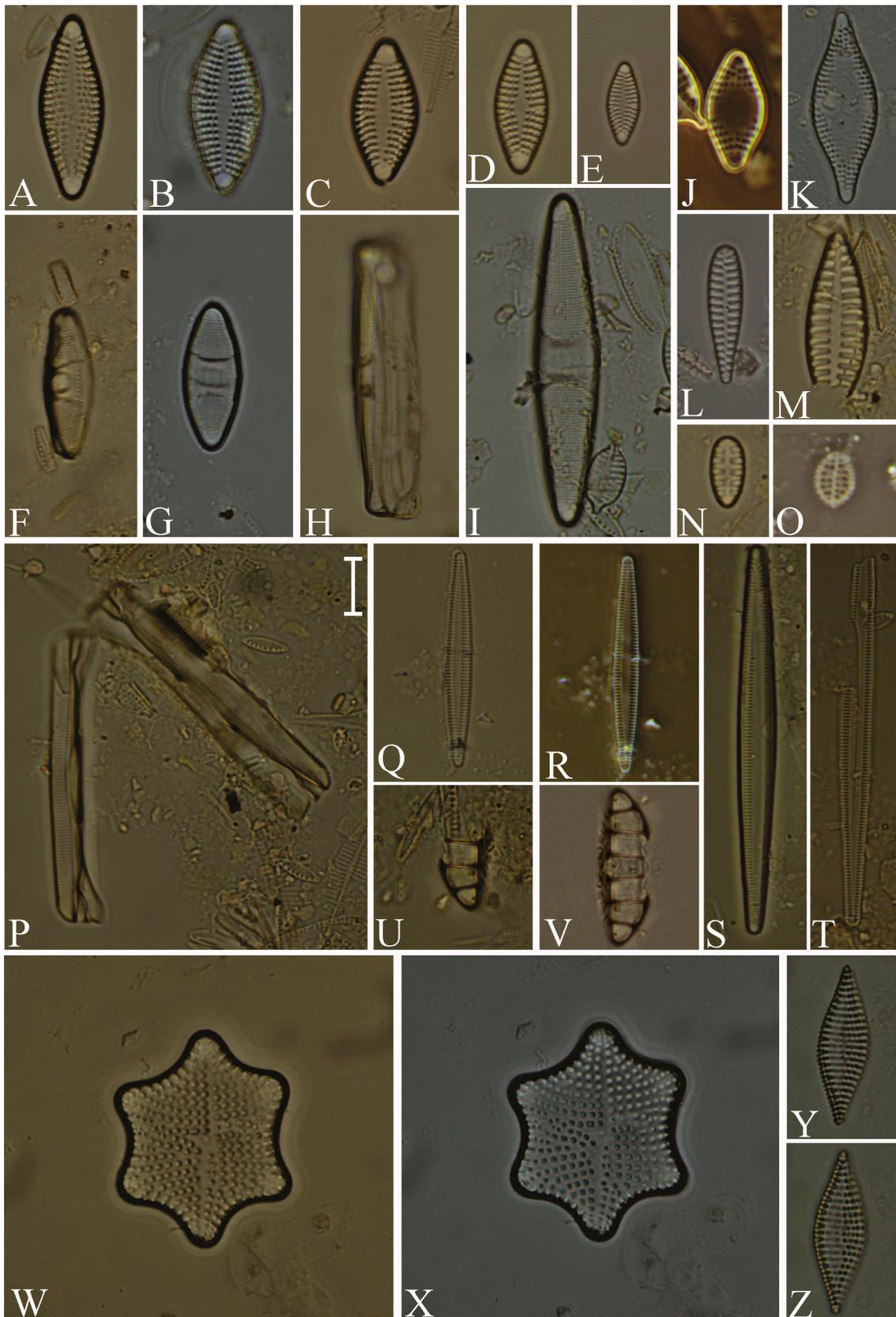
Family Bacillariophyceae familia incertae sedis

Genus *Ralfsiella* Sims, Williams & Ashworth

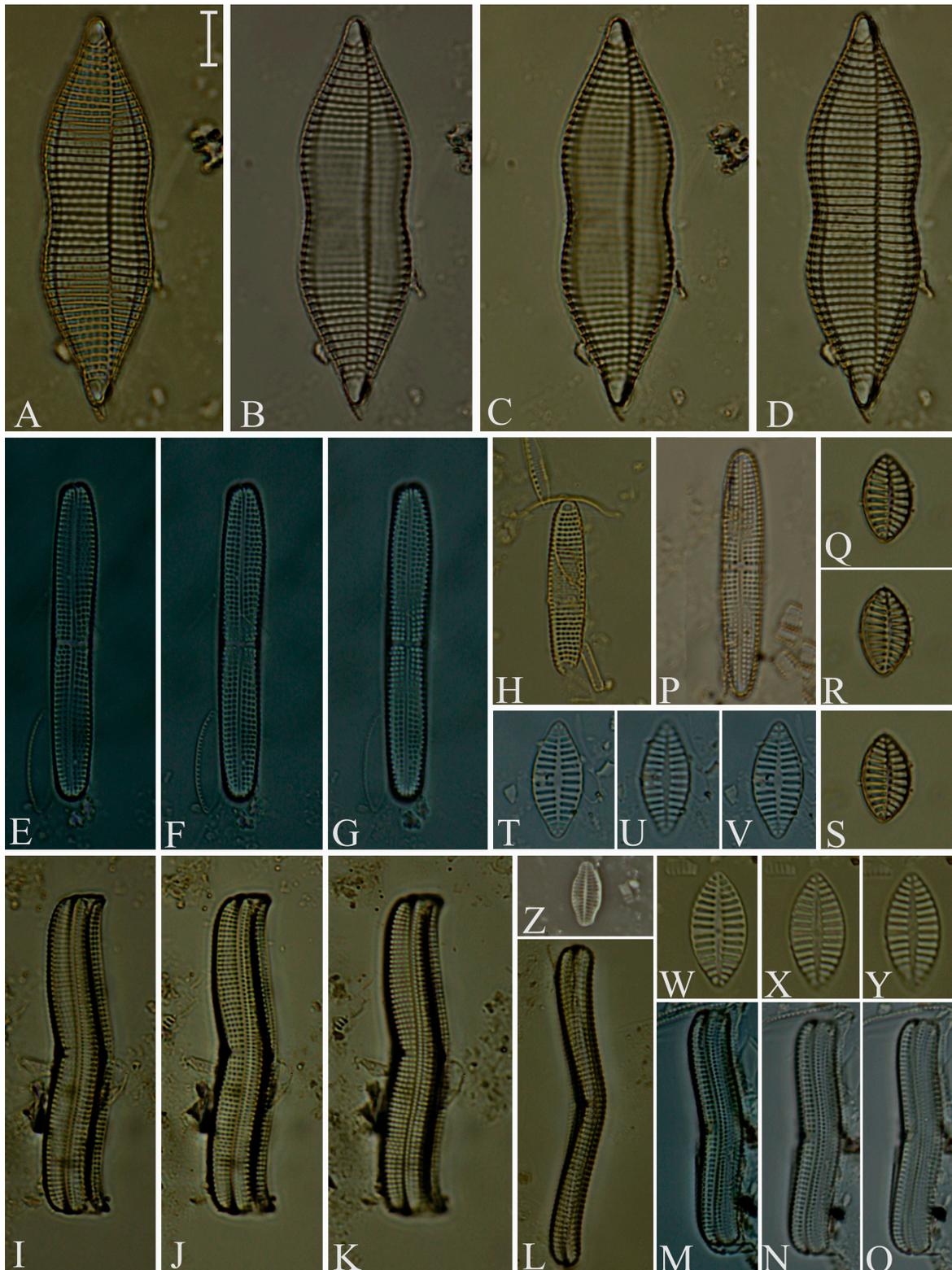
***Ralfsiella smithii* (Ralfs) Sims, Williams & Ashworth** (Figure 3C; SG)



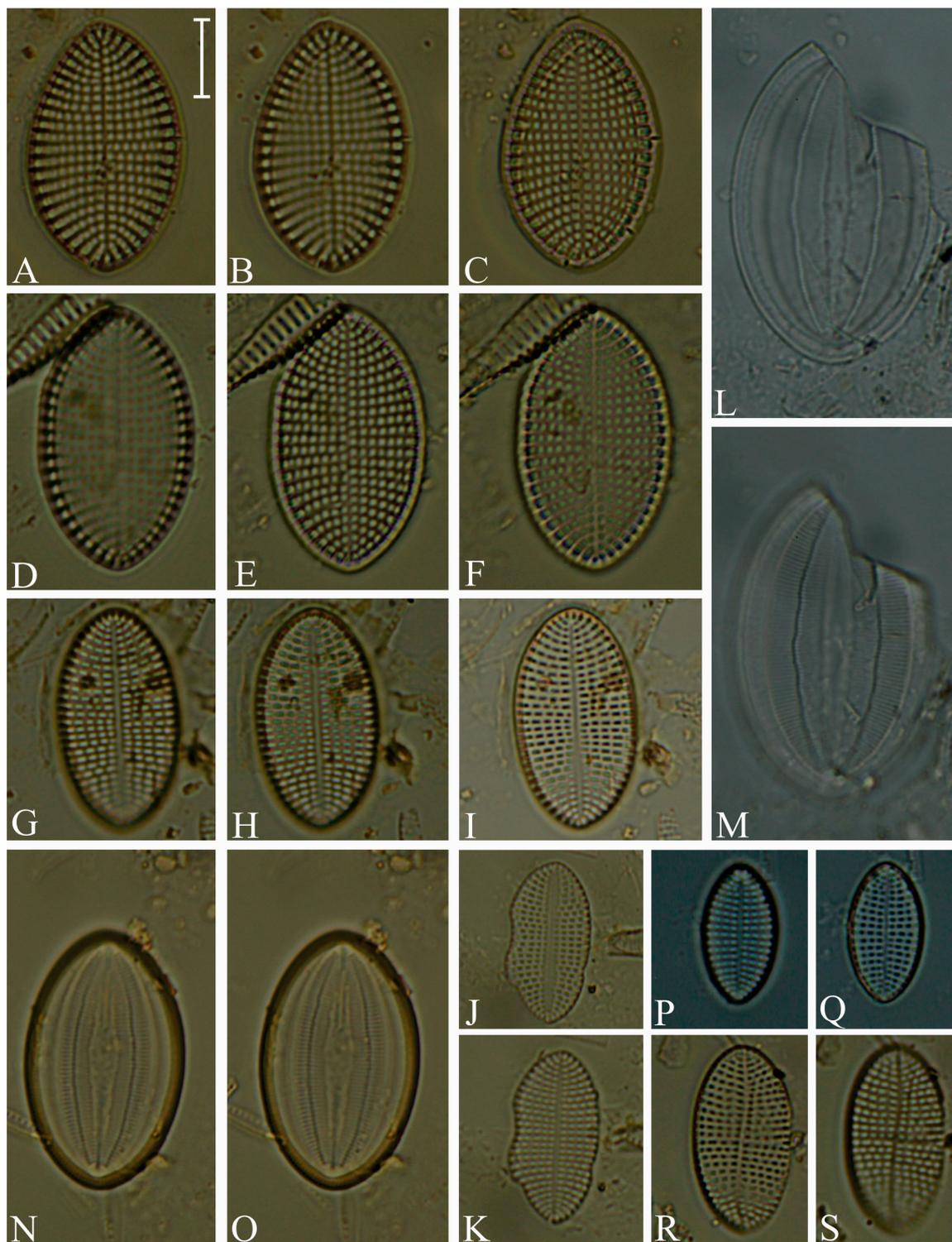
**Figure 3.** (A,B) *Biddulphia californica*; (C) *Ralfsiella smithii*; (D) *Odontella aurita*; (E,F) *Actinoptychus senarius*; (G) *Melosira distans* var. *lyrata*; (H,I) *M. westii* var. *quadrata*; (J) *M. nummuloides*; (K,L) *Paralia sulcata*. Scale bar = 10  $\mu$ m.



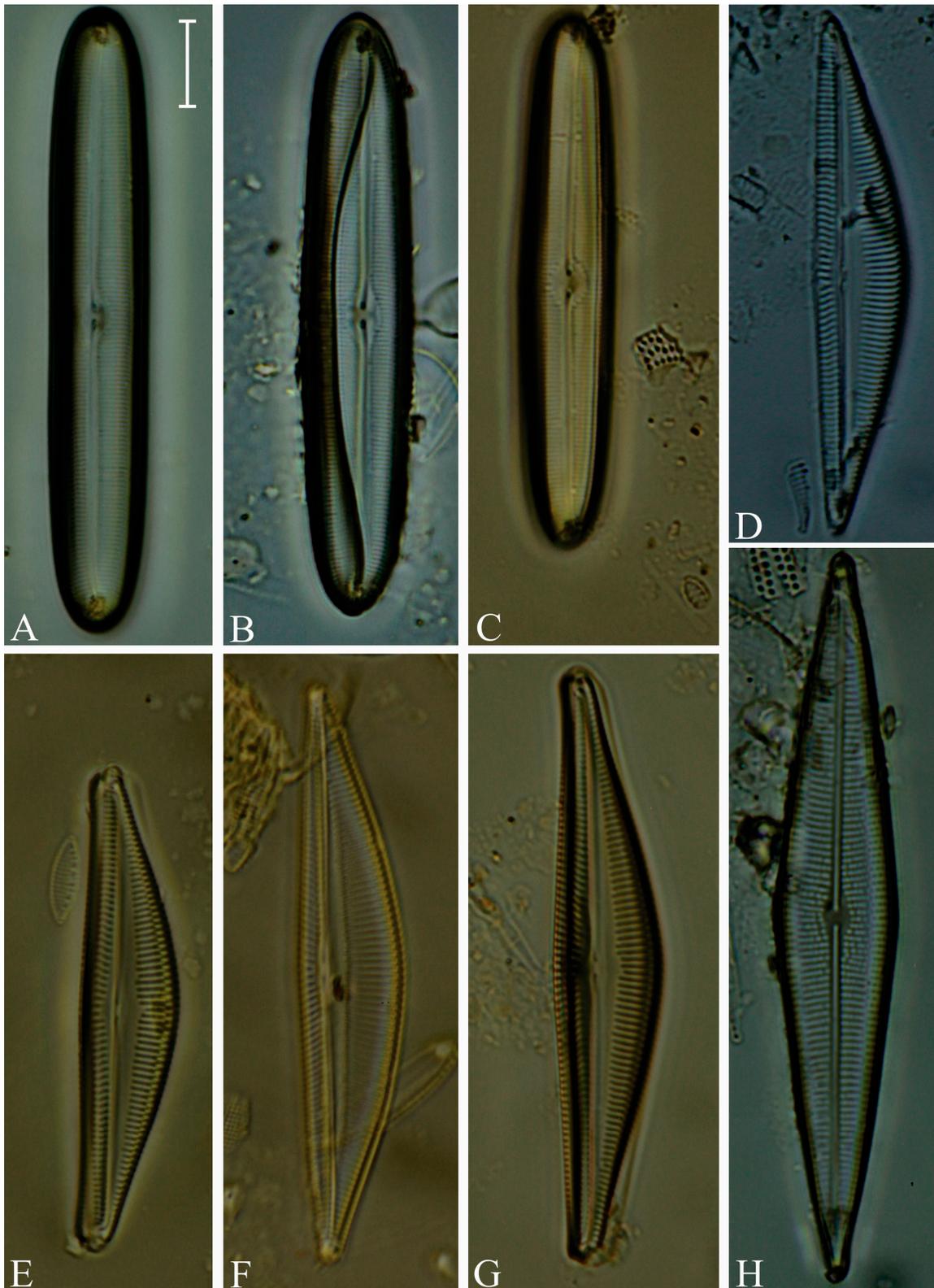
**Figure 4.** (A–E) *Plagiogramma minus*; (F–I) *P. tenuistriatum*; (J,K) *Dimeregramma maculatum*; (L) *Opephora mutabilis*; (M) *O. pacifica*; (N) *Staurosirella martyi*; (O) *Delphineis minutissima*; (P) *Grammatophora oceanica*; (Q–S) *Tabularia fasciculata*; (T) *T. tabulata*; (U,V) *Eunotogramma laeve*; (W,X) *Rhaphoneis castracanei*; (Y,Z) *Nitzschia fusoides*. Scale bar = 10  $\mu$ m.



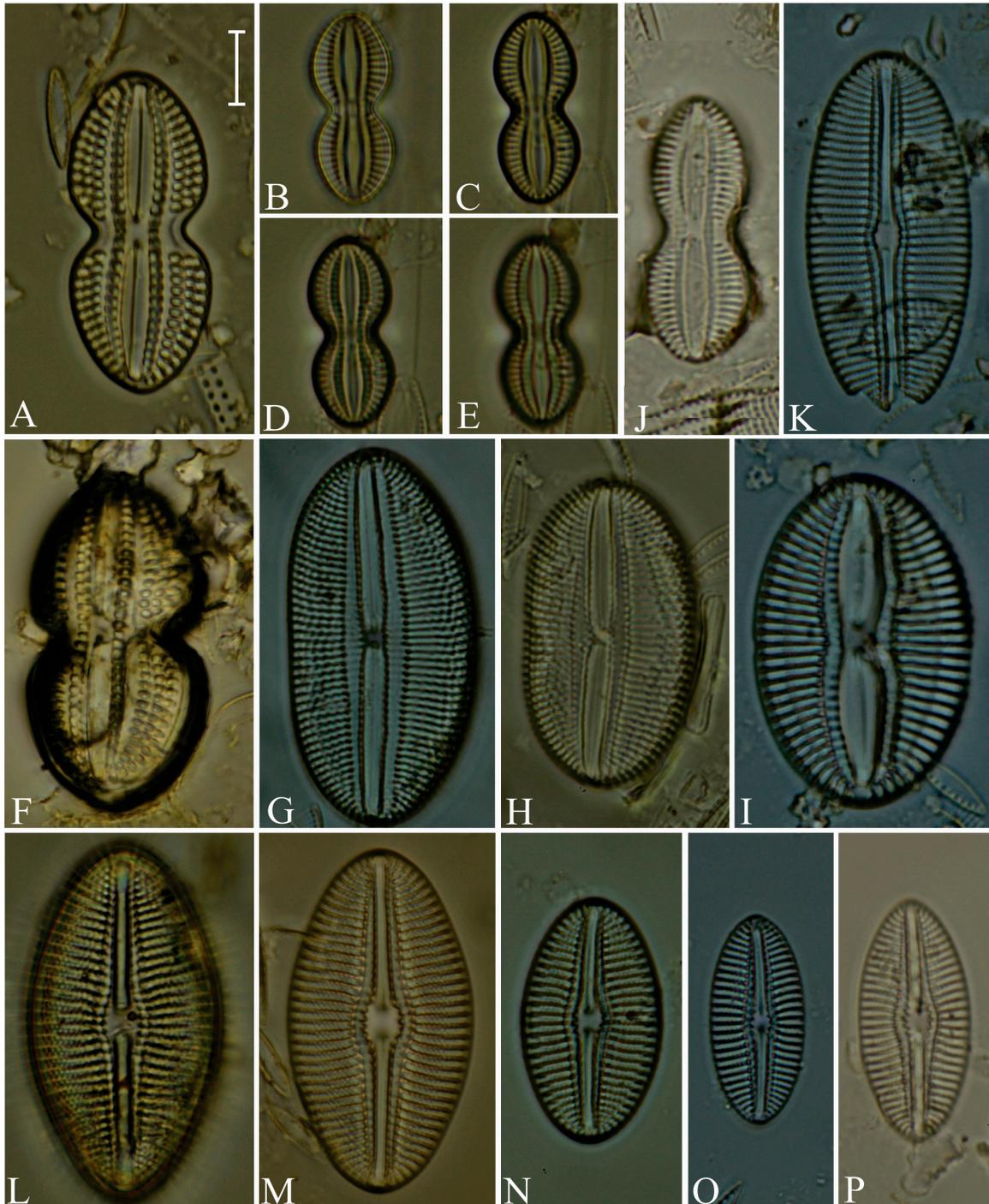
**Figure 5.** (A–D) *Achnanthes yaquinensis*; (E–O) *A. groenlandica*; (P) *A. angustata*; (Q–S) *Planothidium hauckianum*; (T–Y) *P. delicatulum*. (Z) *Achnanthes pyrenaica*. Scale bar = 10  $\mu\text{m}$ .



**Figure 6.** (A–F) *Cocconeis scutellum*; (G–K) *C. lineata*; (L,O) *C. pseudomarginata*; (P,Q) *C. neodiminuta*; (R,S) *C. pseudodiruptoides*. Scale bar = 10 μm.



**Figure 7.** (A–C) *Caloneis linearis*; (D–G) *Seminavis robusta*; (H) *Parlibellus rhombicula*. Scale bar = 10  $\mu\text{m}$ .



**Figure 8.** (A,F) *Diploneis gruendleri*; (B–E) *D. gravelleana*; (G,H) *D. obliqua*; (I) *D. coffeiformis*; (J) *D. interrupta*; (K–O) *D. smithii*; (P) *D. nitescens*. Scale bar = 10  $\mu\text{m}$ .

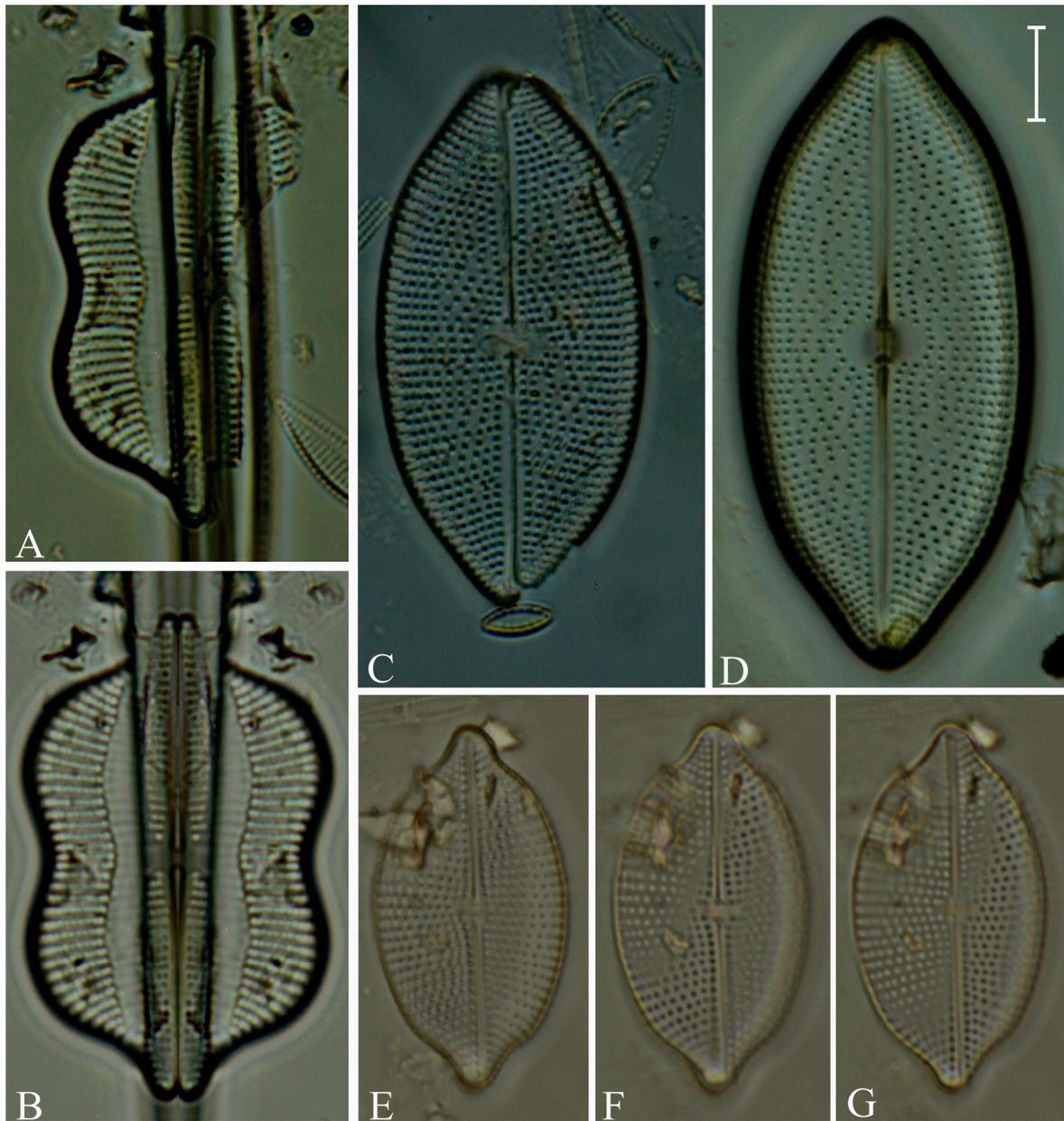


Figure 9. (A,B) *Lyrella exsul*; (C,D) *Petroneis granulata*; (E–G) *P. besarensis*. Scale bar = 10  $\mu\text{m}$ .

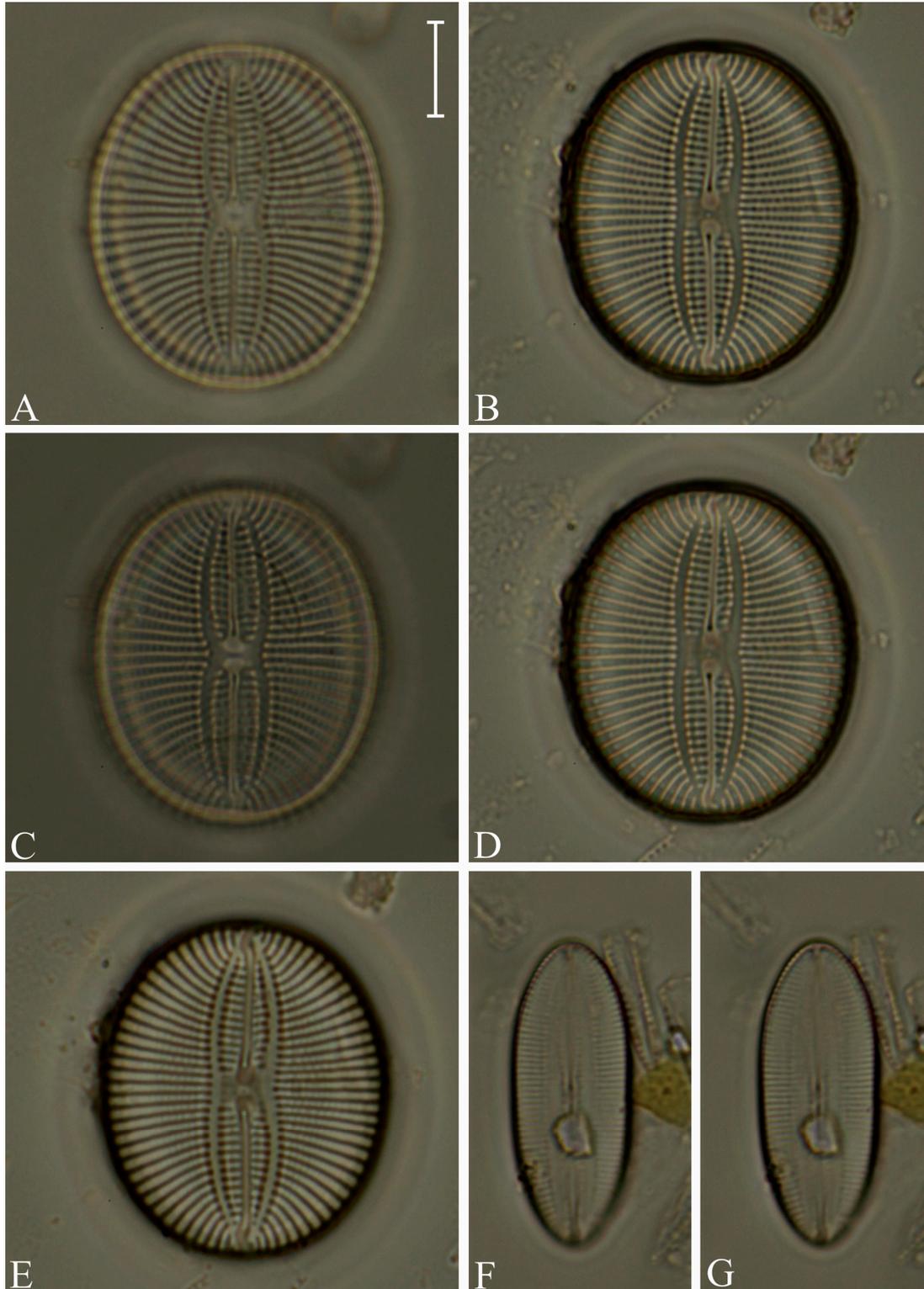
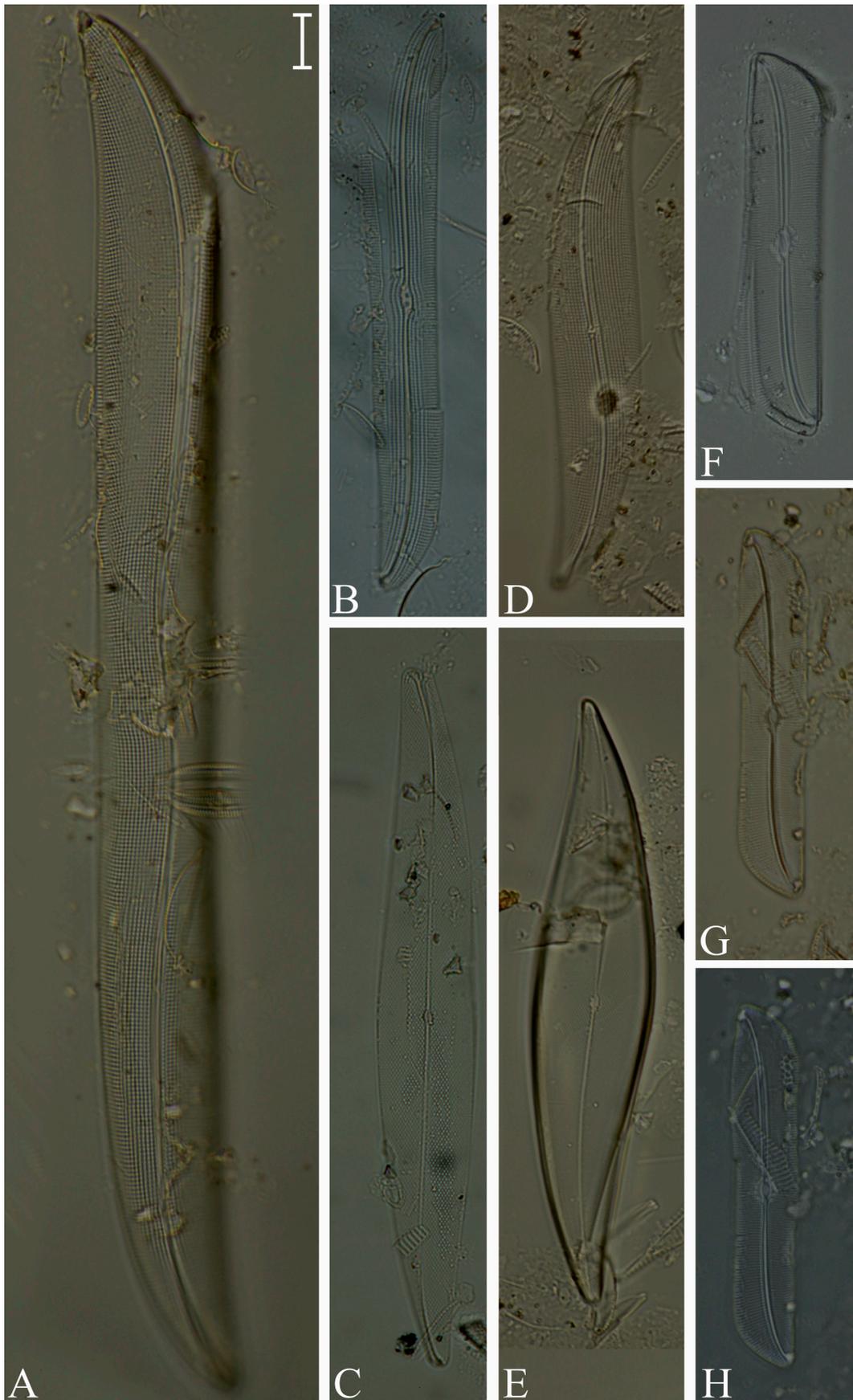
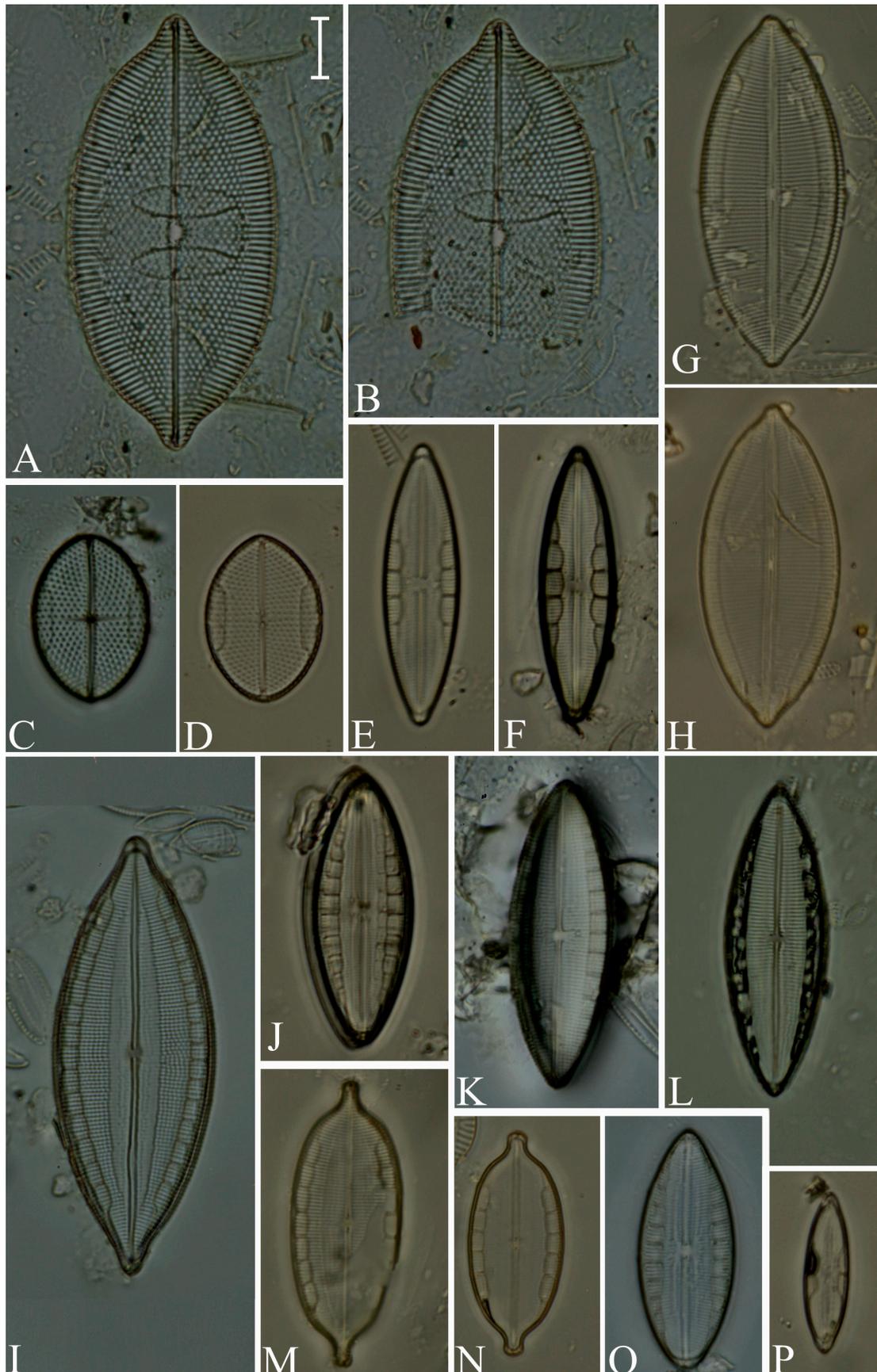


Figure 10. (A–E) *Fallacia nummularia*; (F–G) *F. litoricola*. Scale bar = 10  $\mu\text{m}$ .



**Figure 11.** (A) *Gyrosigma balticum*; (B) *G. variistriatum*; (C) *Pleurosigma salinarum*; (D) *Gyrosigma peisonis*; (E) *Pleurosigma diversestriatum*; (F-H) *Gyrosigma eximium*. Scale bar = 10  $\mu$ m.



**Figure 12.** (A,B) *Mastogloia angulata*; (C,D) *M. binotata*; (E,F) *M. exigua*; (G,H) *M. apiculata*; (I) *M. pisciculus*; (J,O) *M. braunii*; (K,L) *M. robusta*; (M,N) *M. acutiuscula* var. *elliptica*; (P) *M. gieskesii*. Scale bar = 10  $\mu$ m.

#### 4. Discussion

The study area consists mainly of mangrove swamps, thus soft sediments dominate the bottom substrate, with low availability of hard substrate. This means that hard-shell organisms (such as the green swimming crabs) may serve as an alternate substrate for the colonization and settlement of multiple forms of benthic diatoms [17]. In fact, our species richness estimation bears the closest resemblance to the estimated values in previous studies of benthic diatom taxocoenoses from mangrove environments in the La Paz coastal lagoon [52–54]; the latter study yielded 150 taxa recorded overall on several pro-thrombolytic platforms, of which 42% were also found on the inspected green swimming crabs' carapaces. That is, at 53 taxa per crab-specimen, the species richness falls within the interval estimated for samples of benthic diatom assemblages from mangrove (productive) environments [55].

Although studies on benthic diatoms in the northwest Mexican region are scarce and recent, several have been carried out expressly in the mangrove environments and have yielded a high species richness of diatoms thriving in the sediments [55]. Epipelagic diatoms from these environments may constitute a reserve of potential colonizers for various basibionts, including the highly motile green crabs, which may also represent a small-scale dispersion vehicle for benthic diatoms.

When comparing the species richness value estimated in our work (106 taxa) with those of similar studies with other crab species, we found that species richness estimations in said studies were reported to be lower. However, no comparison can be made between this diatom flora and those from other studies with the green swimming crab (or even other crabs from the same genus) because none have been conducted. The closest reference is a study by [18] that inspected basibiotic diatoms on a quite different marine arthropod, albeit with what seems a similar adhesion surface, the horseshoe crab (*Tachypleus gigas* O. F. Müller 1785), a species that dwells in moderately deep waters and migrates nearshore for breeding. These authors recorded 17 and 20 diatom taxa living on female and male specimens, respectively. Whilst, considering studies with crabs in general, 65 diatom taxa were recorded as epibionts from 25 genera living on spider crabs (*Schizophrys dahlak* Griffin & Tranter 1986), confirming that the number of epizoic diatom taxa are normally much lower than in our study (less than half, in this case). Although, life habits between these crab species are quite different and the comparison may just be related to the composition of the shell.

Beyond this, there is great potential to be added to the literature. For instance, even though the floristic reference for the northwestern Mexican region is considerable, the epibiotic taxocenosis on green swimming crabs rendered six new records. This does not necessarily mean that these are epizoic forms, but it supports the premise that continuous and extensive sampling—including various substrates and unexplored areas—along with exhaustive floristic inspection of the samples will enrich the benthic diatom species list, even at a global scale. This was earlier observed by [56] who recorded thirty diatom taxa epizoic on specimens of stone fish (*Scorpaena mystes* Jordan and Starks 1895), from the central Gulf of California that were new for Mexican littorals, and out of which twelve had not hitherto been recorded for American coasts. As such, evidently floristic records of benthic diatoms for the La Paz lagoon are far from being complete. Furthermore, the records that are currently available are the products of discrete sampling, both spatially and temporally, as is the case for taxa epibiotic on green swimming crabs. They are also limited by sampling size; for instance [56] inspected twenty specimens of stone fish, while for the present study, only two specimens of *Callinectes bellicosus* were used.

In this study 93% of the diatom taxa found on the shell of the green crabs are typical of the local epipelagic diatom flora, a degree of similarity that refuted our null hypothesis, i.e., supporting the alternate hypothesis that the epibiotic diatom assemblages living on the shells of green crabs are constituted mainly by typical or characteristic taxa found in mangrove sediments or from neighbor sites in northwestern Mexico. With respect to the significance of said similarity, in our own experience even replicas or repetitions of samples may vary in similarity from 70–80% vs. the main sample when using similarity indices [57]. But because difference in species richness affect the similarity value the approach that we used was direct.

Further hypothesis-driven studies about the ecological relations and small-scale dispersion of benthic diatoms by means of green crab transportation will provide fertile grounds for improving our understanding of the interactive dynamics of epibionts and basibionts. In the case of *Callinectes bellicosus* and diatoms, this research should also help to complete our knowledge of those diatom taxa that are either epizoic or opportunistic, by working to overcome the evident spatial and temporal limitations of the existing contributions to the floristic records for the Mexican coasts. In this manner, it may be explored if the species composition or the structure of the epibiotic assemblages abides by the theoretical patchy distribution typical of benthic diatoms. Furthermore, considering the limited displacement capability of this basibiont, the inspection of specimens of green crab collected in other locations of the La Paz lagoon could broaden our knowledge by yielding distinct epibiotic diatom taxa.

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