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First Account of Epibiotic Diatom Taxa from the Carapaces of Green Swimming Crab *Callinectes bellicosus* (Stimpson 1859) (Decapoda, Portunidae)

Francisco Omar López-Fuerte [1], David Alfaro Siqueiros Beltrones [2,*], Luis Hernández [1] and Sergio Flores-Ramírez [1]

[1] Departamento Académico de Ciencias Marinas y Costeras, Universidad Autónoma de Baja California Sur, Boulevard Forjadores, Colonia Universitario, La Paz 23080, Mexico; folopez@uabcs.mx (F.O.L.-F.); lghm@uabcs.mx (L.H.); fflores@uabcs.mx (S.F.-R.)

[2] Departamento de Plancton y Ecología Marina, Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, Av. Instituto Politécnico Nacional S/N, Col. Playa Palo de Santa Rita, La Paz 23096, Mexico

* Correspondence: dsiquei@gmail.com

Abstract: Diatoms are among the most common epibionts and have been recorded on the surfaces of various living substrates, either plants or animals. However, studies on them 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 carapaces 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. This way, 106 taxa from 46 genera were recorded, including 25 singletons, and 6 new records for the Mexican northwest region. The best-represented genera were *Nitzschia* (10 taxa), *Mastogloia* (9), *Diploneis* (8), *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 that 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

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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 is living substrata, sometimes plants and algae (epiphytic diatoms) and other times animals (epizoic diatoms) [2,3]. In this vein, the importance of the 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 about the species composition, seasonality, or 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 substrates by benthic diatoms. Given the challenge that this presents, in general, there is scarce information on diatom epibiosis with crabs [17,18], in that the species composition and richness of epibiotic diatoms have 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, and it is 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 has 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 also have yet to be revealed. 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 relevant background on this flora shows that the 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 were recorded, providing a reliable reference for our work. Moreover, the structure of the benthic diatom assemblages has been described based on the characteristic taxa in such a way that a typical benthic diatom flora can be recognized for the region. Thus, 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 carapaces 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 (Ho) responds to the influence of the mobility of the basibiont and constant exposure of the colonized surface, plus discrete temporal sampling, which could exhibit a seasonal variation in the 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 La Paz Bay, 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].

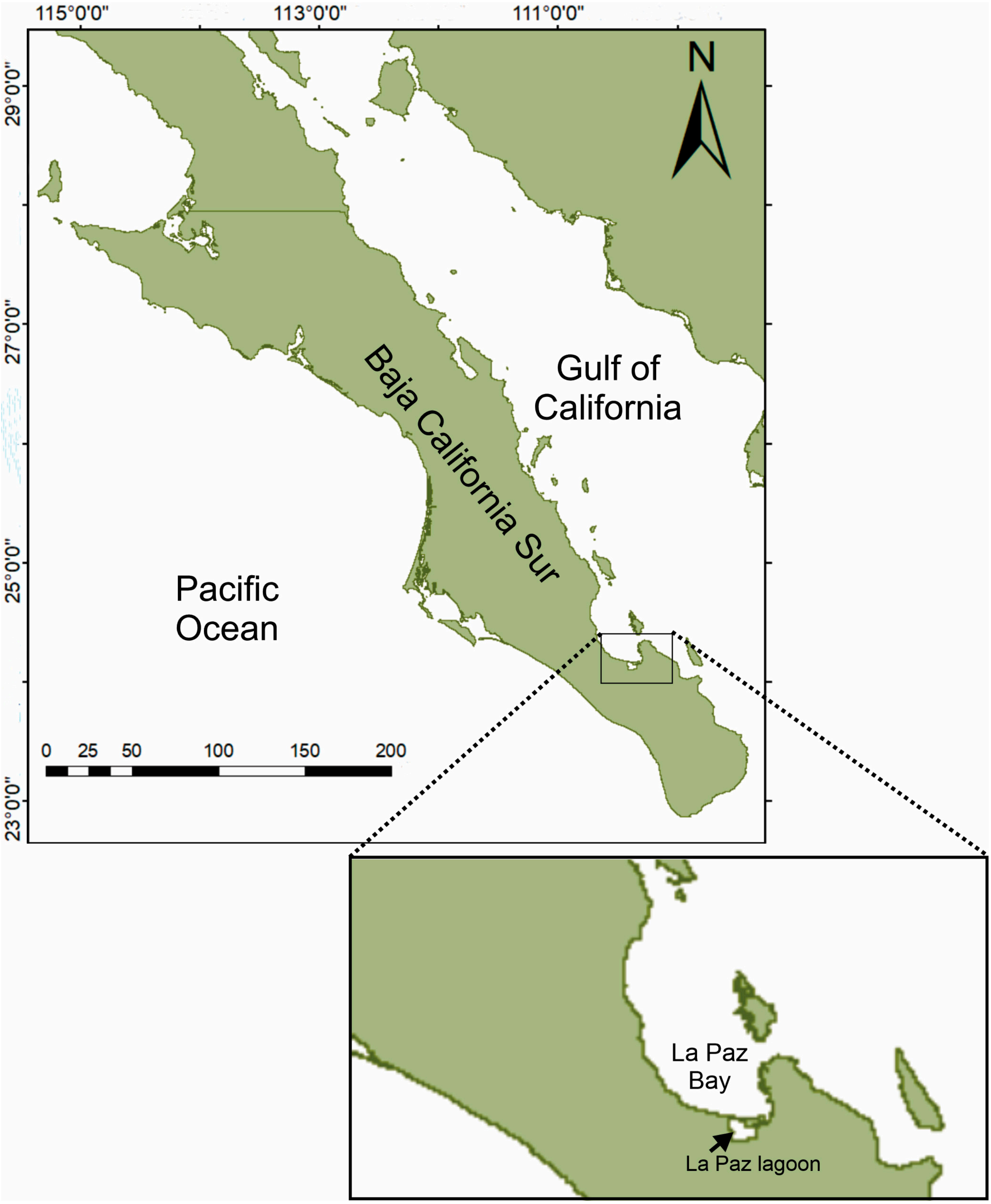

Figure 1. Sampling site where two green swimming crabs were captured in the La Paz coastal lagoon, southeast of Bahia de La Paz, Mexico.

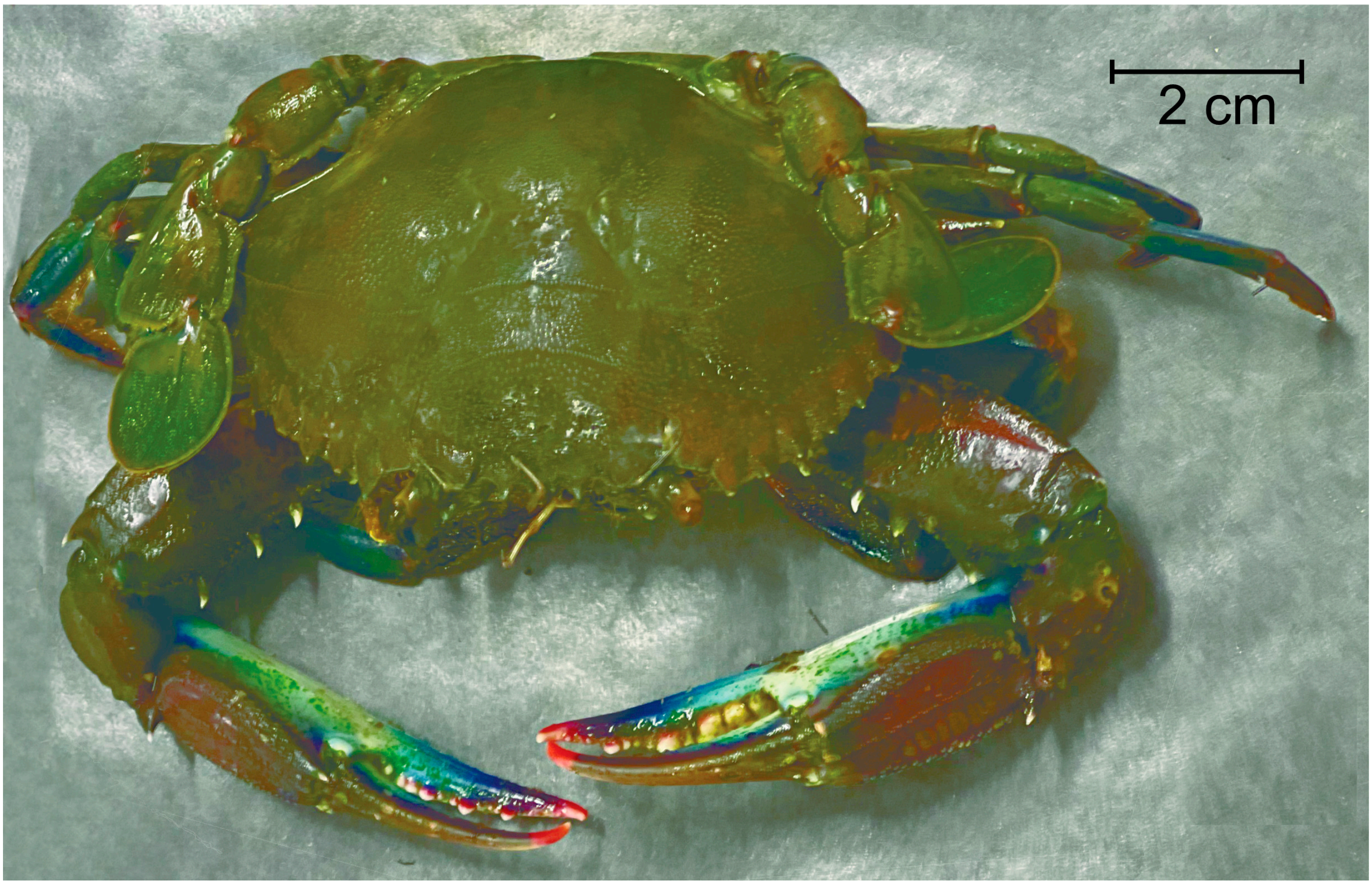

Figure 2. Captured specimen of green swimming crab (*Callinectes bellicosus*) at Estero Zacatecas, La Paz lagoon, B.C.S., Mexico, from which the identified epibiotic diatoms were sampled.

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 the 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 the mixture 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 it reached a circumneutral pH. Then, six mounted slides were inspected under a Zeiss® Axio Lab A1 (Zeiss, Jena, Germany) compound microscope equipped with phase contrast and a Canon 5D Mark II camera (Canon, Tokyo, 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 [50] and www.marinespecies.org (accessed on 1 December 2023) [51]. This was complemented by an iconographic catalog of all the recorded taxa.

3. Results

The inspection of the brushed-off material from the green crab's carapaces yielded 106 diatom taxa belonging to 46 genera (Table 1; Figures 3–18). At the class level, 91% (97 taxa) were Bacillariophyceae, 5% (5) were Coscinodiscophyceae, and 4% (4) were Mediophyceae. The taxonomic families with most species were Bacillariaceae (with 17), Mastogloiaceae (9), Naviculaceae (9), and Diploneidaceae (8). Meanwhile, the highest-represented genera in terms of the number of species were *Nitzschia* (10), *Mastogloia* (9), *Diploneis* (8), *Navicula* (7), *Amphora* (5), *Cocconeis* (5), *Tryblionella* (4), and *Gyrosigma* (4), which accounted for 49% of all taxa. We found that 25 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), *Petroneis besarensis* (Figure 9D–F), 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 carapace of the green crabs were also characteristic or typical of the local epipelic diatom flora recorded for mangrove sediments in the region. This constitutes evidence that refutes the proposed 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. * = new record 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)
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)
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 brevipes var. *angustata* (Greville) Cleve (Figure 5E–P)
Achnanthes yaquinensis McIntire & Reimer (Figure 5A–D)
Family: Achnanthidiaceae D.G. Mann
Genus: *Karayevia* Round & Bukhtiyarova ex Round
Karayevia cf. *amoena* (Hustedt) Bukhtiyarova (Figure 5Z)
Genus *Planothidium* Round & Bukhtiyarova
Planothidium hauckianum (Grunow) Bukhtiyarova (Figure 5T–Y)
Planothidium delicatulum (Kützing) Round & Bukhtiyarova var.? (Figure 5Q–S)
Family Cocconeidaceae Kützing
Genus *Cocconeis* Ehrenberg

Table 1. *Cont.*

Cocconeis cf. *pseudolineata* (Geitler) Lange-Bertalot (Figure 6P,Q)
Cocconeis cf. *euglypta* 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)
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)
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; SG)
Genus *Petroneis* Stickle & Mann
Petroneis besarensis (Giffin) Witkowski, Lange-Bertalot & Witkowski * (Figure 9D–F)
Petroneis granulata Mann, nom. illeg. (Figure 9B,C)
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

Table 1. *Cont*.

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 obliqua (Brun) Hustedt (Figure 8G,H)
Diploneis smithii (Brébisson) Cleve (Figure 8L–P)
Diploneis vacillans (Schmidt) Cleve (Figure 8K)
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 diversestriatum 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) Topachevskyj & 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

Table 1. *Cont.*

Entomoneis paludosa (Smith) Reimer (Figure 15F,G; SG)
Family Surirellaceae Kützing
Genus *Campylodiscus* Ehrenberg ex Kützing
Campylodiscus subangularis Cleve & Möller * (Figure 18L–O, S)
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 & Vyverman, nom. inval. (Figure 4L)
Opephora pacifica (Grunow) Petit (Figure 4M)
Genus *Staurosirella* Wiliams & Round
Staurosirella martyi (Héribaud) 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)

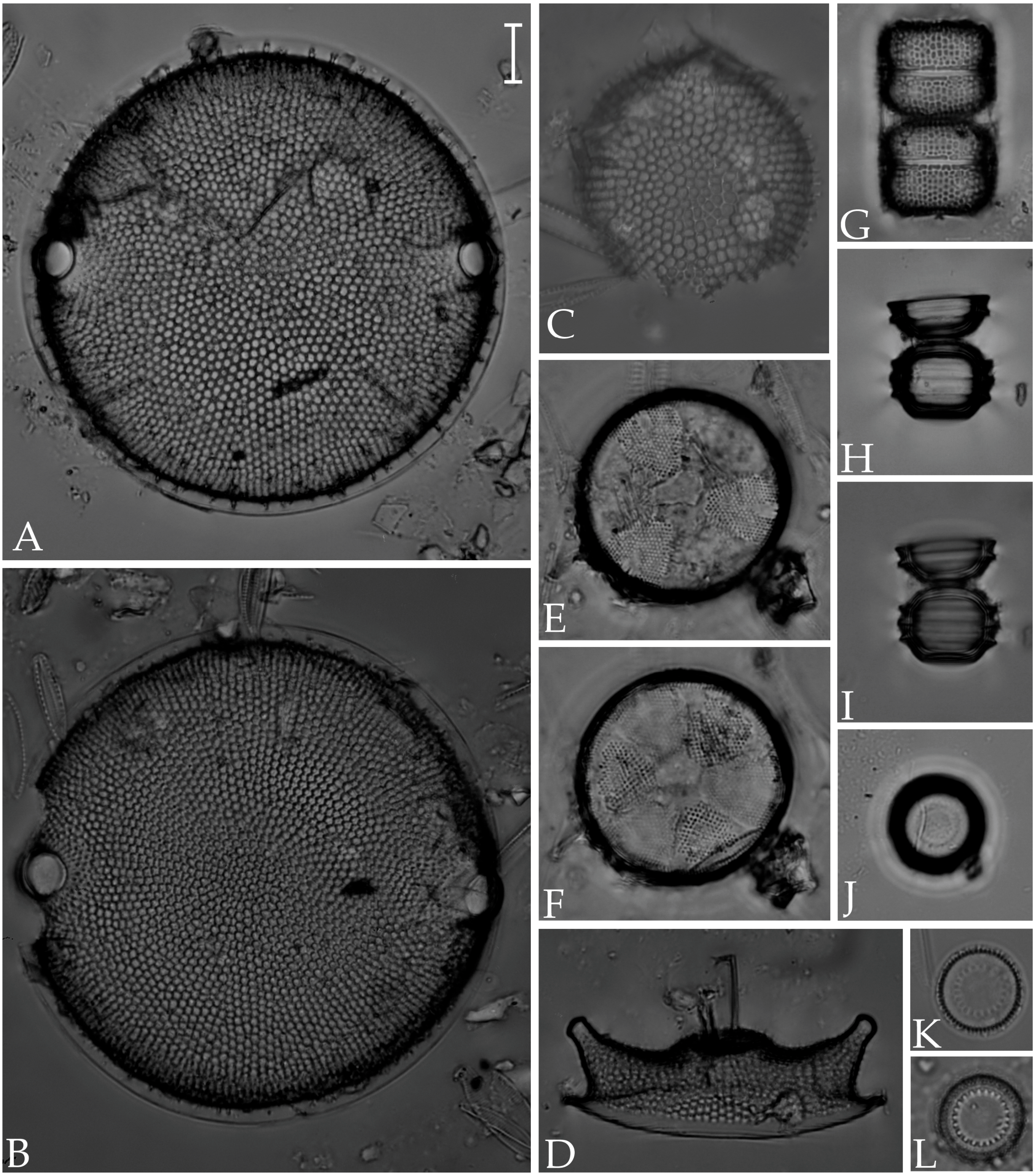

Figure 3. (**A**,**B**) *Biddulphia californica*; (**C**) *Ralfsiella smithii*; (**D**) *Odontella aurita*; (**E**,**F**) *Actinoptychus senarius*; (**G**) *Melosira distans* var. *lyrata*; (**H**,**I**) *M. westii* var. *quadrata*; (**J**) *M. nummuloides*; (**K**,**L**) *Paralia sulcata*. Scale bar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

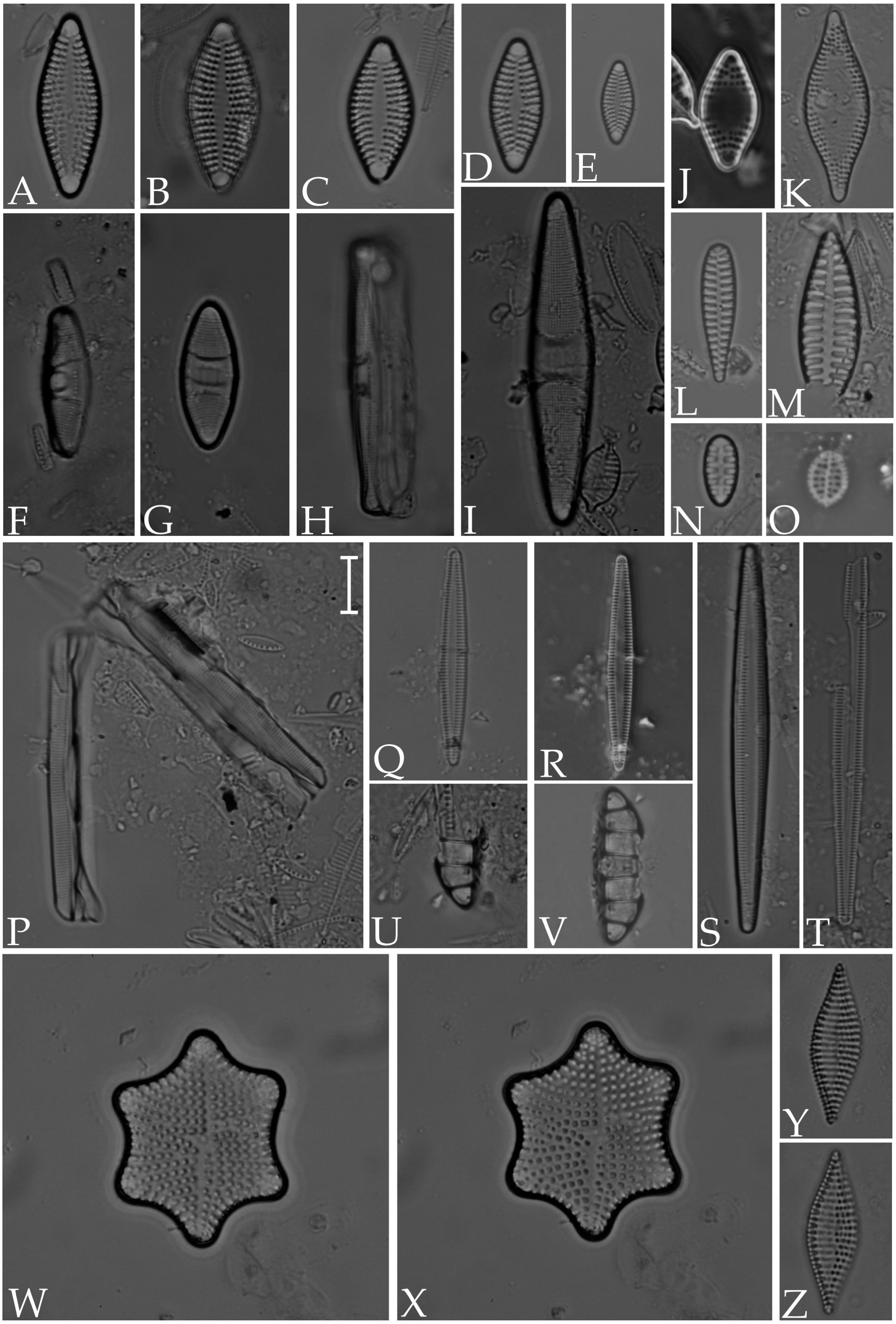

Figure 4. (**A**–**E**) *Plagiogramma minus*; (**F**–**I**) *P. tenuistriatum*; (**J**,**K**) *Dimeregramma maculatum*; (**L**) *Opephora mutabilis*; (**M**) *O. pacifica*; (**N**) *Staurosirella martyi*; (**O**) *Delphineis minutissima*; (**P**) *Grammatophora oceanica*; (**Q**–**S**) *Tabularia fasciculata*;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

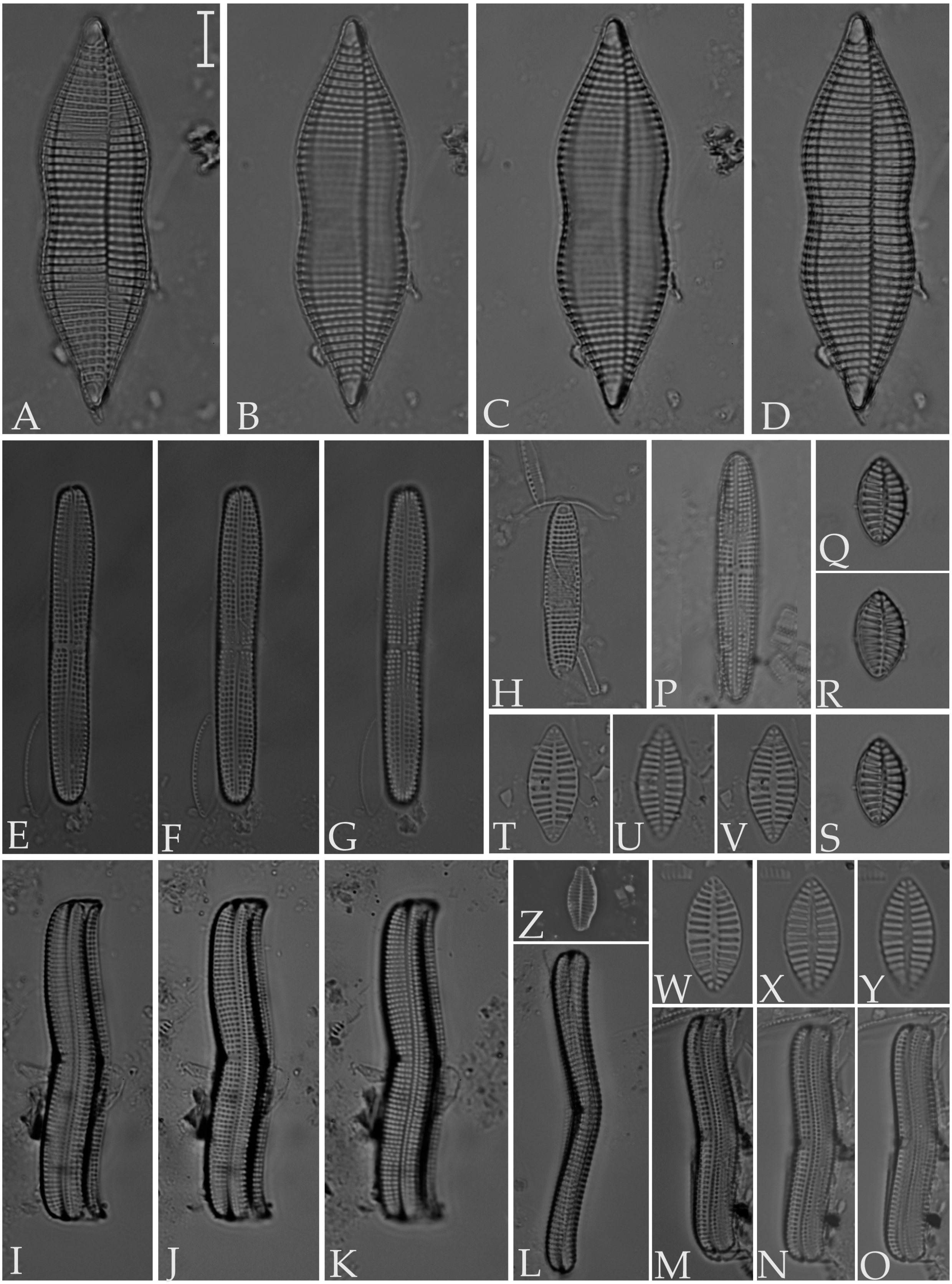

Figure 5. (**A**–**D**) *Achnanthes yaquinensis*; (**E**–**P**) *A. brevipes* var. *angustata*; (**Q**–**S**) *Planothidium delicatulum* var.?; (**T**–**Y**) *P. hauckianum*. (**Z**) *Karayevia* cf. *amoena*. Scale bar = 10 µm.

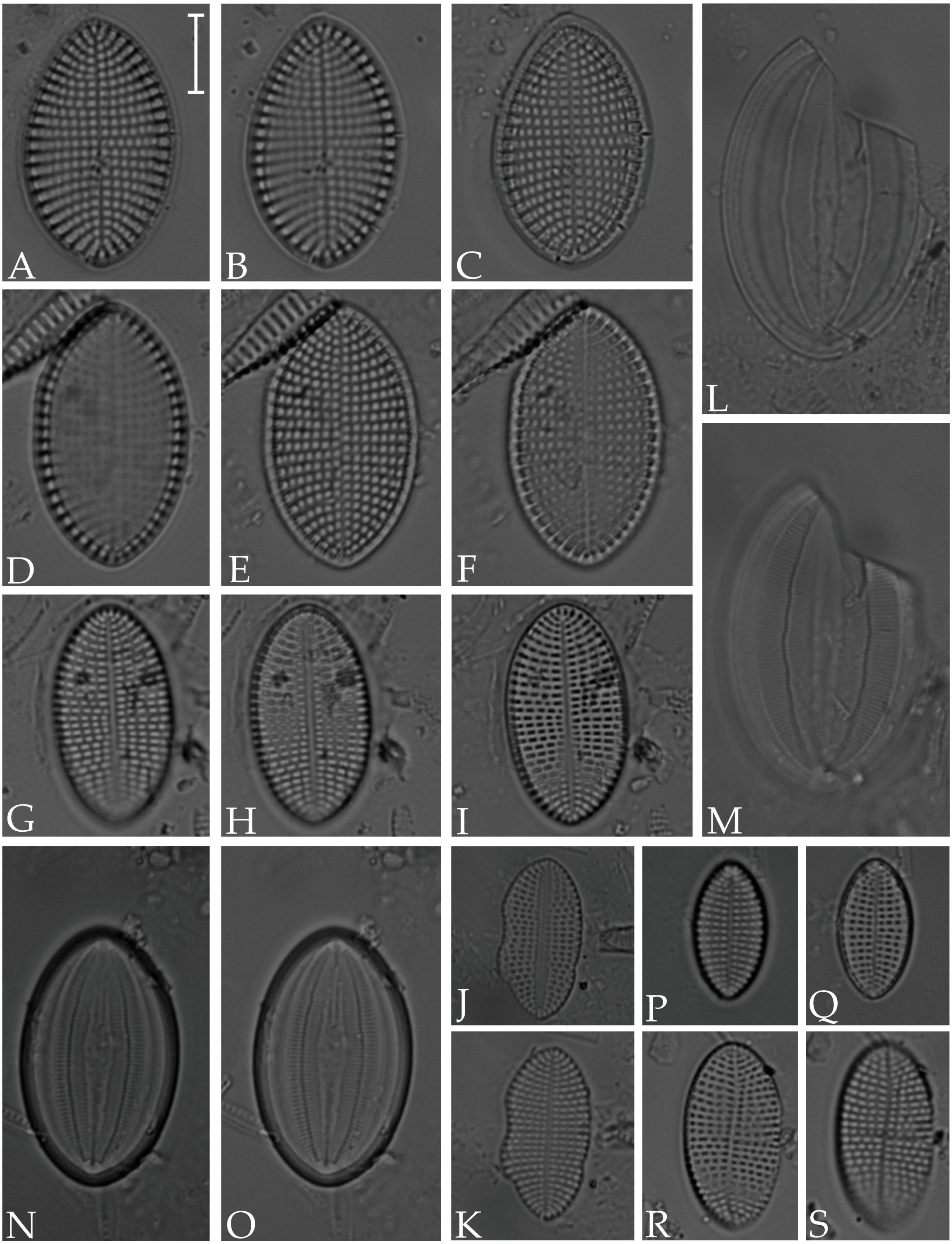

Figure 6. (**A**–**F**) *Cocconeis scutellum*; (**G**–**K**) *C.* cf. *euglypta*; (**L**–**O**) *C. pseudomarginata*; (**P**,**Q**) *C.* cf. *pseudolineata*; (**R**,**S**) *C. pseudodiruptoides*. Scale bar = 10 μm.

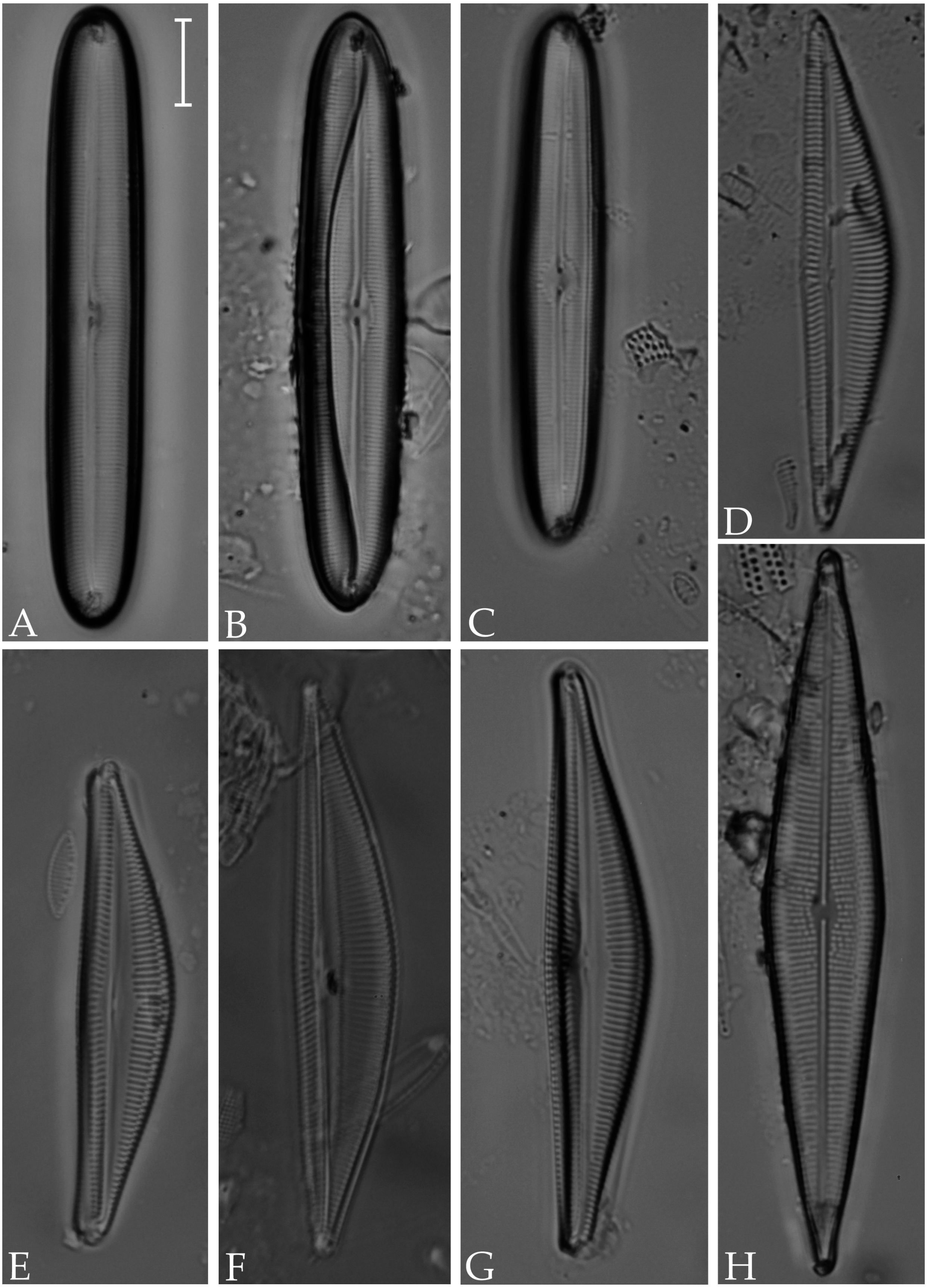

Figure 7. (**A**–**C**) *Caloneis linearis*; (**D**–**G**) *Seminavis robusta*; (**H**) *Parlibellus rhombicula*. Scale bar = 10 µm.

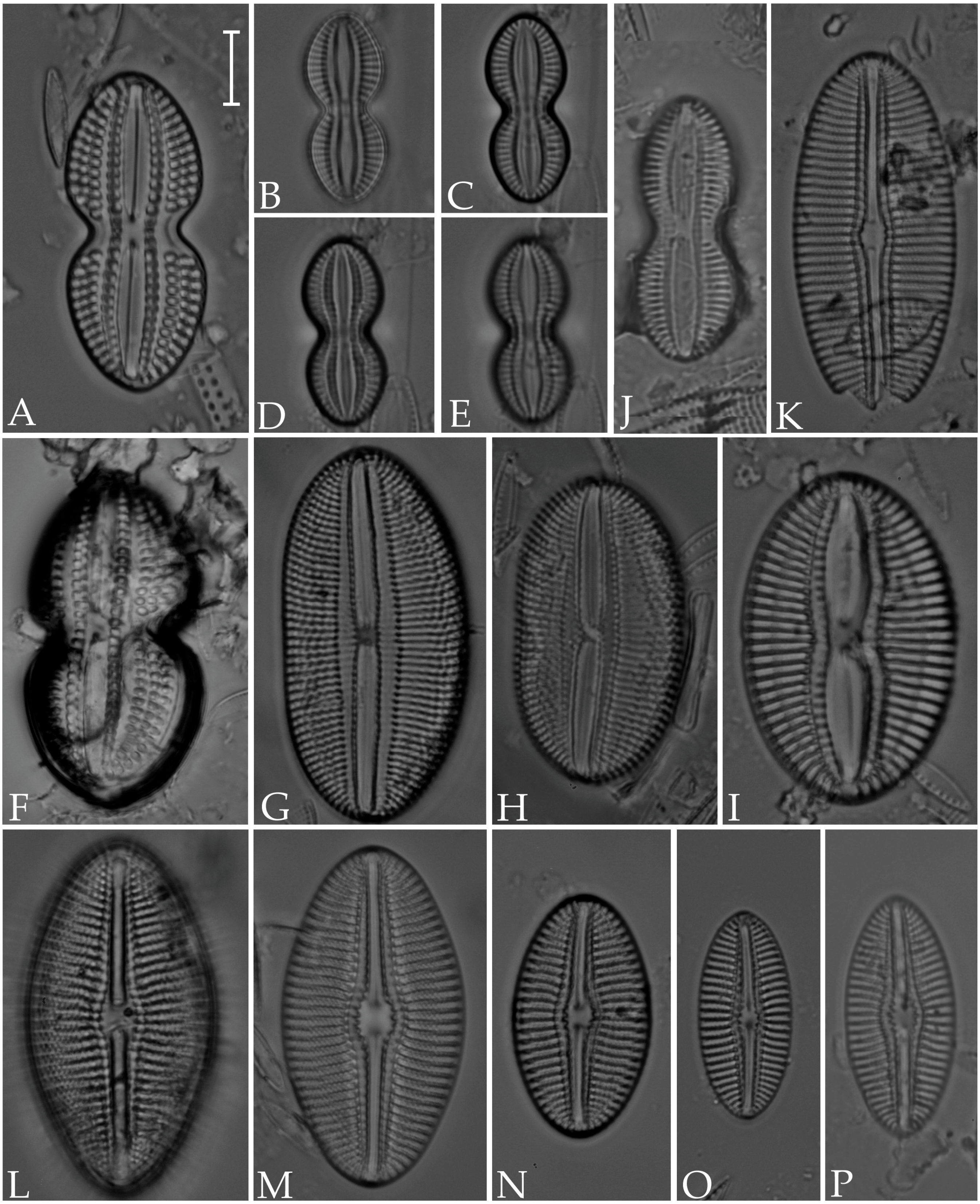

Figure 8. (**A**,**F**) *Diploneis gruendleri*; (**B**–**E**) *D. gravelleana*; (**G**,**H**) *D. obliqua*; (**I**) *D. coffeiformis*; (**J**) *D. interrupta*; (**K**) *D. vacillans*; (**L**–**P**) *D. smithii*. Scale bar = 10 µm.

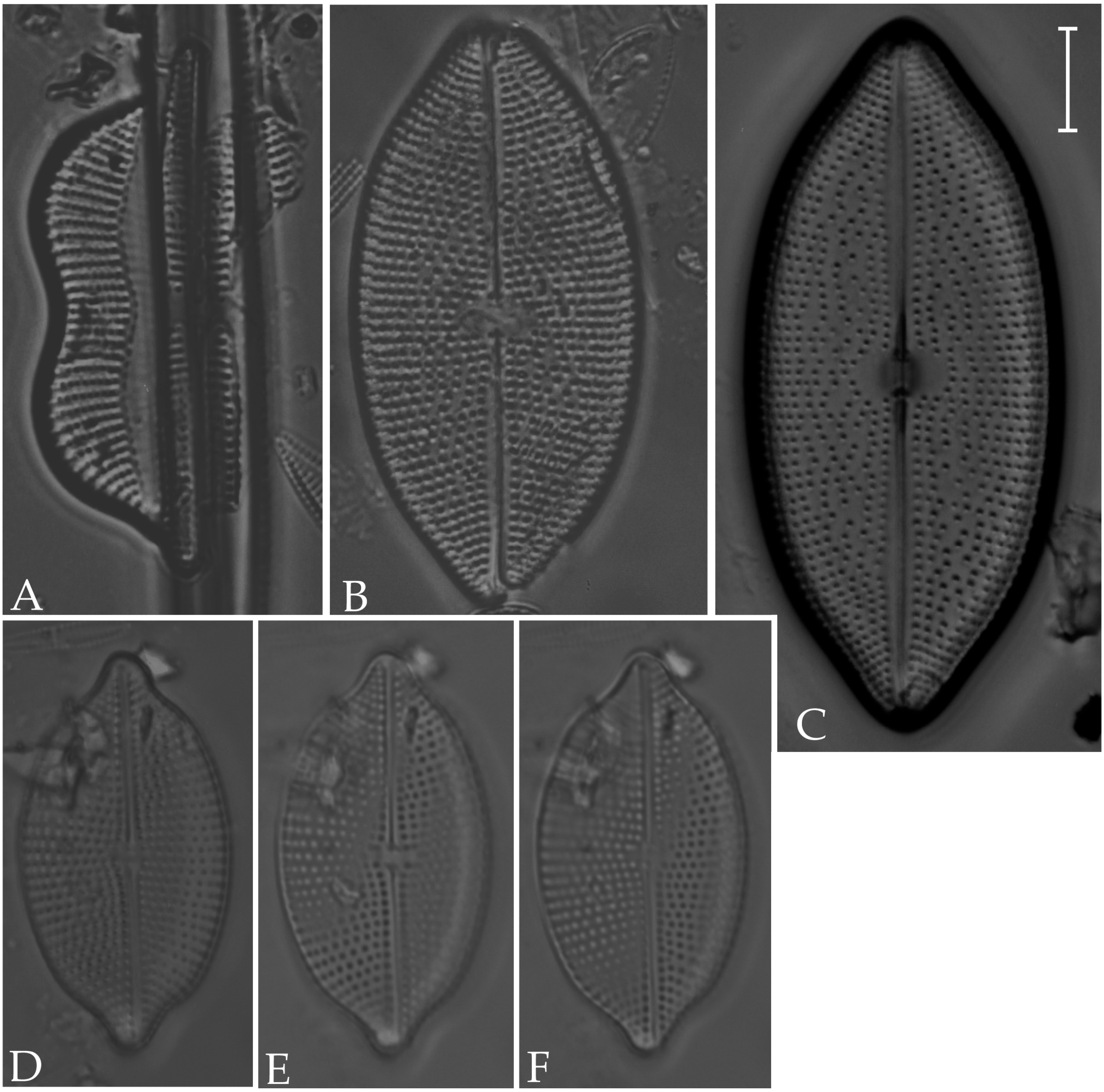

Figure 9. (**A**) *Lyrella exsul*; (**B**,**C**) *Petroneis granulata*; (**D**–**F**) *P. besarensis*. Scale bar = 10 µm.

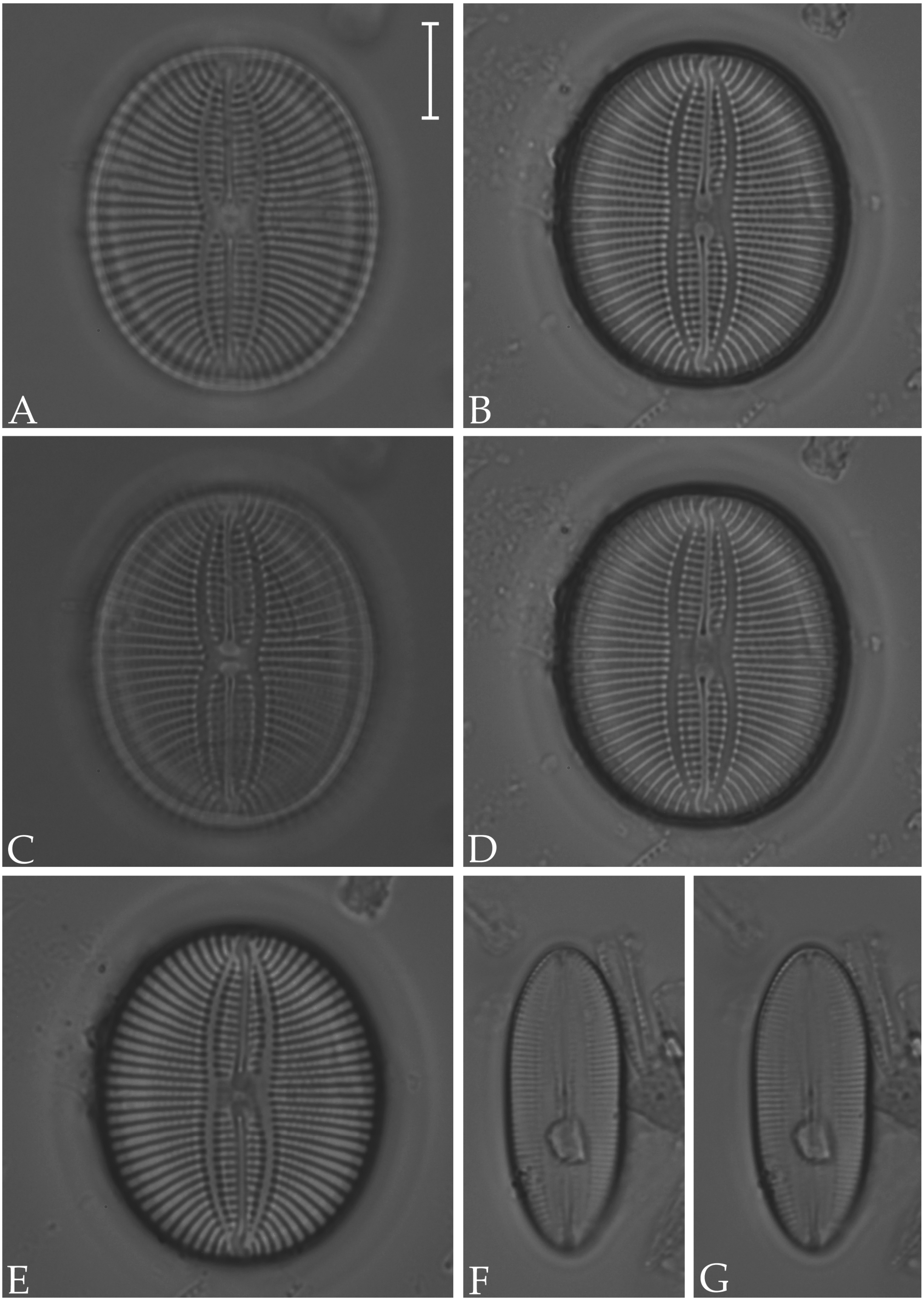

Figure 10. (**A**–**E**) *Fallacia nummularia*; (**F**,**G**) *F. litoricola*. Scale bar = 10 µm.

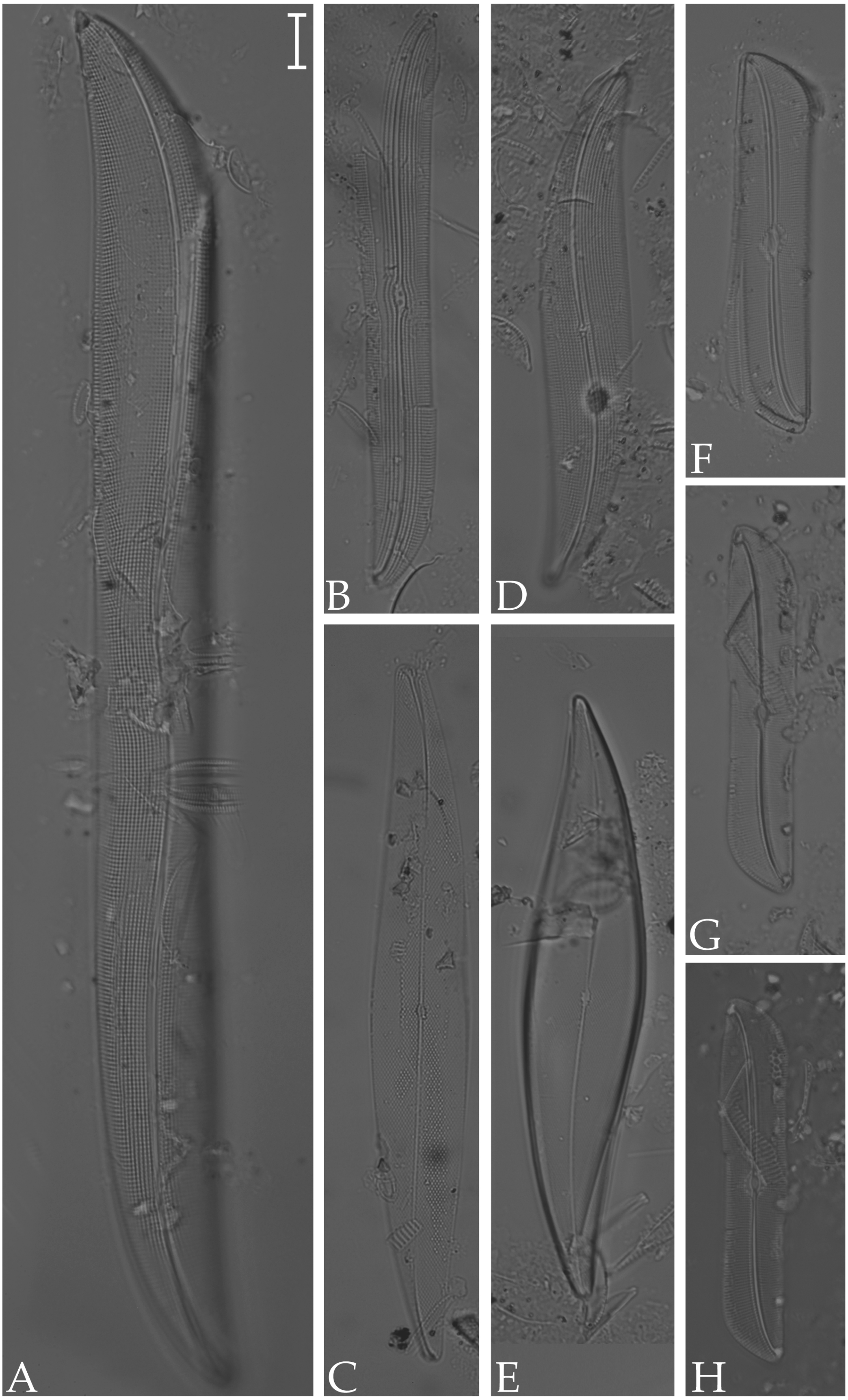

Figure 11. (**A**) *Gyrosigma balticum*; (**B**) *G. variistriatum*; (**C**) *Pleurosigma salinarum*; (**D**) *Gyrosigma peisonis*; (**E**) *Pleurosigma diversestriatum*; (**F–H**) *Gyrosigma eximium*. Scale bar = 10 μm.

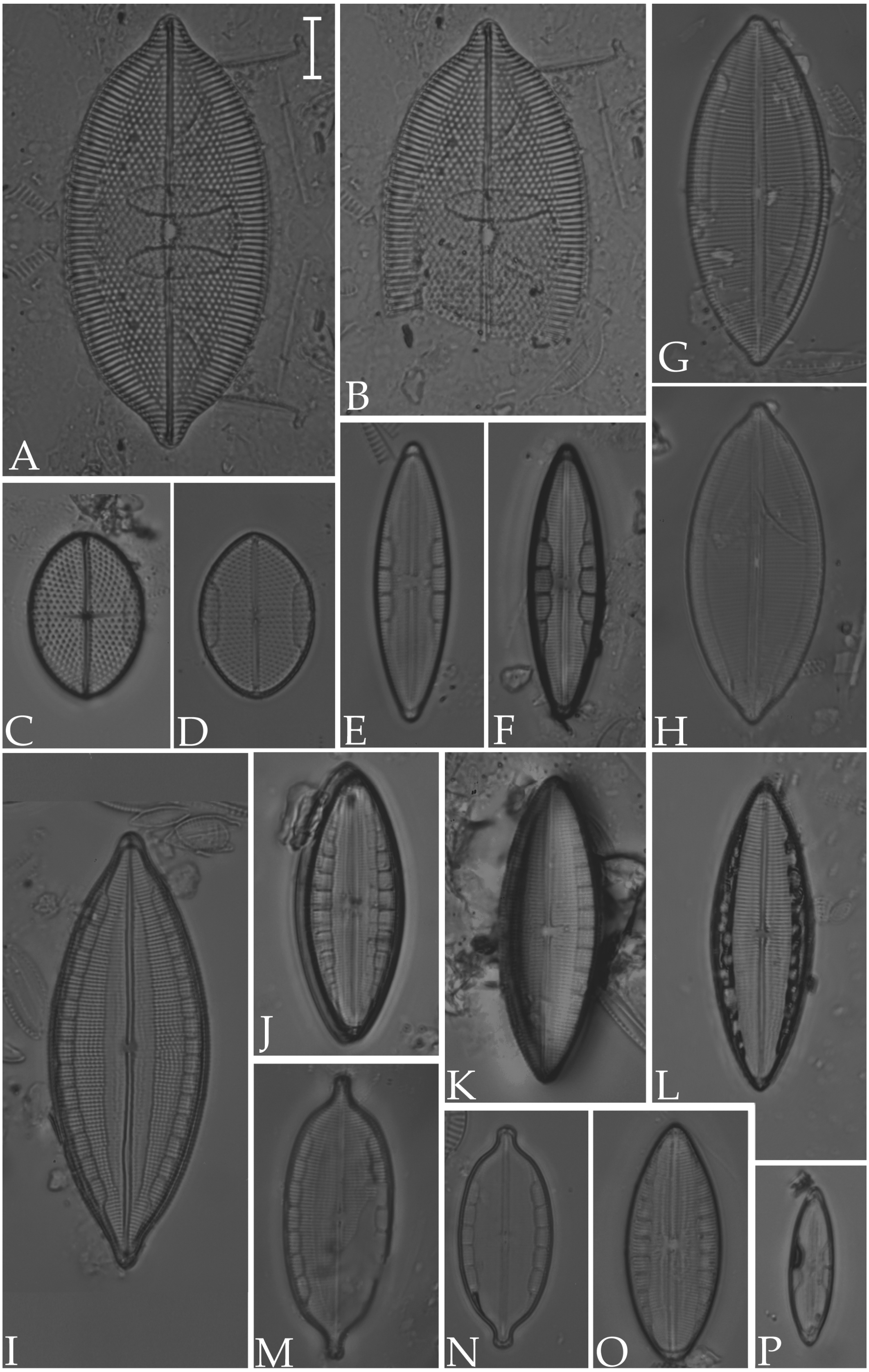

Figure 12. (**A**,**B**) *Mastogloia angulata*; (**C**,**D**) *M. binotata*; (**E**,**F**) *M. exigua*; (**G**,**H**) *M. apiculata*; (**I**) *M. pisciculus*; (**J**,**O**) *M. braunii*; (**K**,**L**) *M. robusta*; (**M**,**N**) *M. acutiuscula* var. *elliptica*; (**P**) *M. gieskesii*. Scale bar = 10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

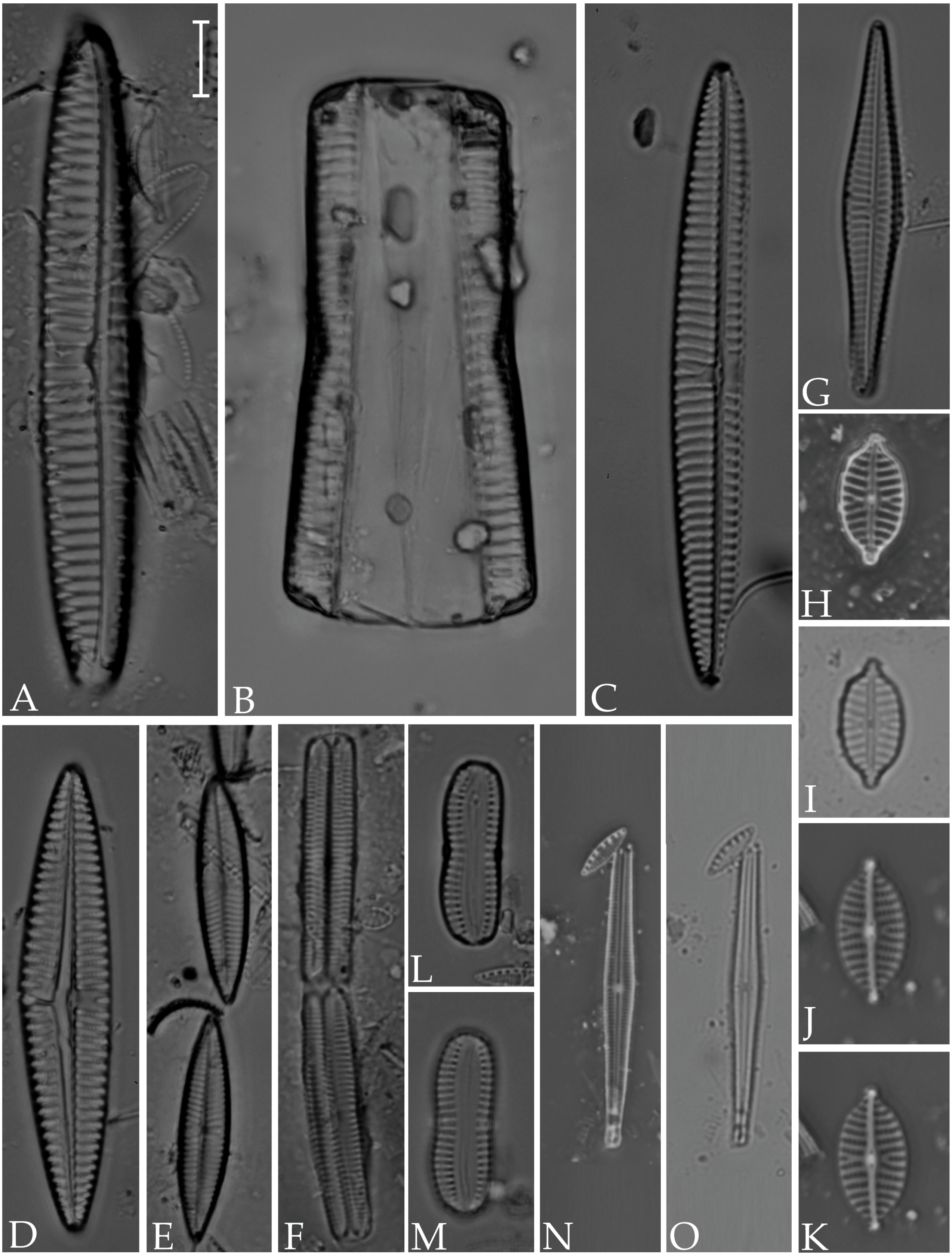

Figure 13. (**A**,**B**) *Navicula cancellata*; (**C**) *N. longa* var. *irregularis*; (**D**) *N. pennata*; (**E**) *N. normaloides*; (**F**) *N. cincta*; (**G**) *N. abunda*; (**H**–**K**) *N. platyventris*; (**L**,**M**) *Biremis ridicula* (**N**,**O**) *Brachysira* cf. *estoniarum*. Scale bar = 10 μm.

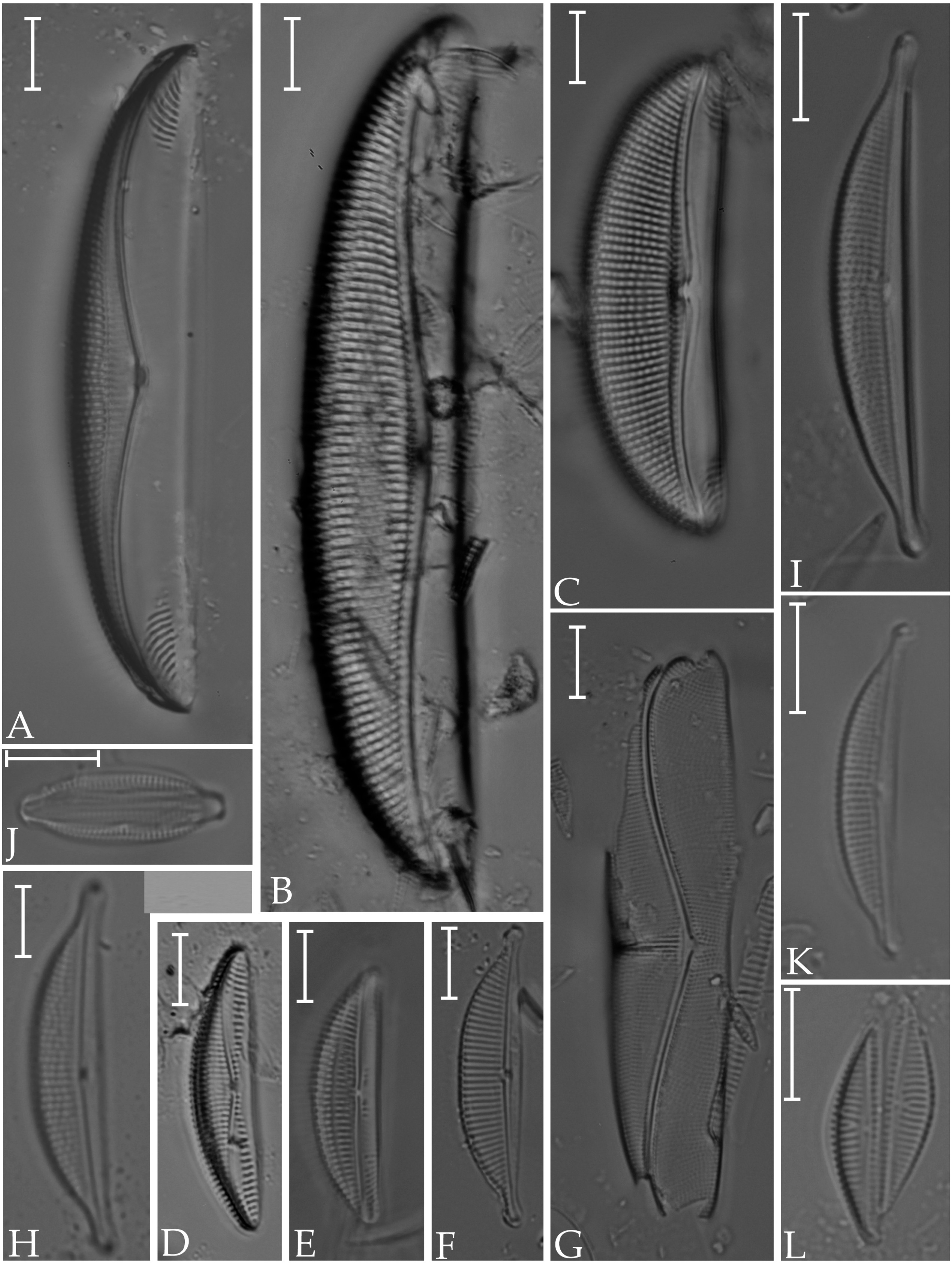

Figure 14. (**A**,**B**). *Amphora proteus* var. *proteus*; (**C**) *A. proteus* var. *contigua*; (**D**,**E**) *A. marina*; (**F**) *A. holsaticoides*; (**G**) *A. cingulata*; (**H**) *Halamphora holsatica*; (**I**,**J**) *H. coffeiformis*; (**K**) *H. acutiuscula*; (**L**) *Navicymbula pusilla* var. *lata*. Scale bars = 10 μm.

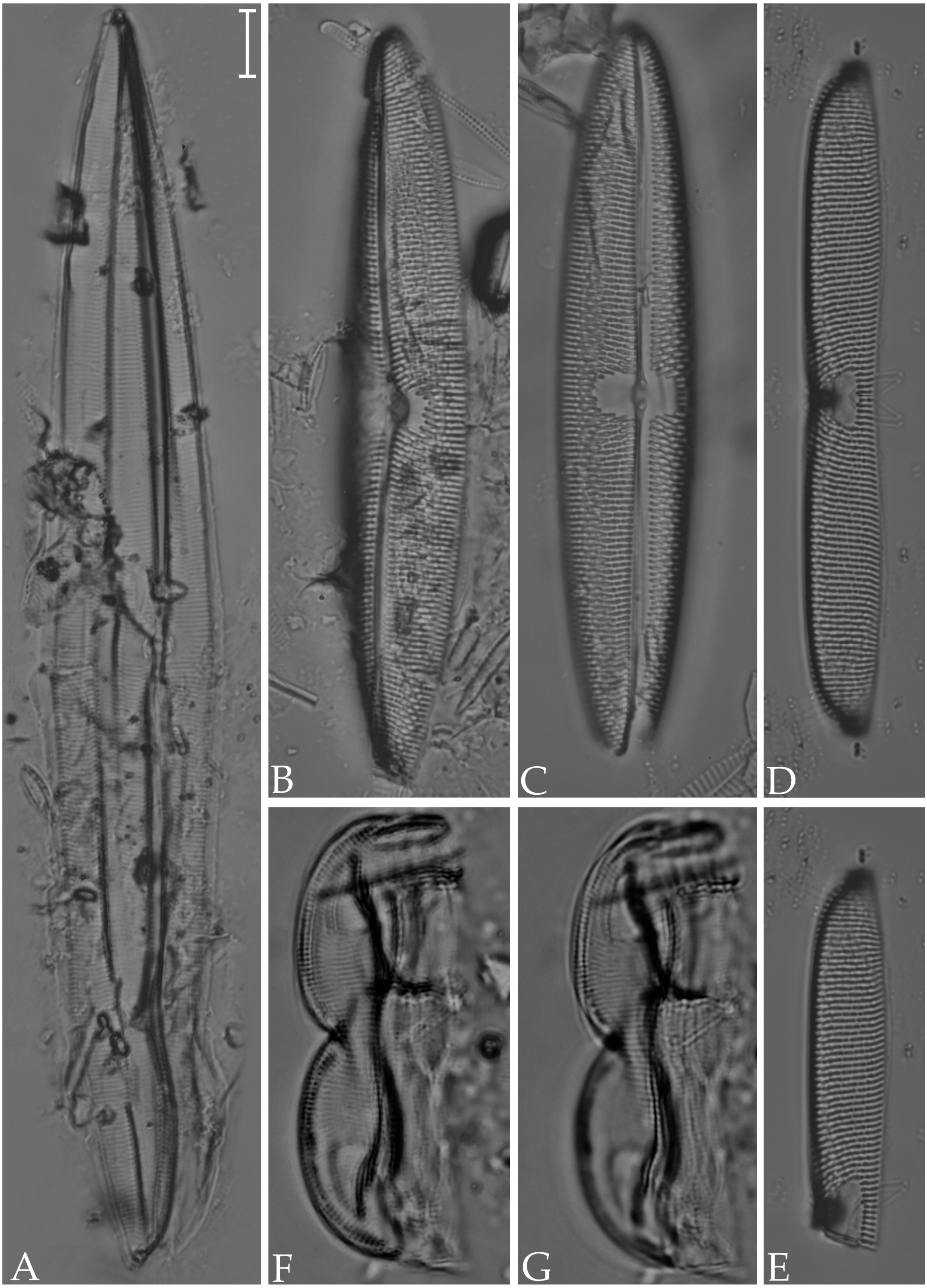

Figure 15. (**A**) *Plagiotropis pusilla*; (**B**,**C**) *Trachyneis velata*; (**D**,**E**) *T. aspera*; (**F**,**G**) *Entomoneis paludosa*. Scale bars = 10 µm.

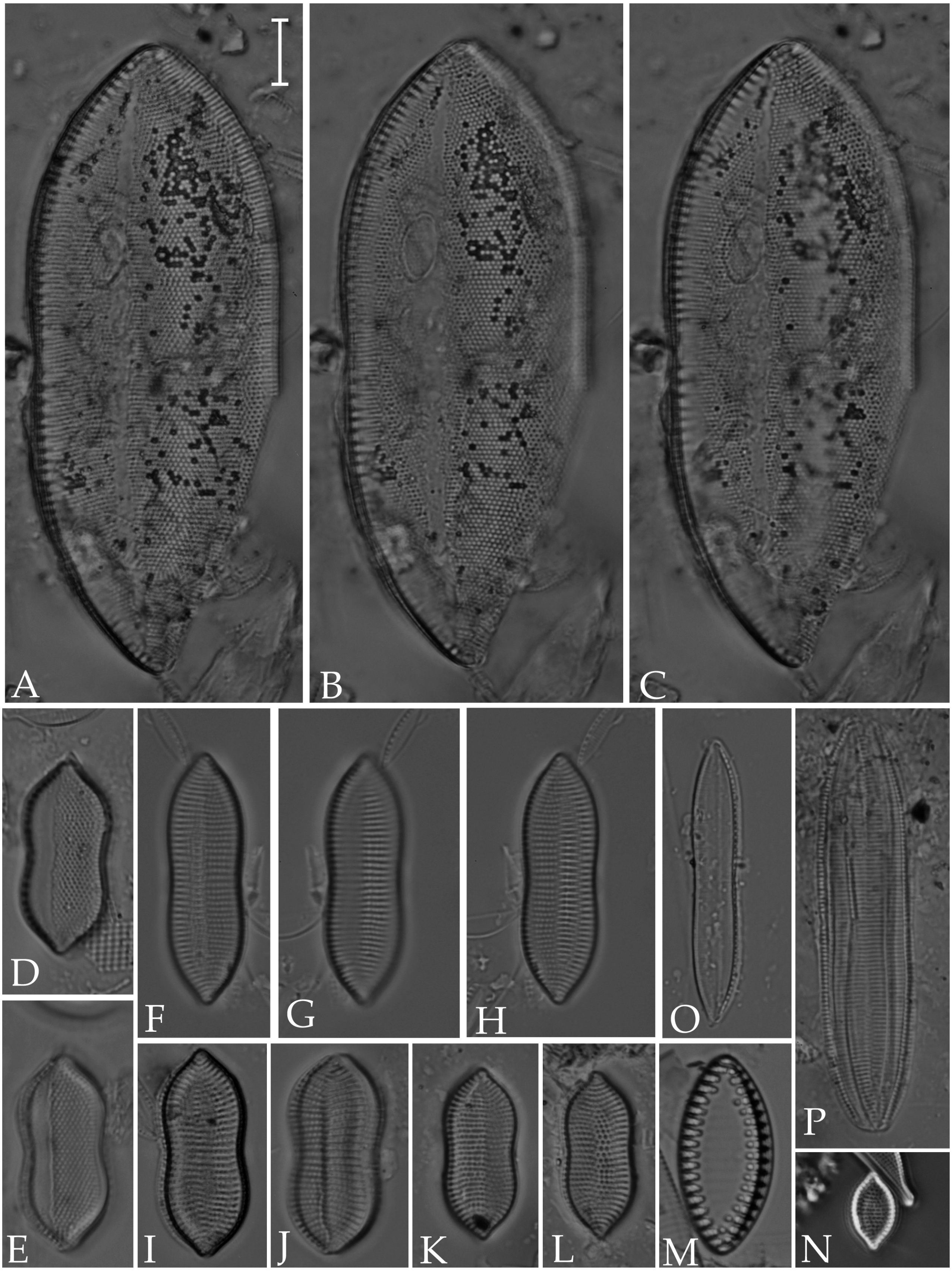

Figure 16. (**A**–**C**) *Psammodictyon panduriforme*; (**D**,**E**) *P. constrictum*; (**F**–**L**) *Tryblionella coarctata*; (**M**) *T. hyalina*; (**N**) *T. pararostrata*; (**O**,**P**) *T. hungarica*. Scale bar = 10 μm.

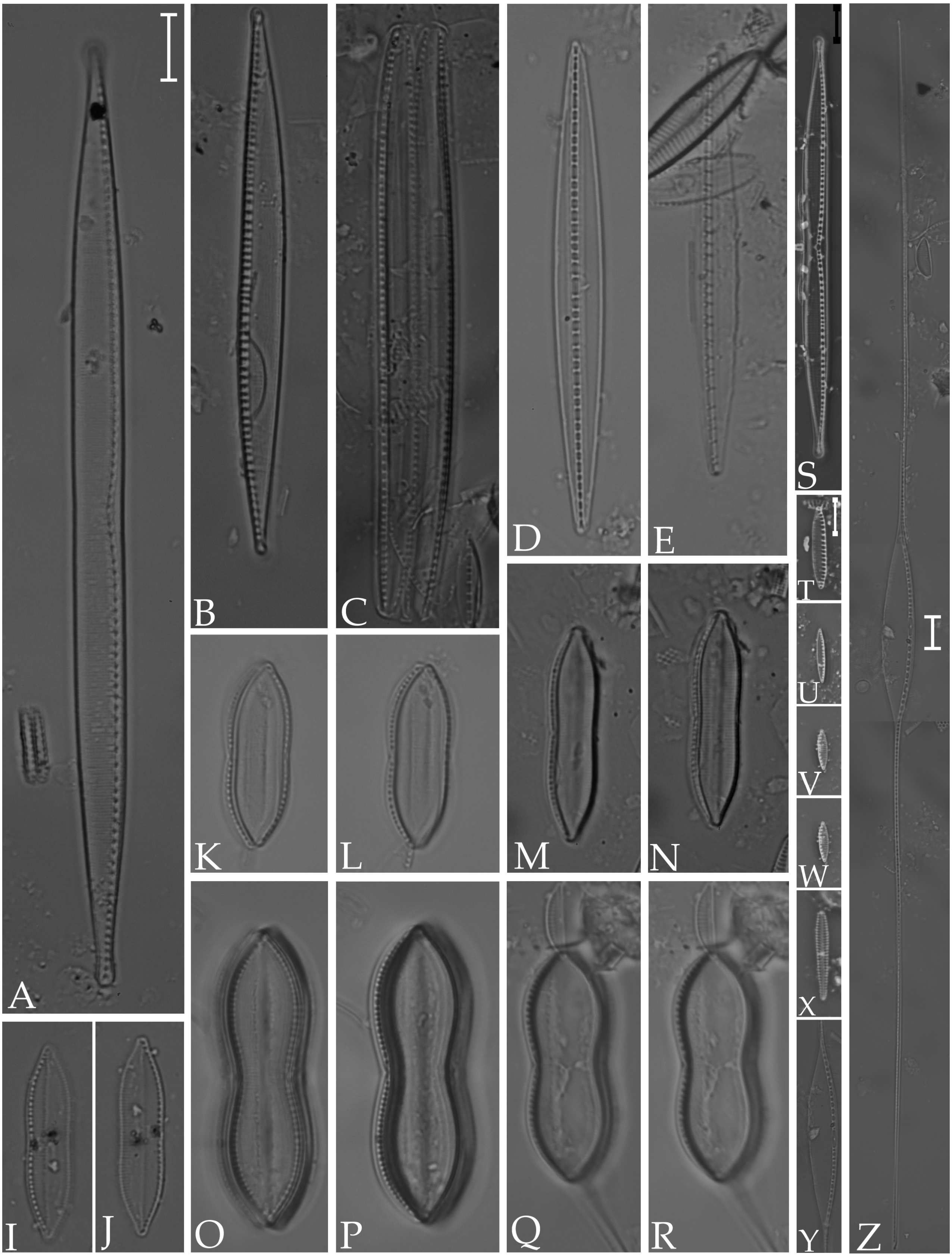

Figure 17. (**A**) *Nitzschia vidovichii*; (**B**,**C**) *N. sigma*; (**D**,**E**) *Homoeocladia distans*; (**I**,**J**) *Nitzschia subconstricta*; (**K**,**L**) *N. persuadens*; (**M**,**N**) *N. ligowskii*; (**O**–**R**) *N. carnicobarica*; (**S**) *N. scalpelliformis*; (**T**–**W**) *N. frustulum*; (**Y**,**Z**) *N. longissima*; (**X**) *Gomphoseptatum aestuarii*. Scale bars = 10 μm.

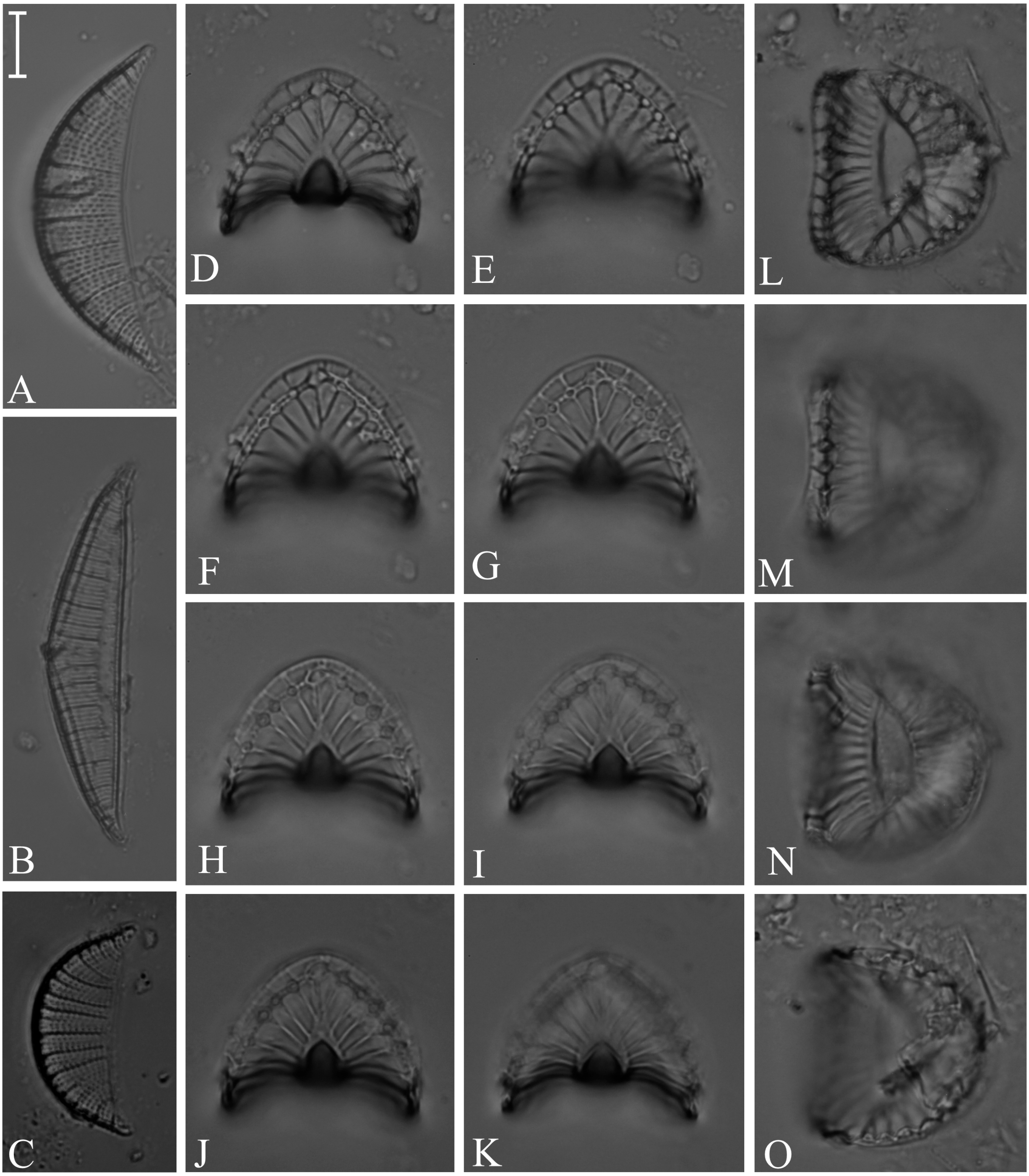

Figure 18. (**A**) *Rhopalodia gibberula*; (**B**) *R. acuminata*; (**C**) *R. musculus*; (**D**–**K**) *Coronia ambigua*; (**L**–**O**) *Campylodiscus subangularis*. Scale bars = 10 µm.

4. Discussion

The study area consists mainly of mangrove swamps; thus, soft sediments dominate the bottom substrate, with a low availability of hard substrate. This means that hard-shell organisms (such as 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]. Epipelic diatoms from these environments may constitute a reserve of potential colonizers for various basibionts, including the highly motile green crab, 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 the authors of [18], which inspected basibiotic diatoms on a quite-different marine arthropod, albeit with what seems to be 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, while 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). However, life habits between these crab species are quite different, and the comparison may just be related to the composition of the carapace.

Beyond this, there is great potential before further studies to be added to the literature. For instance, eventhough 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 the authors of [56], who recorded thirty diatom epizoic taxa on specimens of stone fish (*Scorpaena mystes* Jordan and Starks 1895), from the central Gulf of California, which 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 complete. Furthermore, the records that are currently available are the products of discrete sampling, both spatially and temporally, as is the case for epibiotic taxa on green swimming crabs. They are also limited by sampling size; for instance, the authors of [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 carapace of the green crabs are typical of the local epipelic 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 carapaces of green crabs are composed mainly of 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 to 80% vs. the main sample when using similarity indices [57]. However, because differences in species richness affect the similarity value, the approach that we used was direct.

Further hypothesis-driven studies on 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 floristic records for the Mexican coasts. In this manner, it may be explored if the species composition or the structure of the epibiotic assemblages aligns with 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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References

1. Dvoretsky, A.G.; Dvoretsky, V.G. Epibiotic communities of common crab species in the coastal Barents Sea: Biodiversity and infestation patterns. *Diversity* **2022**, *14*, 6. [CrossRef]
2. Totti, C.; Romagnoli, T.; De Stefano, M.; Camillo, D.C.G.; Bavestrello, G. The diversity of epizoic Diatoms. In *All Flesh Is Grass. Cellular Origin, Life in Extreme Habitats and Astrobiology*; Dubinsky, Z., Seckbach, J., Eds.; Springer: Dordrecht, The Netherlands, 2010; Volume 16. [CrossRef]
3. Tiffany, M.A. Epizoic and Epiphytic Diatoms. In *The Diatom World*; Seckbach, J., Kociolek, J.P., Eds.; Springer: New York, NY, USA, 2011; pp. 197–209. [CrossRef]
4. Wujek, D.E. Epizoic Diatoms on the cerci of Ephemenoptera (Caenidae) Naiads. *Great Lakes Entomol.* **2013**, *46*, 8. [CrossRef]
5. Cribb, A.B. Algae on the Hawks-Bill turtle. *Qsl. Nat.* **1969**, *19*, 108–109.
6. Croll, D.A.; Holmes, R.-W. A note on the occurrence of diatoms on the feathers of diving seabirds. *Auk* **1982**, *99*, 765–766. [CrossRef]
7. Denys, L. Morphology and taxonomy of epizoic diatoms (*Epiphalaina* and *Tursiocola*) on a sperm whale (*Physeter macrocephalus*) stranded on the coast of Belgium. *Diatom. Res.* **1997**, *12*, 1–18. [CrossRef]
8. Hart, T.J. On the diatoms of the skin film of whales, and their possible bearing on problems of whale movements. *Discov. Rep.* **1935**, *10*, 247–282.
9. Holmes, R.W. The Morphology of diatoms epizoic on Cetaceans and their transfer from *Cocconeis* to two new genera, *Bennettella* and *Epipellis*. *Br. Phycol. J.* **1985**, *20*, 43–57. [CrossRef]
10. Becker, K. Epibionts on carapaces of some Malacostracans from the Gulf of Thailand. *J. Crustac. Biol.* **1996**, *16*, 92–104. [CrossRef]
11. Gaiser, E.E.; Bachmann, R.W. The ecology and taxonomy of epizoic diatoms on Cladocera. *Limnol. Oceanogr.* **1993**, *38*, 628–637. [CrossRef]
12. Gibson, R.A. *Pseudohimantidium pacificum*, an epizoic diatom new to the Florida current (western North Atlantic Ocean). *J. Phyc.* **1978**, *14*, 371–373. [CrossRef]
13. Prasad, A.K.S.K.; Livingston, R.J.; Ray, G.L. The marine epizoic diatom *Falcula hyaline* from Chactawatchee Bay, the northeastern Gulf of Mexico: Frustule morphology and ecology. *Diatom. Res.* **1989**, *4*, 119–129. [CrossRef]
14. Russell, D.J.; Norris, R.E. Ecology and taxonomy of an epizoic diatom. *Pac. Sci.* **1971**, *25*, 357–367.
15. Key, M.M.; Winston, J.E.; Volpe, J.W.; Jeffries, W.B.; Voris, H.K. Briozoan fouling of the blue crab *Callinectes sapidus* at Beaufort, North Caroline. *Bull. Mar. Sci.* **1999**, *64*, 513–533.

16. Sánchez-Vargas, D.P.; Hendrickx, M.E. Utilization of algae and sponges by tropical decorating crabs (Majidae) in the Southeastern Gulf of California. *Rev. Biol. Trop.* **1987**, *35*, 161–164.
17. Madkour, F.F.; Sallam, W.S.; Wicksten, M.K. Epibiota of the spider crab *Schizophrys dahlak* (Brachyura: Majidae) from the Suez Canal with special reference to epizoic diatoms. *Mar. Biodivers. Rec.* **2012**, *5*, e64. [CrossRef]
18. Patil, J.S.; Anil, A.C. Epibiotic community of the horseshoe crab *Tachypleus gigas*. *Mar Biol.* **2000**, *136*, 699–713. [CrossRef]
19. Escamilla-Montes, R.; De la Cruz-Agüero, G.; Villalejo-Fuerte, M.T.; Duarte-Plata, G. Fecundidad de *Callinectes arcuatus* (Ordway, 1863) y *C. bellicosus* (Stimpson, 1859) (Decapoda: Brachyura: Portunidae) en la Ensenada de La Paz, Golfo de California, México. *Univ. Cienc.* **2013**, *29*, 53–61.
20. Hendrickx, M.E. Cangrejos. In *Guía FAO para la Identificación de Especies para los Fines de la Pesca. Pacífico Centro-Oriental. Volumen, I. In Plantas e Invertebrados*; Fischer, W., Krupp, F., Schneider, W., Sommer, C., Carpenter, K.E., Niem, V.H., Eds.; FAO: Rome, Italy, 1995; Volume I, pp. 565–636.
21. Hernández, L.; Arreola-Lizárraga, J.A. Estructura de tallas y crecimiento de los cangrejos *Callinectes arcuatus* y *C. bellicosus* (Decapoda: Portunidae) en la laguna costera Las Guásimas, México. *Rev. Biol. Trop.* **2007**, *55*, 225–233. Available online: http://www.redalyc.org/articulo.oa?id=44955124 (accessed on 1 December 2023). [CrossRef]
22. Hines, A.H.; Lipcius, R.N.; Haddon, A.M. Population dynamics and habitat partitioning by size, sex and molt stage of blue crab *Callinectes sapidus* in a subestuary of central Chesapeake Bay. *Mar. Ecol.* **1987**, *36*, 55–64. Available online: https://scholarworks.wm.edu/vimsarticles/1982 (accessed on 1 December 2023). [CrossRef]
23. McLay, C.L. Dispersal and use of sponges and ascidian camouflage by *Cryptodromia hilgendorfi* (Brachyura: Decapoda). *Mar. Biol.* **1983**, *76*, 17–32. [CrossRef]
24. Sato, M.; Wada, K. Resource utilization for decorating in three intertidal Majidae crabs (Brachyura: Majidae). *Mar. Biol.* **2000**, *137*, 705–714. [CrossRef]
25. López-Fuerte, F.O.; Siqueiros Beltrones, D.A. A checklist of marine benthic diatoms (Bacillariophyta) from Mexico. *Phytotaxa* **2016**, *283*, 201–258. [CrossRef]
26. Cleve-Euler, A. Die Diatomeen von Schweden und Finnland. Part V. (Schluss.). *K. Sven. Vetensk. Akad. Handl. Ser. 4* **1952**, *3*, 1–153.
27. Cleve-Euler, A. *Die Diatomeen Von Schweden und Finnland. Teil II. Araphideae, Brachyraphideae. Mit 35 Tafeln*; Almqvist & Wiksells Boktryckeri Ab: Stockholm, Sweden, 1953; p. 158.
28. Cleve-Euler, A. *Die Diatomeen von Schweden und Finnland. Part III. Monoraphideae, Biraphideae 1*; Kongliga Svenska Vetenskaps Akademiens Handligar: Stockholm, Sweden, 1953; p. 255.
29. Cleve-Euler, A. Die Diatomeen von Schweden und Finnland. Part IV. Biraphideae 2. K. *Sven. Vetensk. Akad. Handl. Ser. 4* **1955**, *5*, 1–232.
30. Foged, N. Some littoral diatoms from the coasts of Tanzania. *Biblioth. Phycol.* **1975**, *16*, 1–127.
31. Foged, N. Diatoms in Eastern Australia. *Biblioth. Phycol.* **1978**, *41*, 1–243.
32. Foged, N. Freshwater and littoral diatoms from Cuba. *Biblioth. Diatom.* **1984**, *5*, 1–242.
33. Hustedt, F. Die kieselalgen Deutschlands, Osterreichs and der Schweis, Bacillariophyta (Diatomae) Heft 10. In *Die Süsswasser-Flora Mitteleuropas*; Pascher, A., Ed.; Gustav Fischer: Jena, Germany, 1930; p. 466.
34. Hustedt, F. Die kieselalgen Deutschlands, Osterreichs and der Schweis. In *Kryptogammen-Flora*; VII Band, II Teil; Rabenhorts, L., Ed.; Koeltz Scientific Book: Leipzig, Germany, 1959; p. 845.
35. Hustedt, F. Die kieselalgen Deutschlands, Osterreichs and der Schweis. In *Kryptogammen-Flora*; VII Band, III Teil; Rabenhorst, L., Ed.; Koeltz Scientific Book: Leipzig, Germany, 1966; p. 816.
36. Krammer, K.; Lange-Bertalot, H. Bacillariophyceae 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In *Suesswasserflora von Mitteleuropa 2 (3)*; Gustav Fisher: Jena, Germany, 1991; 576p.
37. Lange-Bertalot, H.; Krammer, K. Bacillariaceae, Epithemiaceae, Surirellaceae. Neue und wenig bekannte Taxa, neue Kombinationen und Synonyme sowie Bemerkungen und Ergänzungen zu den Naviculaceae. *Biblioth. Diatom.* **1987**, *15*, 1–289.
38. Lange-Bertalot, H.; Kulbs, K.; Lauser, T.; Norpel-Schempp, M.; Willmann, M. Diatom taxa introduced by Georg Krasske: Documentation and revision. In *Iconographia Diatomologica*; Lange-Bertalot, H., Ed.; Koeltz Scientific Books: Konigstein, Germany, 1996; Volume 3, 358p.
39. Lobban, C.S.; Schefter, M.; Jordan, R.W.; Arai, Y.U.; Sasaki, A.S.; Theriot, E.C.; Ashworth, M.A.; Ruck, E.C.; Pennesi, C.H. Coral-reef diatoms (Bacillariophyta) from Guam: New records and preliminary checklist, with emphasis on epiphytic species from farmer-fish territories. *Micronesica* **2012**, *43*, 237–479.
40. Loir, M.; Novarino, G. *Marine Mastogloia Thwaites ex W. Sm. and Stigmaphora Wallich Species from the French Lesser Antille*; Diatom Monographs, Koeltz Scientific Books: Königstein, Germany, 2013; Volume 16, p. 133.
41. Moreno, J.L.; Licea, S.; Santoyo, H. *Diatomeas del Golfo de California*; Universidad Autónoma de Baja California Sur-SEP-FOMESPROMARCO: Tijuana, Mexico, 1996; p. 273.
42. Peragallo, H.; Peragallo, M. *Diatomées Marines de France et des Districts Maritimes Voisins*; Tempère, J., Ed.; Micrographe-Editeur: À Grez-sur-Loing, France, 1908.
43. Schmidt, A.; Schmidt, M.V.; Fricke, F.V.; Heiden, H.; Muller, O.; Hustedt, F. *Atlas der Diatomaceenkunde*; Heft 1–120, Tafeln 1–460; Reisland: Leipzig, Germany, 1959.
44. Stidolph, S.R.; Sterrenburg, F.A.S.; Smith, K.E.L.; Kraberg, A.; Stuart, R. Stidolph Diatom Atlas. U.S. Geological Survey Open-File Report 2012-1163. Available online: http://pubs.usgs.gov/of/2012/1163/ (accessed on 1 December 2023).

45. Witkowski, A.; Lange-Bertalot, H.; Metzeltin, D. Diatom Flora of Marine Coasts. In *Iconographia Diatomologica*; Lange-Bertalot, H., Ed.; Koeltz Scientific Books: Königstein, Germany, 2000; pp. 1–925.
46. Kingston, J.C. Araphid and monoraphid diatoms. In *Freshwater Algae of North America, Ecology and Classification*; Wehr, J.D., Sheath, R.G., Eds.; Academic Press: San Diego, CA, USA, 2003; pp. 595–636.
47. Kociolek, J.P.; Spaulding, S.A. Symmetrical naviculoid diatoms. In *Freshwater Algae of North America, Ecology and Classification*; Wehr, J.D., Sheath, R.G., Eds.; Academic Press: San Diego, CA, USA, 2003; pp. 637–654.
48. Medlin, L.K.; Kaczmarska, I. Evolution of the diatoms: V. Morphological and cytological support for the major clades and a taxonomic revision. *Phycologia* **2004**, *43*, 245–270. [CrossRef]
49. Round, F.E.; Crawford, R.M.; Mann, D.G. *The Diatoms: Biology & Morphology of the Genera*; Cambridge University Press: Cambridge, UK, 1990; p. 747.
50. Guiry, M.D.; Guiry, G.M. *Algaebase. World-Wide Electronic Publication*; National University of Ireland: Galway, Ireland. Available online: http://www.algaebase.org (accessed on 1 December 2023).
51. WoRMS Editorial Board. World Register ofMarine Species. Available online: http://www.marinespecies.org (accessed on 1 December 2023).
52. Siqueiros Beltrones, D.A. Diatomeas bentónicas asociadas a trombolitos vivos registrados por primera vez en México. *CICIMAR Oceán.* **2006**, *21*, 113–143.
53. Siqueiros Beltrones, D.A.; Morzaria Luna, H. New records of marine benthic diatom species for the north-western Mexican region. *Oceánides* **1999**, *14*, 89–95.
54. Siqueiros Beltrones, D.A.; Sánchez-Castrejón, E. Structure of benthic diatom assemblages from a mangrove environment in a Mexican Subtropical Lagoon. *Biotropica* **1999**, *31*, 48–70.
55. López-Fuerte, F.O.; Siqueiros Beltrones, D.A.; Navarro, J.N. *Benthic Diatoms Associated with Mangrove Environments in the Northwest Region of Mexico*; CONABIO-UABCS-IPN: La Paz, Mexico, 2010; p. 217.
56. López-Fuerte, F.; Siqueiros-Beltrones, D.; Jakes-Cota, U.; Tripp-Valdéz, A. New Records of Marine Diatoms for the American Continent Found on Stone Scorpionfish *Scorpaena mystes*. *Open J. Mar. Sci.* **2019**, *9*, 98–112. [CrossRef]
57. Siqueiros Beltrones, D.A.; López-Fuerte, F.O.; Martínez, Y.J.; Altamirano-Cerecedo, M.C. A first estimate of species diversity for benthic diatom assemblages from the Revillagigedo Archipelago, Mexico. *Diversity* **2021**, *13*, 458. [CrossRef]