

Article

Species Diversity of Benthic Marine Diatoms from a Natural Protected Area in Cuba

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Abstract: For the Cuban littorals in the Caribbean Sea, information on benthic diatoms is scarce, and hitherto non-existent for natural protected areas. Thus, to describe the structure of benthic diatom associations (BDAs) from a marine protected area in Cuba, sediment samples were collected in Playa Las Gaviotas (Refugio de Vida Silvestre Cayo Santa María) during dry (November) and rainy (July) seasons. Diatoms were separated, mounted in synthetic resin and identified under light microscopy. Species diversity of the BDA was estimated using Shannon (H'), Simpson ($1 - \lambda$) and Pielou evenness (J') indices. We identified 354 taxa including 200 new records for Cuba; the nomenclature of 45 previously recorded taxa was updated. The currently recorded species richness of marine benthic diatoms for Cuba is 595. The most abundant taxa were *Amphora* cf. *copulata*, *A. proteus*, *Diploneis smith* var. *pumila*, *Halammphora turgida*, *H. coffeiformis*, *Navicula zostereti*, *Nitzschia marginulata* var. *didyma* and *Psammodictyon panduriforme*. The best-represented genus was *Mastogloia* with 70 taxa. Similarity values indicated homogeneous distribution of epipelagic diatom taxa along the sandy bottom, suggesting a single diatom association. Mean values of H' ranged from 4.91 bit/taxon in November to 4.95 bit/taxon in July. Structure analysis suggests a stable BDA with high species diversity characteristic of productive, pristine environments.

Keywords: association structure; Bacillariophyceae; Caribbean Sea; floristics



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1. Introduction

Issues regarding conservation and ecology concerning a given ecosystem demand formal scientific knowledge of all living resources found within, and the identification of both faunistic and floristic elements should be considered a priority [1]. Under this perspective, benthic diatom associations (BDAs) are recognized as suitable references for making decisions on conservation and ecological issues in marine ecosystems, particularly for protected areas [2]. However, in many parts of the biosphere where diatoms are abundant, still little is known about their ecological attributes, or even of the species composition in the various substrates they occupy. The significance that these premises may have on ecological and biogeographical topics clearly justifies further research of benthic diatoms in protected areas and in poorly explored, unprotected pristine areas alike. In contrast, simple but valuable floristic studies with basic design are still common

worldwide [3–6]. Moreover, in the regional scene, several recent efforts off Mexican littorals, both Pacific and Atlantic, have mitigated the scarcity of information on marine benthic diatoms [1,2,6–9]. All these are useful for constructing taxonomic bases that support further hypothesis-driven ecological and biogeographical research.

According to the above, research should focus initially on constructing a reliable floristics basis of BDAs which can be further used for estimating ecological parameters that further describe the assemblages in terms of species diversity components, i.e., species richness, relative abundances, evenness and dominance. Alternatively, the individual floral components of diatom taxocenoses may prove useful in the biogeographical characterization of ecosystems based on the frequency, abundance and space-time distribution of a certain taxon. An example is the genus *Mastogloia*, showing a remarkable diversity in Mexican tropical latitudes [6,9], and the high number of species of *Lyrella* found in temperate environments in the NW Mexican Pacific coasts [2]. Recently, *Mastogloia* and *Lyrella* taxa have been proposed as references to detect biogeographical affinities of marine BDAs in a region having transitional oceanographic characteristics [1].

On the other hand, because their high species diversity renders them useful for assessing environmental impact [10], benthic diatoms may also be considered an adequate reference for measuring biodiversity in protected areas. Protected areas are strategic for the conservation of species and their habitats; however, doubts regarding their effectiveness have prompted hypotheses for testing that such measures are in fact effective in conserving species and showing that within-sample species richness could be significantly higher inside protected areas than outside [11]. In this way, the hypothesis that epipellic BDAs from the intertidal zone of Guerrero Negro Lagoon, Mexico (a natural protected area) would exhibit high species richness was supported ($S = 232$ taxa), which was backed up by the estimation of high diversity values ($H' > 4$) based on information theory [2]. Likewise, research in the National Park Archipelago, Revillagigedo (Mexico) yielded an overall high species richness (397 taxa) of epiphytic diatoms on macroalgae, and high values of species diversity ($H' > 4$) were subsequently estimated [6].

The current situation in terms of the Cuban archipelago in the Caribbean/Gulf of Mexico region regarding the knowledge on benthic diatoms presents both problems stated above, i.e., scarce information on the overall diatom flora and on diversity estimations, and lack of a correspondent reference regarding protected areas. This applies to the marine protected area Refugio de Vida Silvestre, Cayo Santa María, which comprises the study area in this investigation, Playa Las Gaviotas. Most of the research on phytoplankton and phytobenthos in Cuban littorals dates from the 1970's. Afterwards, despite a formal previous contribution [12], only a discrete sampling had been done that included benthic diatoms [13], that constitutes an initial floristic effort. The existing research on benthic marine diatoms for Cuba consisted mostly of Foged's account [12] of 395 taxa which resulted from an extensive sampling. This number of taxa matches the high species richness recorded for various pristine localities and protected areas elsewhere, such as the 379 taxa recorded for the Bahamas Archipelago [14] in the Caribbean Sea, where a considerable sampling effort was carried out. Elsewhere, studies in the Archipelago Revillagigedo, a marine national park in the Pacific Ocean, have yielded an overall species richness of 397 epiphytic diatom taxa [6]. At the same time, epipellic diatoms from the intertidal zone of Guerrero Negro Lagoon (Mexico), a natural protected area on the temperate coast of the Baja California Peninsula, constituted assemblages with a species richness of 232 taxa [2].

The objective of this study was to describe the association structure of the epipellic diatom associations living in beach sediments within a marine protected marine area off the Cuban coast. We tested the hypothesis that a high species diversity would be estimated as in other marine protected areas. Since seasonality may influence species composition

of diatom taxocenoses [15,16], sampling was done during the two main seasons (dry and rainy) to obtain a better temporal overview of the diatom flora of the area. We expected that numerous previously unrecorded taxa could be detected, significantly increasing the species richness so far for the Cuban coast. Inevitably, the nomenclature of many taxa recorded earlier for the coast of Cuba [12] had to be updated. The structure of the benthic diatom association in the study area was described based on several ecological indices.

2. Materials and Methods

2.1. Study Area

The sampling site Playa Las Gaviotas is a sandy beach that can be accessed by road, located on the middle north coast ($79^{\circ}11'$ and $78^{\circ}56'$ W, and $22^{\circ}39'$ and $22^{\circ}29'$ N) within the marine protected area Refugio de Vida Silvestre, Cayo Santa María (Figure 1), one of the main areas of the Sabana-Camagüey archipelago in the Buenavista biosphere reserve in Cuba. It covers 298.76 km^2 , comprising 43.42 km^2 land and 255.32 km^2 marine habitats [17]. Cayo Santa María includes an extended seagrass cover with various degrees of plant dominance with a mosaic distribution on muddy, mud-sand, and sandy bottoms [18]. Climate has little variation, but well-defined rainy (May–October) and dry (November–April) seasons [19]. Tidal range does not exceed 20 cm [20].

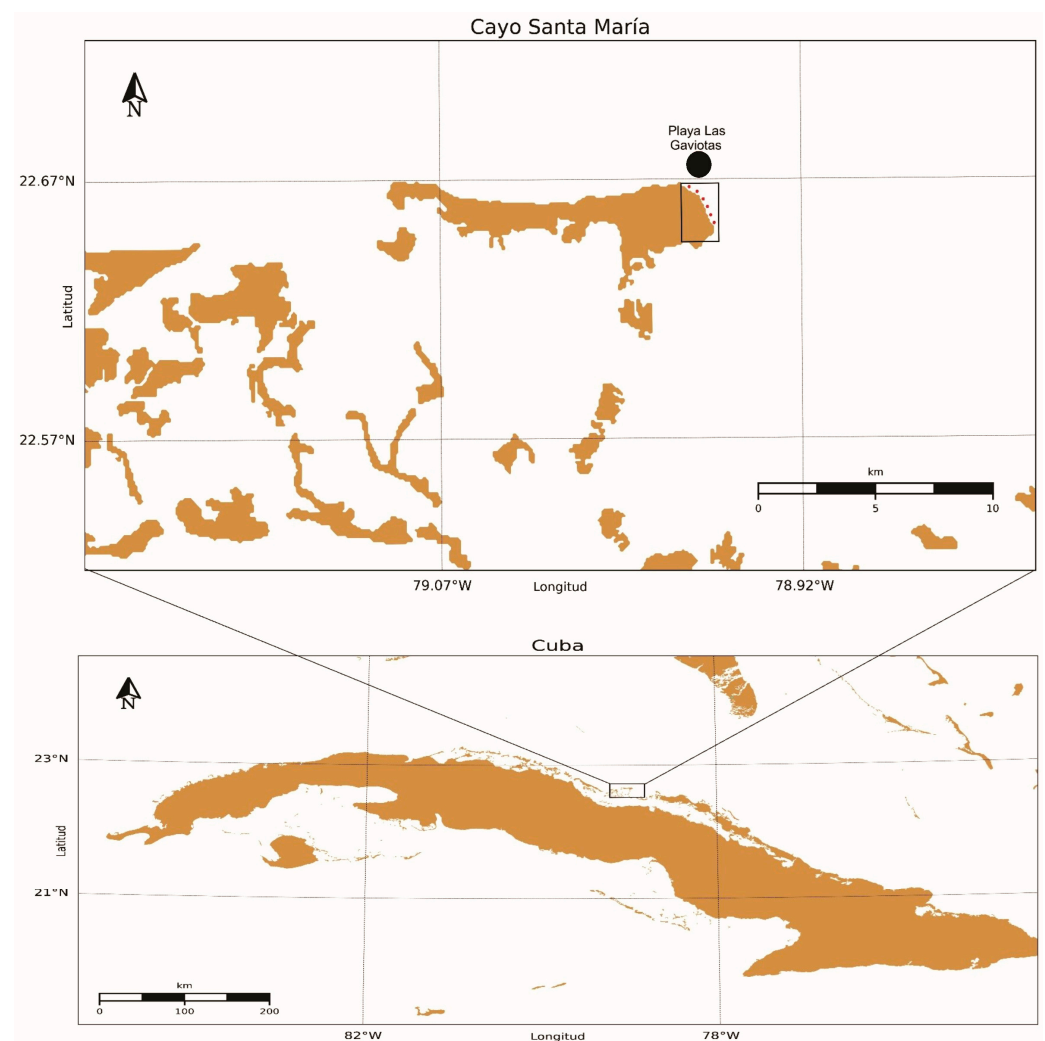


Figure 1. Location of sampling sites for benthic diatoms in sediments of Playa Las Gaviotas (●) within the marine protected area Refugio de Vida Silvestre, Cayo Santa María, Buenavista biosphere reserve, Cuba.

2.2. Sampling and Processing of Samples

To gather epipelagic diatoms from Playa Las Gaviotas (Cuba) during November 2021 and July 2022, three sediment samples (replicates) were collected in the intertidal window at six points along the study area at a medium depth of 70 cm by free diving (Figure 1). Sampling points stood every 200 m while replicates were 2 m apart. The top of a 12 cm diameter Petri dish was used to cut out approximately the first three mm of sediment from the sea-bottom. Samples were preserved in 75% alcohol for their later processing in the laboratory.

In the region that comprises the study area, low dynamics are exerted by tidal currents on the deposition of sediments coming from the island [20] that could influence the species composition of epipelagic diatoms. Differences in sediment composition could result in different diatom associations, instead of a single typical patchy one. So, during the 2022 (second) sampling, at each point an additional sediment sample was collected to carry out a granulometric sorting to explore the homogeneity of the seafloor sediments. In the laboratory, 10 g of the sediment sample was mixed with 30 mL of purified water and treated with ultrasound; a 5% solution of hexametaphosphate was added to help separate particles. A Beckman Coulter LS13320 Laser Diffraction Analyzer (Brea, CA, USA) was used. Samples were sifted to remove particles >2 mm (shell or coral) that could preclude an adequate functioning of the laser analyzer. Approximately 2 g of the recovered solution was emptied into a laser particle analyzer and the [21] scale was used for the readings.

To separate the diatoms, the sediments of each collected replicate were mixed with 60 mL of distilled water and treated with ultrasound for two minutes to detach diatoms fixed on the sand grains. The supernatant was separated and left to rest for 24 h for the settling of the diatom frustules. Thereafter, 2 mL of the supernatant and remaining sediment was separated and placed in a 150 mL test-tube to which, initially, 3 mL of nitric acid and 1 mL of 70% alcohol were added to digest all organic matter to clean the frustules [22]. An exothermal reaction followed, indicating proper oxidation of organic matter. Whenever the digestive reaction idle due to excessive organic matter, 2 mL of nitric acid and 1 mL of alcohol were added to the mixture reaching a ratio of 2:5:2 (sample, acid, alcohol). The oxidized sample was diluted with 100 mL distilled water and left to rest. After 24 h, the sample was rinsed with distilled water until reaching a $\text{pH} \geq 6$. For making permanent mounted slides of the cleaned diatoms, a drop of each replicate was dried on a coverslip and mounted with a drop of synthetic resin Pleurax[®] (RI = 1.7) (Bill Daily, Philadelphia, PA, USA) on a glass slide and heated. Three preparations (repetitions) were mounted for each replicate with two coverslips each [22].

2.3. Qualitative and Quantitative Analyses of Diatom Samples

In the qualitative stage, all mounted preparations were thoroughly inspected to identify as many species and infra-species taxa as possible. The diatom taxa were identified morphologically at $1000\times$ under an Olympus CH-2 compound microscope (Tokyo, Japan) equipped with plan-apochromatic lenses and a photographic ocular lens. To provide an iconographic catalogue, micrographs were taken of representative diatom taxa, i.e., those conspicuous (large) or occurring more frequently. Identification of the taxa followed: [1,2,6,7,11,13,15,16,22–29]. Taxonomic status of all identified diatoms was updated according to the Algaebase platform [30] and the Catalogue of Diatom Names of the California Academy of Science [31].

For numerical analysis of the BDA, relative abundances of the diatom taxa were estimated based on a pre-set sample size for productive habitats of 500 valves per replicate [22], i.e., a total $N = 54,000$ valves. Overall, taxa were classified arbitrarily according to their

relative abundances as follows: abundant ≥ 1000 ; common $500 < x < 1000$; uncommon $50 < x < 500$; rare ≤ 50 .

Relative abundances were used in standardized form to compute ecological indices for estimating species diversity, evenness and dominance of the BDA samples and replicates using the following indices:

Shannon's (H') index is sensitive to the presence of rare taxa; base 2 logarithm was used [32].

$$H' = -\sum_{i=1}^S p_i \log_2 p_i$$

where $p_i = n_i/N$ is the ratio of the i th species in the total number of valves, N and S are the number of valves and species, respectively [33].

Pielou's evenness (J') is a relative diversity index [34] that uses the ratio between the computed diversity and the maximum (theoretical) diversity that corresponds to the species richness (S) [34]:

$$J' = \frac{H'_{obs}}{H'_{max}}$$

where H'_{obs} is the computed diversity value, and H'_{max} is the theoretical diversity calculated as $\log_2 S$.

Simpson's diversity ($1 - \lambda$) and dominance (λ) consider mostly the numerically important taxa, disregarding the rare ones. First, the dominance index was computed:

$$\lambda = \frac{\sum n_i(n_i - 1)}{N(N - 1)} \quad (1)$$

where p_i = proportional abundance of the i th species, and N is the total number of valves counted. Simpson's diversity was calculated as: $1 - \lambda$.

Similarity between sampling sites in both seasons was estimated using both presence-absence of taxa (Jaccard) and considering their relative abundances (Bray-Curtis). Because of the typical patchy distribution of diatom assemblages [35], measurements of similarity should be weighed between the number of rare and uncommon taxa which may be likely missed, and the common and abundant taxa that may define an assemblage based on their importance. In this way, the hypothesis that a single diatom association was present in the sampling sites was tested (H_0).

In addition to the above, a direct similarity was estimated based on presence/absence of taxa between the dry and rainy season based on proportion (%) of the shared abundant and common taxa, i.e., the remaining taxa from the first sampling to the other.

Additionally, overall species diversity (H') was calculated using the genus/species ratio, albeit as a single value for the whole taxocenosis of epipelagic diatoms in Playa Las Gaviotas, Cuba for each sampling season. Because the numbers of species/intra-species taxa per genus show a similar distribution as that of the relative abundances, the parameters describing the structure of the associations estimated using the genus to species ratio were expected to yield similar values. This computation was as follows:

$$H'_{(G/SS)} = -\sum_i^n \left(\frac{G}{SS} \right) \log_2 \left(\frac{G}{SS} \right)$$

where the quantity G/SS is the proportion of species found in the i th genus among the total number of species in the sample [36].

Computed values for H' of multiple samples complied with other requirements for using parametric statistical techniques and were tested (0.05) for normal distribution using

Shapiro–Wilks and Kolmogorov–Smirnov tests [37]. Both tests for the two sampling seasons indicated that an approximate normal distribution existed at $\alpha = 0.05$ (Table 1).

Table 1. Probability for the normality tests of H' values computed for epipellic diatom associations in the two samplings ($\alpha = 0.05$) at Playa Las Gaviotas, Cuba.

Sampling	Kolmogorov–Smirnov		Shapiro–Wilks	
November	D = 0.09	$p = 0.31$	W = 0.97	$p = 0.45$
July	D = 0.09	$p = 0.29$	W = 0.98	$p = 0.54$

D (Kolmogorov–Smirnov statistic), W (Shapiro–Wilks statistic), p (probability value).

Based on the above normality tests, an ANOVA was applied for contrasting the statistical H_0 that no significant differences existed between H' computed values, either seasonally or by sampling site ($\alpha = 0.05$). All statistical tests were performed with R Studio software 2023. Ecological indices and similarity between samples (dendrograms) were processed with PRIMER v7 & PERMANOVA+ 2023 software. Matrices of abundance and ecological indices were constructed using Microsoft Excel 2023.

3. Results

The performed granulometric analysis of the sand samples collected in July 2022 comprises the size-grade type of sediment and its percentage contained in each sample (Table 2). It shows the biogenic origin of the intertidal sediment, composed mostly of sand (mean = 84.6%) and silt (mean = 13.7%), while clay represented 1.7% of the sediment. The three types of sediment occurred in all sampling points to varying degrees, medium and fine sands being dominant. Site 6 showed the smallest percentage of sand, yet reached 73.8%, combined with the highest percentage of silt (23.6%).

Table 2. Classification of sediments from Playa Las Gaviotas based on grain size (μm) for the July sampling. The percentage of sediment grade is given for each sampling point.

Non-Lithified Fraction	Class	Grade	Size (μm)	SITES					
				1	2	3	4	5	6
Sand	Sand	Very coarse	2000–1000	0.8	0.7	5.0	3.5	0	1.0
		Coarse	999–500	18.6	5.2	23.0	13.0	4.6	9.5
		Medium	499–250	39.4	39.6	37.7	50.0	42.8	37.0
		Fine	249–125	23.6	38.3	21.7	23.6	36.0	25.6
		Very fine	124–63	1.5	2.1	1.3	0.0	2.3	0.7
	Total sand			83.9	85.77	88.84	90.02	85.68	73.81
Mudd	Silt	Coarse	62–31	5.7	4.8	3.7	3.2	4.9	9.8
		Medium	30–15	5.2	4.5	3.5	3.5	4.7	8.4
		Fine	14–8	2.0	1.9	1.5	1.3	1.7	3.0
		Very fine	7–4	1.5	1.4	1.1	1.1	1.4	2.5
	Total silt			14.4	12.51	9.81	9.14	12.65	23.62
	Clay		≤ 3	1.7	1.7	1.3	0.9	1.7	2.6

3.1. Diatom Flora

The inspection of sediment samples from Playa La Gaviotas, Cuba yielded a total 354 species and infra-species (Appendix A). The best represented genera were *Mastogloia* (70 taxa), *Amphora* (25), *Navicula* (21), *Nitzschia* (18), *Diploneis* (20) and *Cocconeis* (10). Most of the genera (79 out of 89) were represented by less than five taxa, and more than half of the genera (50 out of 89) by only a single taxon. Among all taxa, 18 (out of 354 taxa) could

only be identified to genus level (Table 3). The species list includes 200 new records (NR, Appendix A) that are added to the previous Cuban diatom flora [12,13]. Additionally, the nomenclature of 45 recorded taxa [12] was updated (NU, Appendix A). A representative assemblage of taxa from the study area in Cuba is presented in Appendix B.

Table 3. Number of diatom taxa (No. spp.) per genus (89) identified in sediment samples from Playa Las Gaviotas, Cuba.

Genus	No. spp.	Genus	No. spp.	Genus	No. spp.
<i>Mastogloia</i>	70	<i>Odontella</i>	2	<i>Grunowago</i>	1
<i>Navicula</i>	26	<i>Oestrupia</i>	2	<i>Hantzschia</i>	1
<i>Amphora</i>	25	<i>Perissonoë</i>	2	<i>Haslea</i>	1
<i>Diploneis</i>	20	<i>Petroneis</i>	2	<i>Hendeyella</i>	1
<i>Nitzschia</i>	18	<i>Pleurosigma</i>	2	<i>Hyalosynedra</i>	1
<i>Cocconeis</i>	10	<i>Podocystis</i>	2	<i>Neohuttonia</i>	1
<i>Halamphora</i>	8	<i>Psammodiscus</i>	2	<i>Orthonais</i>	1
<i>Campylodiscus</i>	8	<i>Toxarium</i>	2	<i>Paralia sulcata</i>	1
<i>Caloneis</i>	7	<i>Trachyneis</i>	4	<i>Podosira</i>	1
<i>Lyrella</i>	7	<i>Amphicocconeis</i>	1	<i>Prestauroneis</i>	1
<i>Seminavis</i>	6	<i>Amphipentast</i>	1	<i>Protoraphis</i>	1
<i>Plagiogramma</i>	5	<i>Anaulus</i>	1	<i>Psammodictyon</i>	1
<i>Fallacia</i>	5	<i>Anorthoneis</i>	1	<i>Rhaphoneis</i>	1
<i>Cocconeopsis</i>	4	<i>Ardissonaea</i>	1	<i>Rhopalodia</i>	1
<i>Dimeregramma</i>	4	<i>Auricula</i>	1	<i>Rutilaria</i>	1
<i>Grammatophora</i>	4	<i>Bacillaria</i>	1	<i>Schizostauron</i>	1
<i>Gyrosigma</i>	4	<i>Berkeleya</i>	1	<i>Shionodiscus</i>	1
<i>Tetramphora</i>	4	<i>Biddulphiella</i>	1	<i>Staurophora</i>	2
<i>Tryblionella</i>	4	<i>Biremis</i>	1	<i>Surirella</i>	1
<i>Achnanthes</i>	3	<i>Brassiereia</i>	1	<i>Tabularia</i>	1
<i>Opephora</i>	3	<i>Climaconeis</i>	1	<i>Talaroneis</i>	1
<i>Parlibellus</i>	3	<i>Climacosphenia</i>	1	<i>Tephanocyclus</i>	1
<i>Plagiotropis</i>	3	<i>Coscinodiscus</i>	1	<i>Terpsinoë</i>	1
<i>Synedra</i>	3	<i>Cymatosira</i>	1	<i>Thalassiosira</i>	1
<i>Synedrosphenia</i>	3	<i>Cymbella</i>	1	<i>Trigonium</i>	1
<i>Triceratium</i>	3	<i>Dictyoneis</i>	1	<i>Ulnaria</i>	1
<i>Actinocyclus</i>	2	<i>Epithemia</i>	1		
<i>Biddulphia</i>	2	<i>Frustulia</i>	1		
<i>Homoeocladia</i>	2	<i>Glyphodesmis</i>	1		
<i>Licmophora</i>	2	<i>Gomphonemopsis</i>	1		

3.1.1. Structure of Epipellic Diatom Taxocenoses in Playa Las Gaviotas, Cuba

In the dry season (November 2021), the species richness (*S*) of epipellic diatoms varied between 32 and 58 taxa with a median of 45 taxa (Table 4), while in the rainy season (July 2022), sampling *S* varied between 37 and 54 taxa with a median of 47 taxa (Table 5). In some samples, the difference in *S* between seasons was higher than 10 taxa. During the quantitative analysis, 147 taxa were accounted for in the November 2021 samples, 41.6% of all the identified taxa (354), and 142 for July 2022, i.e., 40.2%.

In the dry season, the most abundant taxa were as follows: *Halamphora turgida* (2814 out of 54,000 counted valves), *H. coffeiformis* (1735), *Amphora* cf. *copulata* (1434), *Psammodictyon panduriforme* (1370), *Diploneis smithi* var. *pumila* (1195) and *Nitzschia marginulata* var. *didyma* (1047), which along with the rest of the quantified taxa exhibit a typical distribution curve of relative abundances (Figure 2).

Table 4. Estimated values for the association structure parameters of epipellic diatoms from Playa Las Gaviotas, Cuba in the November 2021 sampling.

Sample	<i>S</i>	<i>N</i>	<i>H'</i>	<i>J'</i>	$1 - \lambda$	λ
P1.1R1	44	500	4.76	0.87	0.95	0.05
P1.1R2	50	500	5.01	0.89	0.96	0.04
P1.1R3	47	500	5.02	0.90	0.96	0.04
P1.2R1	48	500	5.02	0.90	0.96	0.04
P1.2R2	47	500	5.01	0.90	0.96	0.04
P1.2R3	45	500	4.76	0.87	0.95	0.05
P1.3R1	49	500	4.93	0.88	0.96	0.04
P1.3R2	56	500	5.21	0.90	0.97	0.03
P1.3R3	56	500	5.25	0.90	0.97	0.03
P2.1R1	43	500	5.11	0.94	0.97	0.03
P2.1R2	51	500	5.21	0.92	0.97	0.03
P2.1R3	51	500	5.05	0.89	0.96	0.04
P2.2R1	45	500	5.03	0.92	0.96	0.04
P2.2R2	51	500	5.21	0.92	0.97	0.03
P2.2R3	46	500	4.92	0.89	0.96	0.04
P2.3R1	49	500	4.97	0.88	0.96	0.04
P2.3R2	49	500	4.91	0.87	0.96	0.04
P2.3R3	46	500	4.77	0.86	0.95	0.05
P3.1R1	38	500	4.74	0.90	0.95	0.05
P3.1R2	40	500	4.85	0.91	0.96	0.04
P3.1R3	50	500	4.99	0.88	0.96	0.04
P3.2R1	56	500	5.26	0.91	0.96	0.04
P3.2R2	51	500	5.17	0.91	0.97	0.03
P3.2R3	47	500	5.03	0.90	0.96	0.04
P3.3R1	56	500	5.36	0.92	0.97	0.03
P3.3R2	52	500	5.24	0.92	0.97	0.03
P3.3R3	58	500	5.35	0.91	0.97	0.03
P4.1R1	48	500	4.85	0.87	0.95	0.05
P4.1R2	48	500	4.96	0.89	0.96	0.04
P4.1R3	51	500	4.88	0.86	0.96	0.04
P4.2R1	34	500	4.39	0.86	0.94	0.06
P4.2R2	34	500	4.34	0.85	0.94	0.06
P4.2R3	35	500	4.56	0.89	0.95	0.05
P4.3R1	38	500	4.71	0.90	0.95	0.05
P4.3R2	38	500	4.64	0.88	0.95	0.05
P4.3R3	36	500	4.59	0.89	0.95	0.05
P5.1R1	40	500	4.65	0.87	0.95	0.05
P5.1R2	43	500	4.72	0.87	0.95	0.05
P5.1R3	39	500	4.87	0.92	0.96	0.04
P5.2R1	32	500	4.55	0.91	0.94	0.06
P5.2R2	33	500	4.44	0.88	0.94	0.06
P5.2R3	40	500	4.77	0.90	0.95	0.05
P5.3R1	36	500	4.66	0.90	0.95	0.05
P5.3R2	42	500	4.86	0.90	0.96	0.04
P5.3R3	45	500	5.01	0.91	0.96	0.04
P6.1R1	37	500	4.69	0.90	0.95	0.05
P6.1R2	44	500	4.98	0.91	0.96	0.04
P6.1R3	45	500	4.98	0.91	0.96	0.04
P6.2R1	52	500	5.03	0.88	0.96	0.04
P6.2R2	41	500	4.88	0.91	0.96	0.04
P6.2R3	48	500	4.97	0.89	0.96	0.04
P6.3R1	45	500	5.03	0.92	0.96	0.04
P6.3R2	40	500	4.88	0.92	0.96	0.04
P6.3R3	46	500	5.03	0.91	0.96	0.04

Species richness (*S*), Sample size (*N*), Shannon's diversity (*H'*), Pielou's evenness (*J'*), Simpson's diversity ($1 - \lambda$), Simpson's dominance (λ).

Table 5. Estimated values for the association structure parameters of epipelagic diatoms from Playa Las Gaviotas, Cuba in the July 2022 sampling.

Sample	<i>S</i>	<i>N</i>	<i>H'</i>	<i>J'</i>	$1 - \lambda$	λ
P1.1R1	43	500	4.63	0.85	0.95	0.05
P1.1R2	50	500	4.91	0.87	0.96	0.05
P1.1R3	52	500	4.86	0.85	0.95	0.05
P1.2R1	49	500	4.65	0.83	0.94	0.06
P1.2R2	52	500	4.90	0.86	0.95	0.05
P1.2R3	49	500	4.97	0.89	0.96	0.04
P1.3R1	50	500	4.94	0.88	0.96	0.04
P1.3R2	49	500	4.82	0.86	0.95	0.05
P1.3R3	39	500	4.78	0.90	0.96	0.04
P2.1R1	47	500	5.06	0.91	0.96	0.04
P2.1R2	44	500	4.98	0.91	0.96	0.04
P2.1R3	44	500	4.80	0.88	0.95	0.05
P2.2R1	38	500	4.78	0.91	0.96	0.04
P2.2R2	37	500	4.70	0.90	0.95	0.05
P2.2R3	46	500	4.92	0.89	0.96	0.04
P2.3R1	40	500	4.73	0.89	0.95	0.05
P2.3R2	52	500	4.97	0.87	0.96	0.04
P2.3R3	49	500	4.91	0.87	0.96	0.04
P3.1R1	41	500	4.91	0.92	0.96	0.04
P3.1R2	48	500	5.00	0.90	0.96	0.04
P3.1R3	54	500	5.16	0.90	0.96	0.04
P3.2R1	42	500	4.96	0.92	0.96	0.04
P3.2R2	50	500	5.10	0.90	0.96	0.04
P3.2R3	53	500	5.26	0.92	0.97	0.03
P3.3R1	45	500	5.06	0.92	0.96	0.04
P3.3R2	51	500	5.10	0.90	0.96	0.04
P3.3R3	53	500	5.24	0.91	0.97	0.03
P4.1R1	45	500	4.94	0.90	0.96	0.04
P4.1R2	51	500	5.06	0.89	0.96	0.04
P4.1R3	45	500	4.92	0.90	0.96	0.04
P4.2R1	52	500	4.96	0.87	0.96	0.04
P4.2R2	47	500	4.97	0.89	0.96	0.04
P4.2R3	42	500	4.85	0.90	0.96	0.04
P4.3R1	50	500	5.00	0.89	0.96	0.04
P4.3R2	47	500	4.87	0.88	0.96	0.04
P4.3R3	46	500	4.90	0.89	0.96	0.04
P5.1R1	48	500	4.83	0.87	0.95	0.05
P5.1R2	46	500	5.00	0.90	0.96	0.04
P5.1R3	49	500	4.99	0.89	0.96	0.04
P5.2R1	46	500	4.95	0.90	0.96	0.04
P5.2R2	49	500	5.01	0.89	0.96	0.04
P5.2R3	45	500	5.05	0.92	0.96	0.04
P5.3R1	53	500	5.13	0.90	0.97	0.03
P5.3R2	49	500	5.04	0.90	0.96	0.04
P5.3R3	45	500	4.96	0.90	0.96	0.04
P6.1R1	49	500	5.00	0.89	0.96	0.04
P6.1R2	43	500	4.89	0.90	0.96	0.04
P6.1R3	41	500	4.88	0.91	0.96	0.04
P6.2R1	52	500	5.10	0.89	0.96	0.04
P6.2R2	47	500	4.90	0.88	0.96	0.04
P6.2R3	40	500	4.90	0.92	0.96	0.04
P6.3R1	47	500	4.96	0.89	0.96	0.04
P6.3R2	43	500	4.93	0.91	0.96	0.04
P6.3R3	45	500	5.04	0.92	0.96	0.04

Species richness (*S*), Sample size (*N*), Shannon's diversity (*H'*), Pielou's evenness (*J'*), Simpson's diversity ($1 - \lambda$), Simpson's dominance (λ).

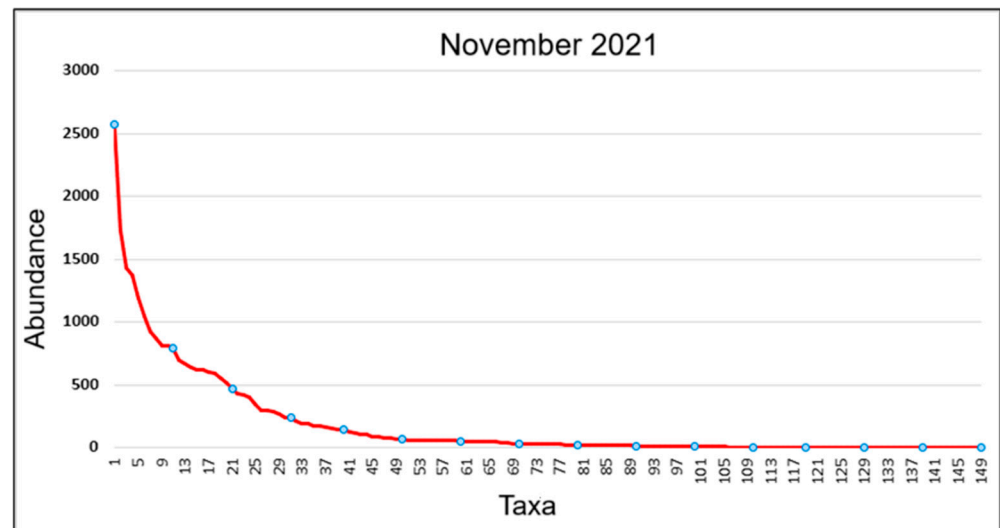


Figure 2. Distribution curve for the relative abundances of 147 epipellic diatom taxa from Playa Las Gaviotas, Cuba in the November 2021 sampling.

In the rainy season, on the other hand, six taxa were abundant, fourteen common, forty uncommon, and eighty-seven rare. In the rainy season, six taxa were abundant: *Amphora proteus* (2538), *Navicula zostereti* (2071), *Diploneis smithi* var. *pumila* (1602), *Psammodictyon panduriforme* (1515), *Halamphora coffeiformis* (1336) and *Amphora* cf. *copulata* (1156). And in general, these are classified as follows: seven taxa were abundant, eleven common, thirty uncommon, and ninety-four rare, likewise depicting a typical distribution curve (Figure 3) from Playa Las Gaviotas, Cuba in November 2021.

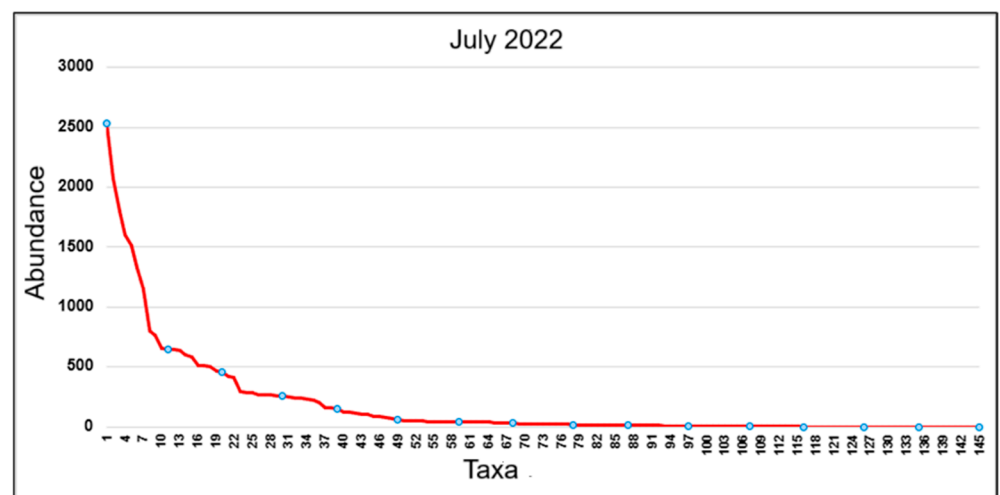


Figure 3. Distribution curve for the relative abundances of 142 epipellic diatom taxa from Playa Las Gaviotas, Cuba in July 2022.

Based on the distribution curves of the taxa abundances (Figures 2 and 3), the epipellic diatoms at Playa Las Gaviotas exhibit a typical undisturbed association structure based on relative abundances of the taxa, since in both samplings a characteristic low number of abundant taxa occurred, followed by few common taxa, and a high number of uncommon and rare taxa (Figure 4).

Regarding the ecological computed indices for the dry season (November 2021 samples), H' values were high, varying between 4.55 and 5.35, with a mean of 4.91 and a median of 4.94. Evenness was also high ($J' = 0.85$ – 0.92), as well as $1 - \lambda$ with most values > 0.94 , while dominance (λ) was correspondently low, varying between 0.03 and 0.06 (Table 4).

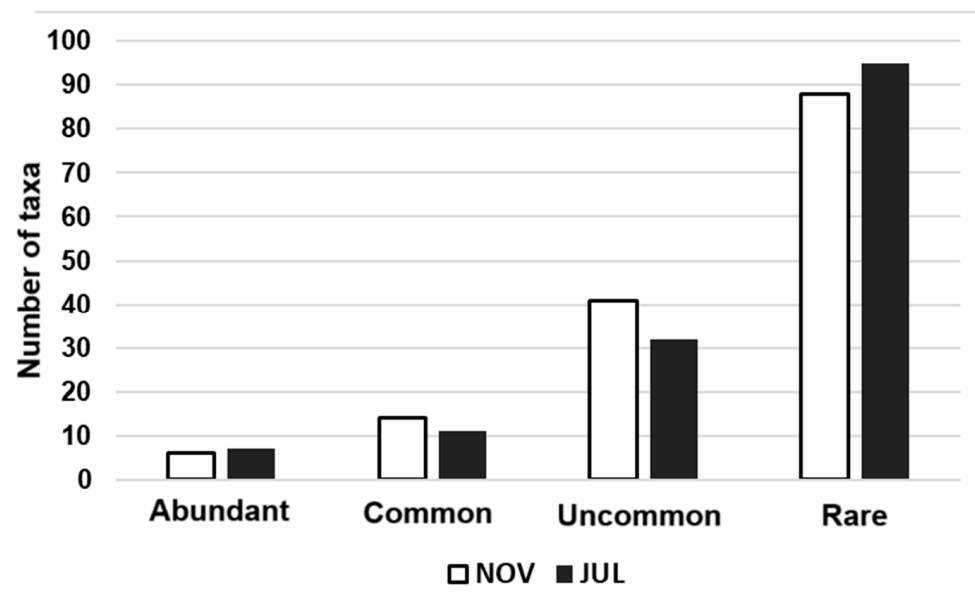


Figure 4. Classification of epipelagic diatom taxa according to their relative abundances by sampling date in Playa Las Gaviotas, Cuba.

For the rainy season (July 2022 samples), H' values were also high, varying between 4.63 and 5.26, with a mean and median value of 4.95. Evenness was also high ($J' = 0.83\text{--}0.92$), as well as $1 - \lambda$ with most values > 0.95 , and dominance (λ) values correspondingly low, varying between 0.03 and 0.05 (Table 5).

Moreover, the computed overall values of $H' = G/SS$ by season were correspondingly high, i.e., 5.2 bit/taxon for November 2021, and 5.06 bit/taxon for July 2022, and higher than the respective mean values of H' computed using relative abundances.

The statistical tests (ANOVA) of the computed H' values proved non-significant ($\alpha = 0.05$), i.e., no significant differences existed between H' values by sampling site in both seasons, which supports the null hypothesis and suggests that a single diatom association was present along the sampling area.

3.1.2. Similarity

Similarity values for the November 2021 sampling using the Bray–Curtis index were high between samples (and their replicates) from the different sites, mostly between 70% and 80%, which comprises the main group, while a smaller group is separated at just over 70% similarity. Notwithstanding, between this interval of similarity, samples from the same sites are included (Figure 5A). Due to the nature of this index, these values of similarity are caused by the shared presence of abundant and common taxa distributed along the sampled sites.

On the other hand, the Jaccard Index (presence/absence of taxa) showed an alike grouping at 60% which comprises most of the inspected samples and replicates (Figure 5B). According to this, uncommon and rare taxa are also homogeneously distributed along the different sampling sites in Playa Las Gaviotas. The varying similarity values are likely a consequence of the characteristic patchy distribution of benthic diatoms [35].

The computed values of similarity using the Bray–Curtis index for the July 2022 samples of epipelagic diatoms from Playa Las Gaviotas, Cuba showed an overall similarity of 50%. At 70% similarity, four groups are defined with many pairings around 80%. Again, between this interval of similarity, groups of samples from the same sites are included (Figure 6A). Likewise, because of the patchy distribution of benthic diatoms, the high similarity ($>70\%$) could be attributed to the homogeneous distribution of abundant

and common taxa along the different sampling sites. And, as in the previous season, Jaccard's index confirms the likely homogeneous distribution of uncommon and rare taxa contributing to the high values of similarity (Figure 6B) that, in this period, occurred along dominant sandy sediments classified mainly in the range of fine and medium-sized grains. Moreover, the similarity between the abundant and common taxa of each sampling period based on presence/absence of taxa indicated that the proportion of taxa remaining from the dry to rainy season was 84.2%. In sum, there is evidence to support the null hypothesis that a single diatom association was present along the sampling area in both sampling seasons.

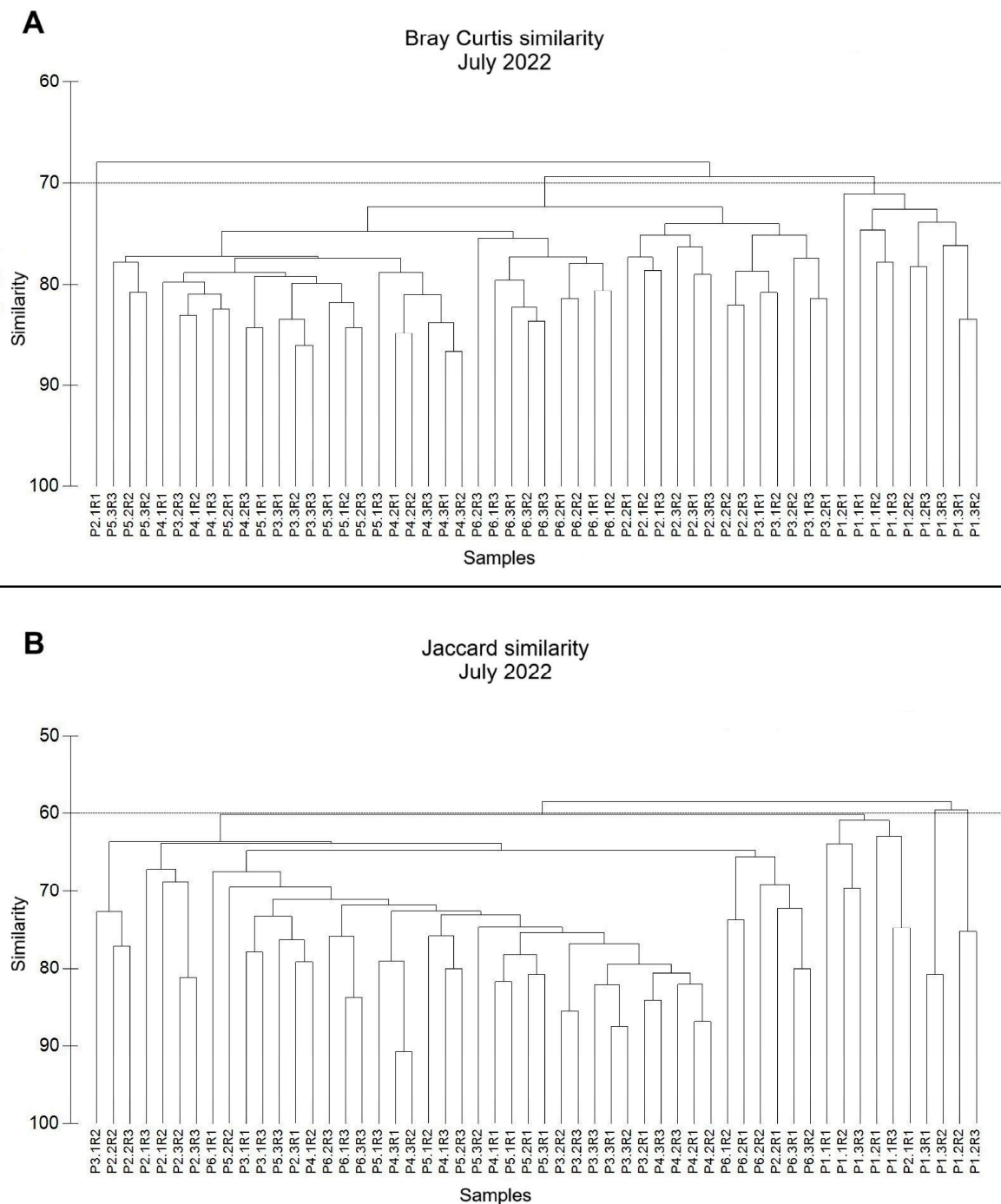


Figure 5. Cluster dendrograms of the dry season (November) samples from Playa Las Gaviotas, Cuba, based on: (A) taxa abundances (Bray-Curtis similarity index) and (B) presence/absence of taxa (Jaccard index).

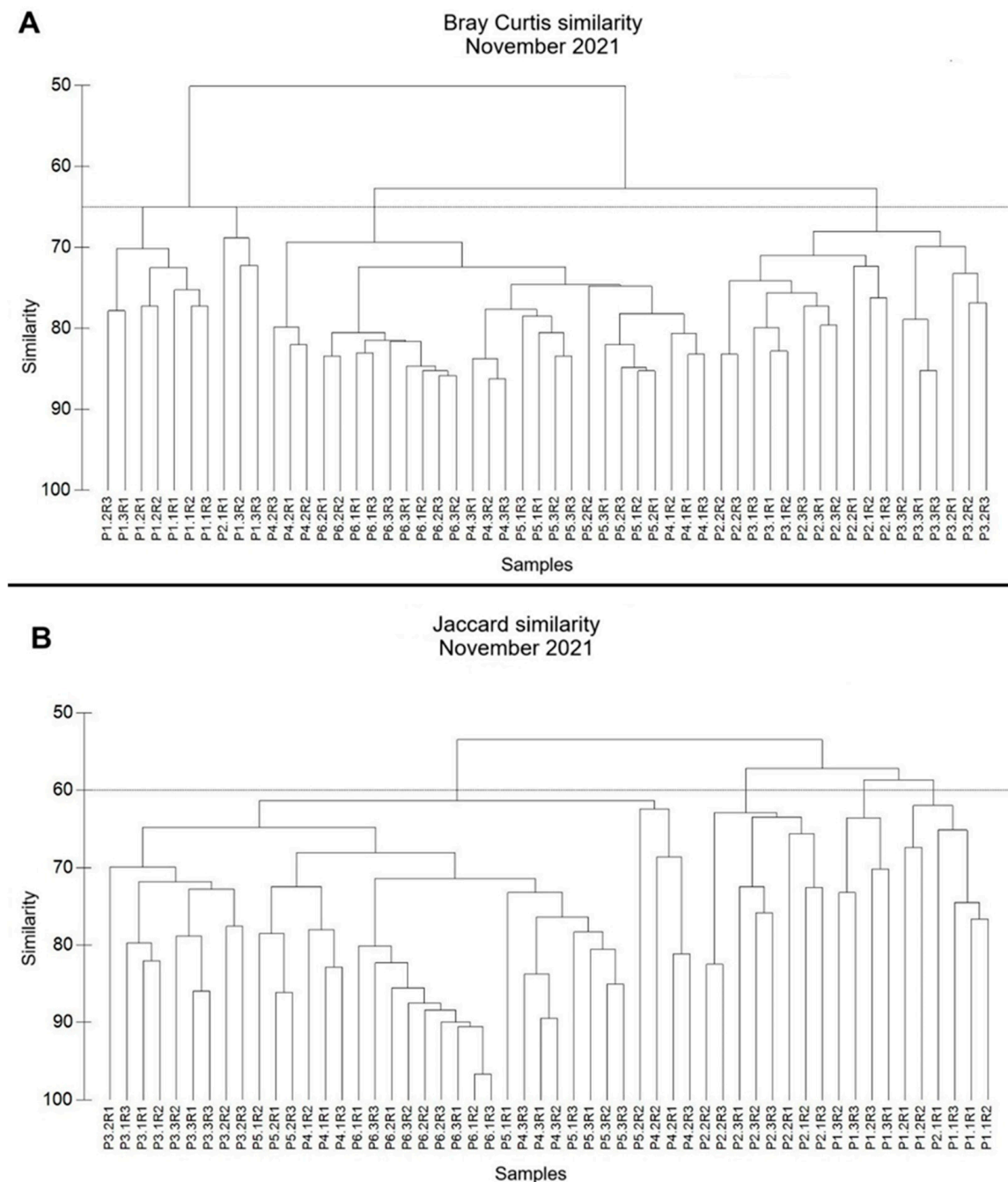


Figure 6. Cluster dendrograms of the rainy season (July) samples from Playa Las Gaviotas, Cuba, based on: (A) taxa abundances (Bray-Curtis similarity index) and (B) presence/absence of taxa (Jaccard index).

4. Discussion

The data generated in this research backed the posed hypotheses that species richness and diversity would be as high ($H' > 4$) as in other marine protected areas and pristine productive environments, that in the sampling sites a single diatom association was present, and that in the Cuban coasts, numerous unrecorded benthic diatom taxa would be found, significantly increasing the species richness previously recorded [12,13].

4.1. Species Composition of the BDA in Playa Las Gaviotas, Cuba

In this study, the species composition of the BDA in the Cuban coasts was enriched by the addition of 200 previously unrecorded taxa, including 43 new records of the genus

Mastogloia that reached 102 specific and infra-specific taxa [9]. Additionally, the number of genera (89) now surpasses the 79 genera reported in Foged (1984) [12], which included freshwater taxa, and the number of singletons (50 vs. 29 in the previous study). Floristics required replacing several obsolete taxonomic names due to the creation of new taxonomic groups, mainly separated from *Navicula*, and *Amphora*. In this way, 45 names were updated out of the 395 taxa recorded previously [12]. By adding seven records in [13], the number of taxa of marine benthic diatoms recorded for Cuban littorals is currently 595.

Comparative studies on benthic marine diatoms in other marine protected areas worldwide are scarce. For the Mexican Pacific coasts there is a record of 397 taxa of epiphytic diatoms for the Revillagigedo Archipelago, while in the Guerrero Negro Lagoon, a natural protected area in a temperate region, the epipelagic diatom taxocenosis yielded 232 taxa. With respect to studies on benthic diatom flora in the Mexican Atlantic (Gulf of Mexico and Caribbean) from undisturbed tropical and productive environments, an ample and exhaustive sampling was carried out in the Bahamas that yielded 379 taxa [14], and recently [7] with 184. These differences in species richness may be explained mainly by the effort spent on inspecting the mounted samples, the extent of the sampling area and the heterogeneity of the processed substrates. In the case of Playa Las Gaviotas, it is more likely that sampling two seasons and thorough inspection of the samples under the microscope account for the high number of taxa recorded, which is evidence of a high *S* potential of the Cuban archipelago. In this way, the BDA floristic list from Cuban currently surpasses the species richness of the Revillagigedo study, as well as those in the Gulf of Mexico and the Caribbean. However, despite the high species richness recorded, it is expected that many more taxa may be added with further exploration of other localities and by surveying different substrates [1].

In the sediment samples of Playa Las Gaviotas, *Mastogloia* had the highest number of specific and infraspecific taxa of the diatom taxocenosis. This coincides with the 59 *Mastogloia* taxa recorded by [12] who reports *Navicula* as the richest genus, though mainly because it still included taxa now classified in other genera, e.g., *Lyrella*, *Petroneis*, *Fallacia* and *Oestrupia*. In this way, the current 102 *Mastogloia* taxa in the BDA of Cuban coasts, the highest ever recorded in similar floristic studies, depicts them as of tropical affinity [9]. To what extent these similarities in species richness at a genus level are useful in a biogeographical sense requires an ex profeso study that permits inferences on connectivity or other factors explaining the co-occurrence of taxa in far-apart localities. In the case of widely distributed taxa, the nine most abundant in the Cuban samples (*Amphora* cf. *copulata*, *A. proteus*, *Diploneis smithi* var. *pumila*, *Halamphora coffeiformis*, *H. turgida*, *Navicula zostereti*, *Nitzschia marginulata* var. *didyma* and *Psammodictyon panduriforme*) are known to occur in both the Atlantic and Pacific littorals. Except for the first one, all others are duly identified and thus require further in-depth taxonomic analysis to confirm their identity considering the distances in distribution. In the case of *Campylodiscus* sp. 1 (Figure A28f,g) that has been recorded in the Revillagigedo Archipelago (Ref. [6], Figure A27h,i), it poses an interesting problem, both taxonomically (since the species could not be identified) and biogeographically.

Other taxonomic remarks include the misidentification of *Nitzschia fusoides* Ehrlich (Figure A28m, Appendix B) as *N. lanceolata* W. Smith by Foged (1984) [12] or *N. lanceola* Grunow in other reports [3]. However, *N. fusoides* was initially proposed by Ehrlich [38] who described it from hypersaline environments. In contrast, *N. lanceolata* [23], represents a different taxon, described from the southern coast of England. Likewise, the *Dictyoneis* taxa here identified (Figure A10, Appendix B) are *D. marginata* var. *marginata* [7], *D. marginata* var. *elongata* and *D. marginata* var. *spectatissima*, both as in Schmidt et al. (1874–1959) [23]. Across the different studies, these rarely reported taxa show large morphological variations,

and further studies will be necessary to clarify their identities and distribution. Also, there is the case of *Amphora graeffi* (Grunow) in Cleve which has been synonymized with *A. graeffeana* Hendey and though later reviewed [27], there is still confusion on the subject, whereas they are noticeably different taxa as can be noted in Figure A20a,c,e,f (Appendix B), respectively. And, finally, an unidentified taxon has been proposed here as similar to but not *Rutilaria obesa*, since this is a fossil form, earlier recorded [39] as an unidentified cymatosiroid diatom (Figure A8l,m), and needs an ex profeso treatment. This case and what we report as an unidentified centric diatom together with the above and the many new records and updated taxa show the need for further benthic diatom surveys along the Cuban coasts, as well as in new and unexplored littorals, since it is evident that much floristic and taxonomic work is lacking.

4.2. Structure of the BDA in Playa Las Gaviotas

In general, benthic diatoms exhibit a typical patchy or aggregated distribution that produces low values of similarity between samples and reflects the characteristic opportunistic growth of diatoms that responds to temperature, salinity, and sediment variations [15]. Similarity values computed for the diatom samples from Playa Las Gaviotas were commonly >80%, some surpassing 90%, and the slight heterogeneity perceived in the pairwise comparisons may be attributed to the aggregated distribution due to presence/absence of rare and uncommon taxa, and varying numerosity of shared common and abundant taxa that, nonetheless, depicts a single diatom association. Moreover, the dry and rainy season samples shared 87 taxa, i.e., 60% on average for both sets of samples, which coincides with the overall similarity depicted in the respective dendrograms for all samples each season. The observed homogeneity in species composition requires that the prevailing factor conditioning the species composition be singled out, both spatially and temporally, resorting to appropriate techniques, e.g., Simper analyses which could show which taxa contribute to the similarity between samples during one season, and for both seasons. In this way, an adequate hypothesis should be posed, abducted from a premise derived in turn from the conclusions reached in this study.

Concerning the above, grain size determines variations in species composition and distribution of BDAs [40,41]. And, although the granulometric analysis of sediments from the study area was performed only for the July samples, it showed that fine and medium sand dominated in all sampling points. This textural homogeneity seemed to correspond with species composition of epipelagic diatoms and their opportunistic nature resulting in the patchy distribution reflected in variations in the estimated sample values of S and H' of a single diatom association of Playa Las Gaviotas. These variations are caused by presence/absence of rare or uncommon taxa and numerical differences of common and abundant taxa in sediments [22,35]. However, these did not statistically affect the computed values of H' , either spatially or temporally. And, because the description of the BDA of Playa Las Gaviotas comprised a rainy and a dry season, which were selected to assure collecting a higher number of taxa, a representativity of the BDA from the Cuban coasts and of the natural protected zone Refugio de Fauna, Cayo Santa Maria is considered to have been achieved.

Seasonally, the three most abundant taxa in the dry season (*Amphora* cf. *copulata*, *Halamphora turgida* and *H. coffeiformis*) were numerically displaced by *Amphora proteus*, and *N. zostereti* in the rainy season. Considering that similarity values between subsamples of the same sample commonly variate between 60 and 80% and denote the patchy distribution of diatom assemblages [22], the high similarity measurements in general indicated homogeneous distribution of the diatom association along the fine and medium sand. Likewise, the similarity between rainy and dry seasons estimated by counting the shared common and

abundant taxa (87) was high (84.2%); it suggests also a continuous temporal distribution of the taxa. In this way, the species lists of both periods are deemed complementary and adequate to be compared with other studies based on association structure, i.e., species richness, relative abundances of the taxa, species diversity, evenness and dominance. In this sense, the computed values for ecological indices are used to describe for the first time the association structure of benthic diatoms in Cuban coasts. Mean values of H' computed for the Playa Las Gaviotas samples ranged from 4.91 bit/taxon ($H' = 4.55\text{--}5.35$) in November to 4.95 (4.63–5.26) in July. Correspondence between these values of H' with those computed for J' and λ (and $1 - \lambda$) indicate that, despite the high number of rare and uncommon taxa in the inspected samples, common and abundant taxa also contribute significantly to the diversity parameter, balancing the effects due to H' sensibility and the “insensibility” of λ to rare taxa. Whilst the relative diversity values (J') reflect a certain generalized homogeneity of the taxa relative abundances.

On the one hand, these high values of H' contrast with those proposed for typical BDAs for which modal values vary between 2.6 and 3.8 bit/taxon [22]. On the other hand, although values of $H' > 5$ and $H' < 2$ are frequent, they may also be interpreted ecologically as improbable, and thus indicating instability within the association [2] may be due to successional (transitional) change. The high H' values for the BDAs from Cuba are quite similar to those estimated for other natural protected areas of the Mexican Pacific such as Laguna Guerrero Negro where the computed mean value for H' was 4.96 bit/taxon (3.7–5.9), and the Revillagigedo Archipelago for which a mean value of $H' = 4.68$ (3.92–5.2) was estimated [2,6], indicating that such high values of diversity are common in productive undisturbed environments. However, although the computed $H' = G/SS$ values by season were correspondently high, they were lower than those in similar studies [36]. In this sense, it must be noticed that the “low” number of singletons in the Cuban taxonomic list (17%) in contrast with other studies for which singletons reach >50% of the S [36] seems to have influenced the equitability in the BDA, cushioning the H' (G/SS) values. More thorough inspection of benthic diatom samples may be expected to yield other common taxa, especially more singletons which seem to be the pattern in species-rich environments.

5. Conclusions

Results support the post-facto hypothesis that benthic diatoms of Playa Las Gaviotas (Cuba) constitute a single species-rich association of tropical affinity, with high species diversity characteristic of productive environments and pristine areas that is homogeneously distributed along a fine-medium sandy bottom, showing a stable structure both temporally and spatially. Albeit, the estimated species richness may be considered an underestimation for the Cuban coasts, and it is expected to increase significantly as more extensive spatial and temporal samplings are carried out that comprise other substrates and undergo more exhaustive floristic inspection. Notwithstanding, widely distributed taxa are sometimes difficult to identify due to morphological variations which may reflect local environmental conditions. The 18 taxa identified only to genus level and two for which the genus is also unknown may represent potential new records. In this case (most likely episammic forms), besides their low frequency (rare), their small size precluded the inspection of distinctive morphometric and meristic characters, and ornamentations under light microscopy. As corollary, high diversity values (≥ 5) computed for H' in the study area may be considered common or probable as other “class of modal” values and deemed to depict ecological stability in these types of environments.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Diatom taxa found in sediments of Playa Las Gaviotas, Cuba. New records (NR); the *Mastogloia* taxa are from a previous study [9]. Nomenclatural update (NU).

Taxon	NR	NU
<i>Achnanthes biasolettiana</i> (Kützing) Grunow (Figure A20y)	x	
<i>Achnanthes longipes</i> Agardh	x	
<i>Achnanthes javanica</i> f. <i>subconstricta</i> (Meister) Hustedt		
<i>Actinocyclus crassus</i> (W.Smith) Ralfs ex Pritchard		
<i>Actinocyclus octonarius</i> var. <i>sparsus</i> (Gregory) Hustedt (Figure A1a,d)		x
<i>Amphicocconeis discrepans</i> (A.W.F.Schmidt) Riaux-Gobin, Witkowski, Ector & Igersheim (Figure A9n)		x
<i>Amphipentastema pentacrinus</i> Ehrenberg (Figures A2e, A3g–i and A4a–d,g–j,m)	x	
<i>Amphora alaeziarum</i> Alvarez-Blanco & S. Blanco		x
<i>Amphora arenaria</i> Donkin (Figure A23a–d,g)	x	
<i>Amphora bigibba</i> var. <i>interrupta</i> (Grunow) Cleve (Figure A24a–c)		
<i>Amphora biundulata</i> Bérard-Therriault, Cardinal & Poulin (Figure A26k)	x	
<i>Amphora capensis</i> A.W.F.Schmidt	x	
<i>Amphora clevei</i> Grunow		
<i>Amphora</i> cf. <i>copulata</i> (Kützing) Schoeman & R.E.M.Archibald (Figure A25o–t)	x	
<i>Amphora corpulenta</i> Cleve & Grove (Figure A22c)	x	
<i>Amphora corpulenta</i> var. <i>capitata</i> Tempère & Peragallo (Figure A22d)	x	
<i>Amphora farcimen</i> Grunow (Figure A22h,i)	x	
<i>Amphora floridae</i> A.H.Wachnicka & E.E.Gaiser (Figure A23v)	x	
<i>Amphora gigantea</i> var. <i>fusca</i> (Schmidt 1875 in Schmidt et al. 1874–1959) Cleve (Figure A25k)	x	
<i>Amphora graeffeana</i> Hendey (Figure A25f–h)		
<i>Amphora graeffeana</i> Hendey var.? (Figure A24n,o)	x	
<i>Amphora graeffei</i> Grunow (Figure A25d,e)	x	
<i>Amphora hamata</i> Heiden & Kolbe	x	
<i>Amphora immarginata</i> Nagumo (Figure A25a–c)	x	
<i>Amphora laevissima</i> W.Gregory (Figure A23e,f)	x	
<i>Amphora montgomeryi</i> A.H.Wachnicka & E.E.Gaiser	x	
<i>Amphora proteus</i> W.Gregory (Figure A25l–n,u,v)	x	
<i>Amphora</i> sp. 1 (Figure A23p–r,m–o,u)	x	
<i>Amphora</i> sp. 2 (Figure A24k)		
<i>Amphora spectabilis</i> W.Gregory (Figure A26i)		
<i>Amphora tegetum</i> A.H.Wachnicka & E.E.Gaiser		
<i>Amphora tomiakae</i> Witkowski, Lange-Bertalot & Metzeltin		

Table A1. Cont.

Taxon	NR	NU
<i>Anaulus minutus</i> Grunow (Figure A6g,h)	x	
<i>Anorthoneis eurystoma</i> Cleve (Figure A9k-l)	x	
<i>Ardissonea formosa</i> (Hantzsch) Grunow (Figure A8a)	x	
<i>Asteromphalus robustus</i> Castracane (Figure A1e)		
<i>Auricula intermedia</i> (F.W.Lewis) Cleve (Figure A22a)	x	
<i>Azpeitia nodulifer</i> (Schmidt) Fryxell & Sims (Figure A1j,k)	x	
<i>Bacillaria socialis</i> (W.Gregory) Ralfs	x	
<i>Berkeleya scopulorum</i> (Brébisson ex Kützing)		
<i>Biddulphia biddulphiana</i> (J.E.Smith) Boyer		x
<i>Biddulphia subaequa</i> (Kützing) Ralfs		x
<i>Biddulphiella regina</i> (W.Smith) P.A.Sims & M.P.Ashworth		x
<i>Biremis ambigua</i> (Cleve) D.G.Mann	x	
<i>Brassiereia vivens</i> M.K.Hein & B.M.Winsborough		x
<i>Caloneis linearis</i> (Cleve) Boyer (Figure A15l)		x
<i>Caloneis bacillum</i> (Grunow) Cleve	x	
<i>Caloneis egena</i> (A.W.F.Schmidt) Cleve (Figure A15m)		
<i>Caloneis excentrica</i> (Grunow) Boyer (Figure A15j)		
<i>Caloneis liber</i> (W.Smith) (Figure, 22a–e,h)		
<i>Caloneis sectilis</i> (A.W.F.Schmidt) Cleve (Figure A15i–k)	x	
<i>Caloneis</i> sp. 1	x	
<i>Campylodiscus cordatus</i> Hagelstein		
<i>Campylodiscus giffenii</i> Lobban & J.S.Park		
<i>Campylodiscus hodgsonii</i> W.Smith	x	
<i>Campylodiscus intermedius</i> Grunow	x	
<i>Campylodiscus neofastuosus</i> Ruck & Nakov (Figure A31a,c,e,f)		
<i>Campylodiscus ralfsii</i> W.Smith	x	
<i>Campylodiscus</i> sp. 1 (Figure A28f,g)		
<i>Campylodiscus subangularis</i> Cleve & Möller (Figure A28a–c)		x
<i>Catacombas gaillonii</i> (Bory) Williams & Round (Figure A8h–j)		
<i>Climaconeis lorenzii</i> Grunow (Figure A27w)	x	
<i>Climacosphenia</i> cf. <i>moniligera</i> Ehrenberg	x	
<i>Cocconeopsis fraudulenta</i> (A.W.F.Schmidt) Witkowski, Lange-Bertalot & Metzeltin (Figure A27r,v)	x	
<i>Cocconeopsis orthoneoides</i> (Hustedt) Witkowski, Lange-Bertalot & Metzeltin (Figure A9f)		x
<i>Cocconeopsis patrickiae</i> (Hustedt) A.Witkowski, Lange-Bertalot & Metzeltin (Figure A20w,x)		
<i>Cocconeopsis pullus</i> (Hustedt) Witkowski, Lange-Bertalot, Metzeltin (Figure A20u)	x	
<i>Cocconeopsis regularis</i> (Hustedt) Witkowski, Lange-Bertalot, Metzeltin	x	
<i>Cocconeopsis</i> sp. 1 (Figure A9m)	x	
<i>Cocconeopsis</i> sp. 2 (Figure A20s)	x	
<i>Cocconeis guttata</i> Hustedt & Aleem	x	
<i>Cocconeis pseudodiruptoides</i> Foged	x	
<i>Cocconeis</i> sp. 1 (Figure A9i,j)	x	
<i>Cocconeis britannica</i> Naegeli ex Kützing (Figure A9a–c)	x	
<i>Cocconeis caribensis</i> O.E.Romero & J.N.Navarro (Figure A9h)	x	
<i>Cocconeis clandestina</i> A. Schmidt (Figure A6a)	x	
<i>Cocconeis comis</i> A.W.F.Schmidt	x	
<i>Cocconeis dirupta</i> var. <i>flexella</i> (Janisch & Rabenhorst) Grunow	x	
<i>Cocconeis heteroidea</i> Hantzsch		
<i>Cocconeis singularis</i> R.Hagelstein (Figure A9d,e)	x	
<i>Coscinodiscus asteromphalus</i> Ehrenberg	x	
<i>Cymatosira lorenziana</i> Grunow (Figure A6i)	x	
<i>Cymbella</i> sp. 1	x	
<i>Dictyoneis marginata</i> (F.W.Lewis) Cleve (Figure A10a–d)		
<i>Dictyoneis marginata</i> var. <i>elongata</i> (Cleve) Fricke (Figure A10e)		
<i>Dictyoneis marginata</i> var. <i>spectatissima</i> (Greville) Cleve (Figure A10f–i)	x	

Table A1. Cont.

Taxon	NR	NU
<i>Dimeregramma</i> sp. 1	x	
<i>Dimeregramma fulvum</i> (W.Gregory) Ralfs	x	
<i>Dimeregramma marinum</i> (W.Gregory) Ralfs		
<i>Diploneis advena</i> (A. Schmidt) Cleve	x	
<i>Diploneis bomboides</i> var. <i>media</i> (Grunow) Hustedt		
<i>Diploneis coffeiformis</i> (A.W.F.Schmidt) Cleve (Figure A14d–g)	x	
<i>Diploneis chersonensis</i> (Grunow) Cleve (Figures A12f–h and A13b,d,e,h,i)	x	
<i>Diploneis crabro</i> (Ehrenberg) Ehrenberg (Figure A12a–e)	x	
<i>Diploneis fusca</i> (Greg.) Cleve (Figure A14a–c)	x	
<i>Diploneis fusca</i> var. <i>amphigomphus</i> Hustedt	x	
<i>Diploneis gemmatula</i> (Grunow) Cleve (Figure A13a)	x	
<i>Diploneis littoralis</i> var. <i>littoralis</i> (Donkin) Cleve		
<i>Diploneis littoralis</i> var. <i>clathrata</i> (Østrup) Cleve (Figure A11a,b,j)		
<i>Diploneis nitescens</i> (Gregory) Cleve (Figure A11s,t)	x	
<i>Diploneis obliqua</i> (Brun) Hustedt (Figure A14h,i)	x	
<i>Diploneis oblongella</i> var. <i>gibbosa</i> McCall	x	
<i>Diploneis papula</i> (A.W.F.Schmidt) Cleve (Figure A11o–q)		
<i>Diploneis papula</i> var. <i>constricta</i> Hustedt (Figure A13f,g,l)		
<i>Diploneis parca</i> (A.W.F. Schmidt) Boyer	x	
<i>Diploneis smithi</i> var. <i>pumila</i> (Grun.) Hustedt (Figure A11m,n,u)		
<i>Diploneis smithii</i> var. <i>smithii</i> (Brébisson in Wm. Smith) Cleve (Figure A11r)		
<i>Diploneis suborbicularis</i> (Gregory) Cleve (Figure A14e,f)		
<i>Diploneis vacillans</i> var. <i>renitens</i> (A.W.F.Schmidt) Cleve		
<i>Diploneis weissflogii</i> (A.W.F.Schmidt) Cleve (Figure A13h–k)	x	
<i>Epithemia guetteringi</i> (Krammer) Lobban & J.S.Park (Figure A28l)		
<i>Fallacia floriniae</i> (M.Møller) Witkowski (Figure A11l)		
<i>Fallacia forcipata</i> (Greville) Stickle & D.G.Mann		
<i>Fallacia litoricola</i> (Hustedt) D.G.Mann	x	
<i>Fallacia ny</i> (Cleve) D.G.Mann		
<i>Fallacia nyella</i> (Hustedt) D.G.Mann in Round, R.M.Crawford & D.G.Mann	x	
<i>Fallacia oculiformis</i> Hustedt D.G.Mann (Figure A11f,g,k)	x	
<i>Frustulia</i> sp. 1		x
<i>Glyphodesmis eximia</i> Greville (Figure A6e,f)	x	
<i>Gomphonemopsis lindae</i> Witkowski, Metzeltin & Lange-Bertalot	x	
<i>Grammatophora macilenta</i> W.Smith	x	
<i>Grammatophora oceanica</i> Ehrenberg	x	
<i>Grammatophora serpentina</i> Ehrenberg (Figure A6j)	x	
<i>Grammatophora undulata</i> Ehrenberg		x
<i>Grunowago bacillaris</i> (Grunow) Lobban & Ashworth	x	
<i>Gyrosigma</i> cf. <i>balticum</i> (Ehrenberg) Rabenhorst	x	
<i>Gyrosigma beaufortianum</i> Hustedt (Figure A27g)		
<i>Gyrosigma hummii</i> Hustedt (Figure A27f)	x	
<i>Gyrosigma simile</i> (Grunow) Boyer (Figure A27e)		
<i>Gyrosigma tenuissimum</i> (W.Smith) J.W.Griffith & Henfrey		
<i>Halamphora turgida</i> (W.Gregory) Levkov (Figure A24d–j)		
<i>Halamphora capitata</i> (R.Hagelstein) Álvarez-Blanco & S.Blanco	x	
<i>Halamphora coffeiformis</i> (C.Agardh) Mereschkowsky		
<i>Halamphora cymbifera</i> (W.Gregory) Levkov	x	
<i>Halamphora eunotia</i> (Cleve) Levkov	x	
<i>Halamphora wisei</i> (M.M.Salah) I.Álvarez-Blanco & S.Blanco (Figure A24l,m)		
<i>Hantzschia pseudomarina</i> Hustedt (Figure A28n)		x
<i>Hendeyella dubia</i> (Grunow) Li, Witkowski & Ashworth, nom. inval.	x	
<i>Homoeocladia angularis</i> (W.Smith) Kuntze	x	
<i>Homoeocladia distans</i> (W.Gregory) Kuntze (Figure A29g,h)		x
<i>Hyalosynedra laevigata</i> (Grunow) D.M.Williams & Round (Figure A8g)		x

Table A1. Cont.

Taxon	NR	NU
<i>Navicula</i> cf. <i>sovereignae</i> Hustedt (Figure A20l–p)	x	
<i>Karayevia</i> cf. <i>carissima</i> (Lange-Bertalot) Bukhtiyarova (Figure A27m)	x	
<i>Karayevia</i> sp. 1 (Figure A27n)	x	
<i>Licmophora gracilis</i> (Ehrenberg) Grunow	x	
<i>Licmophora remulus</i> (Grunow) Grunow (Figure A8k)		x
<i>Lyrella approximata</i> (Greville) D.G.Mann		x
<i>Lyrella clavata</i> var. <i>indica</i> J.L.Moreno (Figure A19a)		
<i>Lyrella diffluens</i> (A.W.F.Schmidt) D.G.Mann (Figure A18e,f)		
<i>Lyrella lyra</i> var. <i>lyra</i> (Ehrenberg) Karayeva (Figure A16a,c and Figure A17a,d–f)	x	
<i>Lyrella lyroides</i> Hendey	x	
<i>Lyrella praetexta</i> (Ehrenberg) D.G.Mann (Figure A19b)	x	
<i>Lyrella subforcipata</i> (Hustedt) Gusliakov & Karayeva		x
<i>Mastogloia achmanthioides</i> var. <i>elliptica</i> Hustedt		x
<i>Mastogloia adriatica</i> Voight	x	x
<i>Mastogloia affinis</i> Cleve		x
<i>Mastogloia angulata</i> F.W.Lewis	x	
<i>Mastogloia apiculata</i> W.Smith	x	
<i>Mastogloia (Orthonais) aspera</i> H. Peragallo & M. Peragallo		x
<i>Mastogloia asperula</i> Grunow	x	
<i>Mastogloia asperuloides</i> Hustedt	x	
<i>Mastogloia bahamensis</i> Cleve	x	
<i>Mastogloia beaufortiana</i> Hustedt		
<i>Mastogloia biapiculata</i> Hustedt		
<i>Mastogloia binotata</i> (Grunow) Cleve		
<i>Mastogloia biocellata</i> (Grunow) G.Novarino & A.R.Muftah	x	
<i>Mastogloia bisulcata</i> Grunow	x	
<i>Mastogloia (Orthonais) clevei</i> Grunow	x	
<i>Mastogloia cocconeiformis</i> Grunow		
<i>Mastogloia corsicana</i> (Grunow) H.Peragallo & M.Peragallo	x	
<i>Mastogloia corsicana</i> var. <i>capitata</i> Meister	x	
<i>Mastogloia cribrosa</i> Grunow		
<i>Mastogloia crucicula</i> (Grunow) Cleve	x	
<i>Mastogloia crucicula</i> var. <i>alternans</i> Zanon	x	
<i>Mastogloia cuneata</i> (Meister) Simonsen	x	
<i>Mastogloia decipiens</i> Hustedt		
<i>Mastogloia delicatissima</i> Hustedt		x
<i>Mastogloia elegans</i> Lewis	x	
<i>Mastogloia emarginata</i> Hustedt		
<i>Mastogloia erythraea</i> Grunow		
<i>Mastogloia fallax</i> f. <i>biloculis</i> Foged		
<i>Mastogloia fimbriata</i> (T.Brightwell) Grunow	x	
<i>Mastogloia floridensis</i> Lobban & Franckovich		
<i>Mastogloia funafutensis</i> A.W.F.Schmidt	x	
<i>Mastogloia gilberti</i> A. Schmidt		
<i>Mastogloia gracillima</i> Hustedt		
<i>Mastogloia graciloides</i> Hustedt		
<i>Mastogloia</i> cf. <i>horvathiana</i> Grunow		
<i>Mastogloia jelineckii</i> var. <i>jelineckii</i> Grunow (Figure A19e)		
<i>Mastogloia jelineckii</i> var. <i>extensa</i> (Grunow) Voigt	x	
<i>Mastogloia lacrimata</i> Voigt	x	
<i>Mastogloia lancetula</i> Cleve (Figure A21p)	x	
<i>Mastogloia latecostata</i> Hustedt		
<i>Mastogloia laterorostrata</i> Hustedt	x	
<i>Mastogloia lineata</i> var. <i>albifrons</i> (Brun) Hustedt	x	
<i>Mastogloia lucayensis</i> Lobban & Franckovich	x	

Table A1. Cont.

Taxon	NR	NU
<i>Mastogloia manokwariensis</i> Chohnoki		
<i>Mastogloia matthaei</i> Pennesi & Poulin	x	
<i>Mastogloia mauritiana</i> Brun	x	
<i>Mastogloia mauritiana</i> var. <i>capitata</i> Voigt	x	
<i>Mastogloia minuta</i> Grevillei	x	
<i>Mastogloia ovata</i> Grunow		
<i>Mastogloia parva</i> Hustedt	x	
<i>Mastogloia peracuta</i> Janisch	x	
<i>Mastogloia pisciculus</i> Cleve	x	
<i>Mastogloia pseudoelegans</i> Hustedt	x	
<i>Mastogloia pseudolacrimata</i> T.A.Yohn & R.A.Gibson	x	
<i>Mastogloia pseudolatecostata</i> Yohn & R.A.Gibson	x	
<i>Mastogloia punctatissima</i> (Greville) Ricard		
<i>Mastogloia punctifera</i> Brun	x	
<i>Mastogloia rigida</i> Hustedt		
<i>Mastogloia rimosa</i> Cleve	x	
<i>Mastogloia rostellata</i> Grun		
<i>Mastogloia sigillata</i> Voigt	x	
<i>Mastogloia similis</i> Hustedt	x	
<i>Mastogloia</i> sp. 1		x
<i>Mastogloia staurophora</i> Hustedt (Figure A27l)		
<i>Mastogloia stephensiana</i> Yohn & R.A.Gibson	x	
<i>Mastogloia subaffirmata</i> Hustedt	x	
<i>Mastogloia sublatericia</i> Hustedt		
<i>Mastogloia tenera</i> Hustedt		
<i>Mastogloia tenuis</i> Hustedt	x	
<i>Mastogloia umbra</i> Paddock & Kemp	x	
<i>Mastogloia varians</i> Hustedt	x	
<i>Navicula abunda</i> Hustedt (Figure A21k)		
<i>Navicula agnita</i> Hustedt (Figure A21h,m,n)		
<i>Navicula apta</i> Hustedt (Figure A21l)	x	
<i>Navicula cancellata</i> Donkin		
<i>Navicula</i> cf. <i>bipustulata</i> A.Mann		
<i>Navicula</i> cf. <i>sovereignae</i> Hustedt	x	
<i>Navicula digitoradiata</i> (Gregory) Ralfs in Pritchard	x	
<i>Navicula directa</i> (W.Smith) Brébisson	x	
<i>Navicula (Lyrella) irrorata</i> f. <i>mexicana</i> Cleve (Figure A16b,d and Figure A17b,c)	x	
<i>Navicula irroratoides</i> f. <i>elliptica</i> Hustedt	x	
<i>Navicula johanrossii</i> Giffen (Figure A21e)	x	
<i>Navicula longa</i> var. <i>longa</i> (W.Gregory) Ralfs (Figure A21a)	x	
<i>Navicula longa</i> var. <i>irregularis</i> Hustedt (Figure A21c,d)		
<i>Navicula lusoria</i> M.F.Giffen		
<i>Navicula lyra</i> (Lyrella) var. <i>elliptica</i> A.W.F.Schmidt (Figure A16e–h)	x	
<i>Navicula microdigitoradiata</i> Lange-Bertalot (Figure A21j)	x	
<i>Navicula palpebralis</i> Brébisson ex W.Smith (Figures A20d and A21r)		
<i>Navicula pennata</i> A. Schmidt		
<i>Navicula ponticula</i> Giffen (Figure A20t)	x	
<i>Navicula</i> sp. 1 (Figure A27x,y)	x	
<i>Navicula</i> sp. 2 (Figure A21k)	x	
<i>Navicula</i> sp. 3 (Figure A27s–u)	x	
<i>Navicula subrostellata</i> Hustedt		
<i>Navicula torifera</i> Hustedt	x	
<i>Navicula viminea</i> Hustedt (Figure A20f–h)		
<i>Navicula zostereti</i> Grunow (Figure A21b)		
<i>Neodelphineis silenda</i> (M.H. Hohn & J. Hellerman) N. Desianti & M. Potapova	x	

Table A1. Cont.

Taxon	NR	NU
<i>Neohuttonia reichardtii</i> (Grunow) Kuntze	x	
<i>Nitzschia</i> cf. <i>hummi</i> Hustedt	x	
<i>Nitzschia</i> cf. <i>pseudofonticola</i> Hustedt		
<i>Nitzschia fusiformis</i> Grunow in Cleve & Grunow	x	
<i>Nitzschia lorenziana</i> Grunow		
<i>Nitzschia pellucida</i> Grunow	x	
<i>Nitzschia</i> sp. 1		
<i>Nitzschia amphibia</i> Grunow		
<i>Nitzschia fluminensis</i> Grunow (Figure A29e)	x	
<i>Nitzschia fusoides</i> Ehrlich (Figure A28m)		
<i>Nitzschia grossestriata</i> Hustedt	x	
<i>Nitzschia longissima</i> (Brébisson) Ralfs		
<i>Nitzschia majuscula</i> Grunow		x
<i>Nitzschia marginulata</i> var. <i>didyma</i> Grunow (Figure A30j–m)	x	
<i>Nitzschia miserabilis</i> Chohnoky		
<i>Nitzschia parvula</i> W.Smith	x	
<i>Nitzschia scabra</i> Cleve (Figure A29c,d)		
<i>Nitzschia scalpelliformis</i> Grunow		x
<i>Nitzschia sigma</i> (Kützing) W.Smith (Figure A29a,b,f)		
<i>Odontella aurita</i> (Lyngbye) C.Agardh (Figure A2a–d,g–j)		x
<i>Oestrupia ergadensis</i> (W.Gregory) Witkowski, Lange-Bertalot & Metzeltin (Figure A21g,s–u)	x	
<i>Oestrupia powellii</i> (F.W.Lewis) Heiden	x	
<i>Opephora marina</i> (W.Gregory) Petit (Figure A6k–m)	x	
<i>Opephora mutabilis</i> Sabbe & Wyverman, nom. inval.	x	
<i>Opephora pacifica</i> (Grunow) Petit (Figure A6o)		
<i>Paralia sulcata</i> (Ehrenberg) Cleve		
<i>Parlibellus bennikei</i> Witkowski, Metzeltin & Lange-Bertalot		
<i>Parlibellus delognei</i> (Van Heurck) E.J.Cox		
<i>Parlibellus grevilleoides</i> (Hustedt) E.J.Cox		
<i>Parlibellus phoebeae</i> Witkowski, Metzeltin & Lange-Bertalot (Figure A20e)		
<i>Perissonoe crucifera</i> (Kitton) Desikachary & al. (Figure A7g–j)		
<i>Petroneis granulata</i> D.G.Mann (Figure A18b,c)	x	
<i>Petroneis plagiostoma</i> (Grunow) D.G.Mann (Figure A18a–d)	x	
<i>Plagiogramma constrictum</i> Greville	x	
<i>Plagiogramma minus</i> var. <i>minus</i> (Gregory) Chunlian Li, Ashworth & Witkowski (Figure A6c,d)		x
<i>Plagiogramma minus</i> var. <i>nanum</i> (Gregory) Chunlian Li, Ashworth & Witkowski		
<i>Plagiogramma pulchellum</i> var. <i>pygmaeum</i> (Greville) H.Peragallo & M.Peragallo	x	
<i>Plagiogramma wallichianum</i> Greville		x
<i>Plagiotropis lepidoptera</i> (W.Gregory) Kuntze (Figure A31g,h)	x	
<i>Plagiotropis pusilla</i> (W.Gregory) Kuntze (Figure A28p)		
<i>Plagiotropis vitrea</i> (W.Smith) Grunow (Figure A28o,q)	x	
<i>Pleurosigma affine</i> Grunow (Figure A19f,g)	x	
<i>Pleurosigma latiusculum</i> H.Peragallo	x	
<i>Pleurosigma salinarum</i> Grunow (Figure A27a–d)		x
<i>Podocystis adriatica</i> (Kützing) Ralfs (Figure A7a,d)	x	
<i>Podocystis spathulata</i> (Shadbolt) Van Heurck (Figure A7e,f)	x	
<i>Podosira hormoides</i> var. <i>adriatica</i> (Kützing) Grunow (Figure A1g)	x	
<i>Prestauroneis</i> cf. <i>crucicula</i> (W.Smith) Genkal & Yarushina		
<i>Protoraphis hustediana</i> Simonsen	x	
<i>Psammodyctyon panduriforme</i> (W.Gregory) D.G.Mann		x
<i>Psammodyctyon rudum</i> (Chohnoky) D.G.Mann		x
<i>Psammodiscus calceatus</i> T. Watanabe, T. Nagumo & J.Tanaka (Figure A1l)	x	
<i>Psammodiscus nitidus</i> (W.Gregory) Round & D.G.Mann (Figure A1h,i)		
<i>Rhaphoneis amphiceros</i> (Ehrenberg) Ehrenberg		x
<i>Rhoikoneis</i> sp. (Figure A20k)		x

Table A1. Cont.

Taxon	NR	NU
<i>Rhopalodia gibberula</i> (Ehrenberg) O.Müller (Figure A28h,i)	x	
<i>Rhopalodia musculus</i> var. <i>musculus</i> (Kützing) O.Müller	x	
<i>Rhopalodia musculus</i> var. <i>producta</i> (Grunow) Peragallo & Peragallo (Figure A28j,k)		
<i>Rossia linearis</i> Voigt		
<i>Rutilaria</i> cf. <i>obesa</i> (unidentified) Greville ex Cleve (Figure A8l,m)		x
<i>Schizostauron citronella</i> (A.Mann) Górecka, Riaux-Gobin & Witkowski	x	
<i>Seminavis barbara</i> Witkowski, Lange-Bertalot & Metzeltin	x	
<i>Seminavis eulensteinii</i> (Grunow) Danielidis, Ford & Kennett		
<i>Seminavis delicatula</i> Wachnicka & Gaiser (Figure A23s,t)	x	
<i>Seminavis lunulata</i> (A.H.Wachnicka & E.E.Gaiser) C.H.Li, Y.H.Gao & C.P.Chen (Figure A23h–l)	x	
<i>Seminavis latior</i> (Schmidt) Danielidis & Mann (Figure A22f)	x	
<i>Seminavis robusta</i> Danielidis & Mann (Figure A22g)	x	
<i>Shionodiscus oestrupii</i> (Ostenfeld) A.J.Alverson, S.-H.Kang & E.C.Theriot	x	
<i>Staurophora salina</i> (W.Smith) Mereschowsky (Figure A19c,d)	x	
<i>Staurophora</i> sp. 1 (Figure A27o)	x	
<i>Surirella platylloba</i> F.Meister (Figure A31b–d)	x	
<i>Synedra</i> sp. 2	x	
<i>Synedra</i> sp. 3	x	
<i>Synedra pulcherrima</i> Hantzsch	x	x
<i>Synedrosphenia</i> cf. <i>crystallina</i> (C.Agardh) Lobban & Ashworth	x	x
<i>Synedrosphenia fulgens</i> (Greville) Lobban & Ashworth	x	
<i>Synedrosphenia gomphonema</i> (Janisch & Rabenhorst) Hustedt (Figure A8b,c)		
<i>Tabularia affinis</i> var. <i>acuminata</i> (Grunow) Aboal		
<i>Talaroneis furcigera</i> (Grunow) Sterrenburg		
<i>Tephanocyclus meneghinianus</i> (Kützing) Kulikovskiy, Genkal & Kociolek	x	
<i>Terpsinoë musica</i> Ehrenberg		x
<i>Tetramphora sulcata</i> (Brébisson) Stepanek & Kociolek		
<i>Tetramphora intermedia</i> (Cleve) Stepanek & Kociolek (Figure A22e)	x	
<i>Tetramphora ostrearia</i> (Brébisson) Mereschowsky (Figure A22b)	x	
<i>Tetramphora rhombica</i> (Kitton) Stepanek & Kociolek	x	
<i>Thalassiosira decipiens</i> (Grunow ex Van Heurck) Jørgensen (Figure A1f)		x
<i>Toxarium hennedyanum</i> (W.Gregory) Pelletan	x	
<i>Toxarium undulatum</i> Bailey		
<i>Trachyneis aspera</i> var. <i>aspera</i> (Ehrenberg) Cleve (Figure A27j)		
<i>Trachyneis aspera</i> var. <i>elliptica</i> Hendey		
<i>Trachyneis aspera</i> var. <i>oblonga</i> (Bailey) Cleve (Figure A27h)	x	
<i>Trachyneis velata</i> (A.W.F.Schmidt) Cleve (Figure A27k)		
<i>Triceratium balearicum</i> f. <i>quadratum</i> Hustedt (Figure A3a,b,j–n)		
<i>Triceratium balearicum</i> Cleve & Grunow (Figures A3c–f and A4e,f,k,l)		
<i>Triceratium reticulum</i> Ehrenberg (Figure A3o)		x
<i>Trigonium formosum</i> var. <i>pentagonale</i> (A.W.F.Schmidt) Desikachary & Prema		x
<i>Tryblionella</i> cf. <i>graeffei</i> (Grunow ex Cleve) D.G.Mann (Figure A30i)	x	
<i>Tryblionella coarctata</i> (Grunow) D.G.Mann (Figure A30f,g)	x	
<i>Tryblionella jelineckii</i> (Grunow) D.G.Mann		x
<i>Tryblionella levidensis</i> W.Smith		x
<i>Tryblionella parvula</i> (W.Smith) T.Ohtsuka & Y.Fujita (Figure A30o,p)		
<i>Tryblionella persuadens</i> (Cholnoki) K.P.Cavalcante, P.I.Tremarin & T.A.V.Ludwig		
<i>Tryblionella punctata</i> W.Smith	x	
<i>Ulnaria ulna</i> (Nitzsch) Compère	x	
Diatom sp. (Figure A5a,f)	x	

Appendix B. Iconographic Catalog of Representative Diatom Taxa Found in Sediments of Playa Las Gaviotas, Cuba

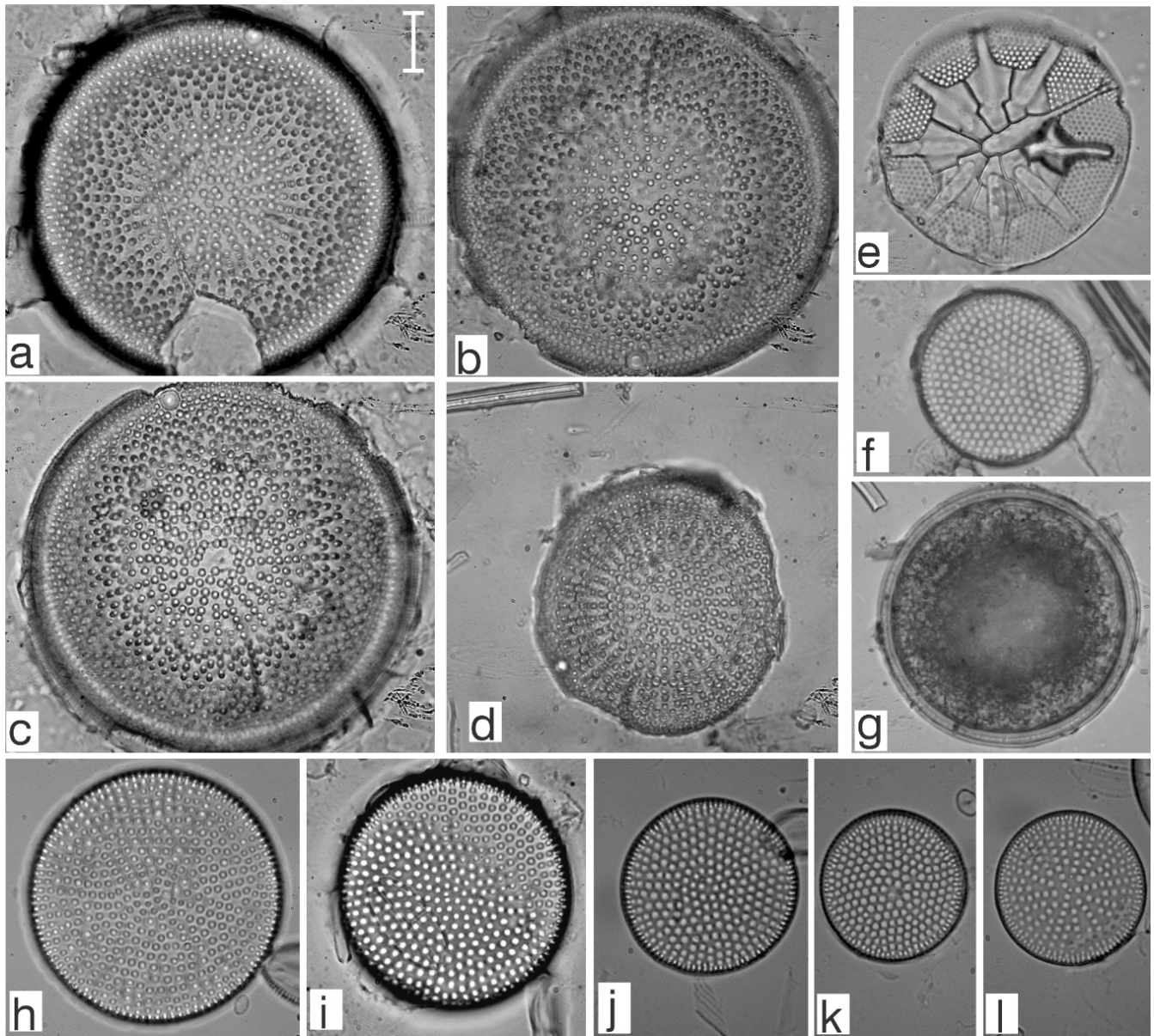


Figure A1. (a–d) *Actinocyclus octonarius* var. *sparsus*; (e) *Asteromphalus robustus*; (f) *Thalassiosira decipiens*; (g) *Podosira hormoides* var. *adriatica*; (h,i) *Psammodiscus nitidus*; (j,k) *Azpeitia nodulifer*; (l) *Psammodiscus calceatus*. Bar = 10 μ m.

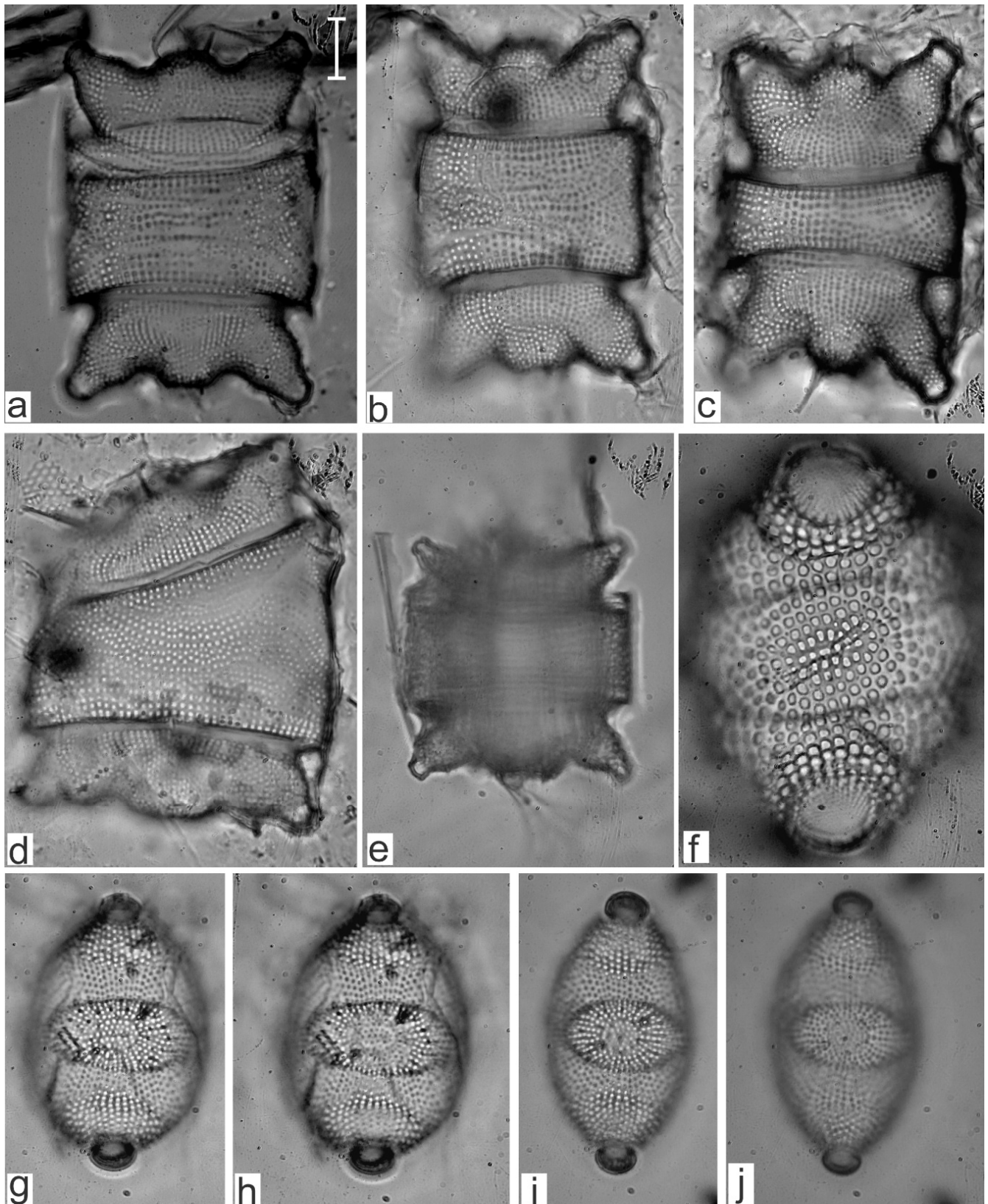


Figure A2. (a–d,g–j) *Odontella aurita*; (e) *Amphipentas pentacrinus*; (f) *Biddulphia biddulphiana*. Bar = 10 μm.

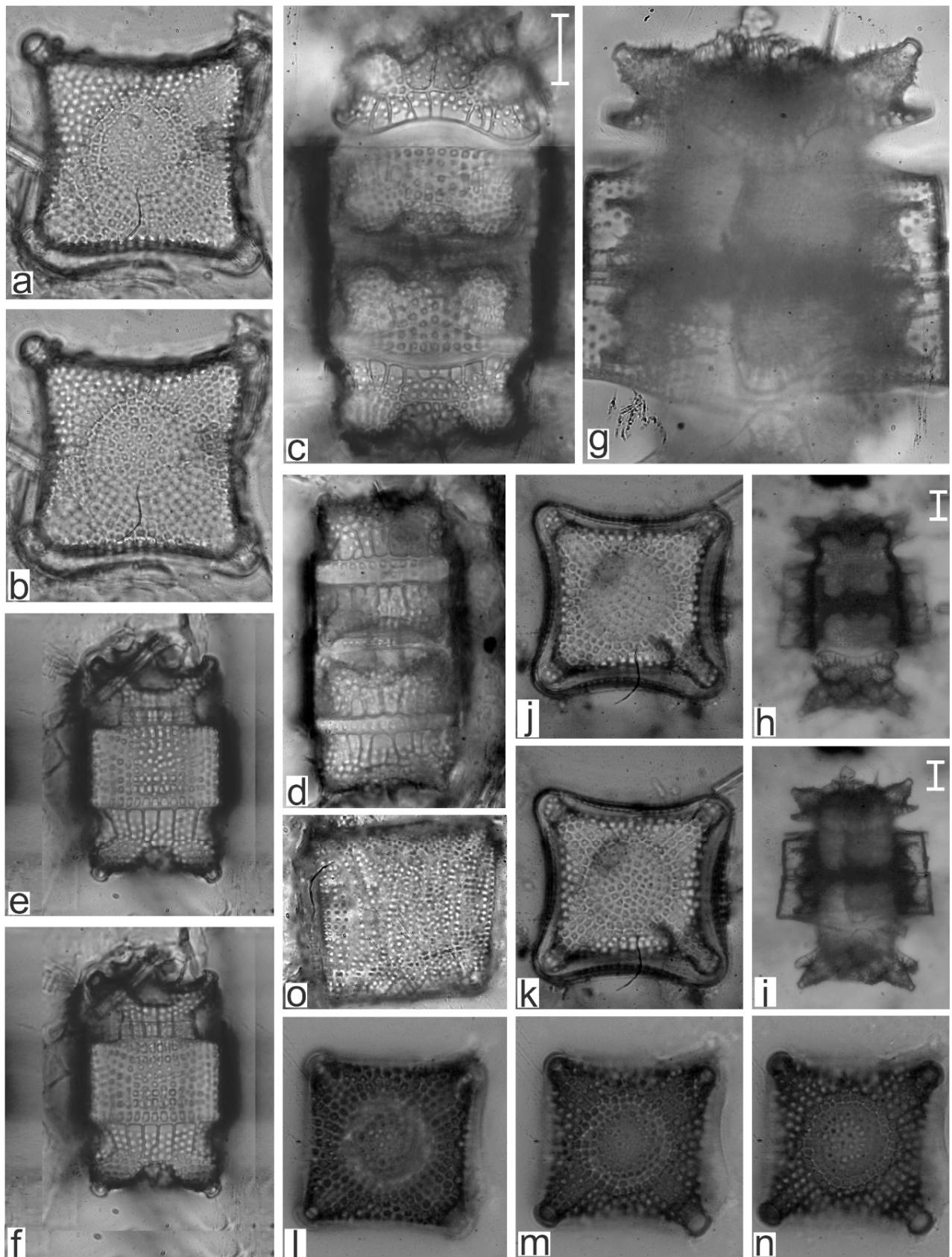


Figure A3. (a,b,j–n) *Triceratium balearicum* f. *quadratum*; (c–f) *T. balearicum*; (g–i) *Amphipentax pentacrinus*; (o) *Triceratium reticulum*. Bar = 10 μ m.

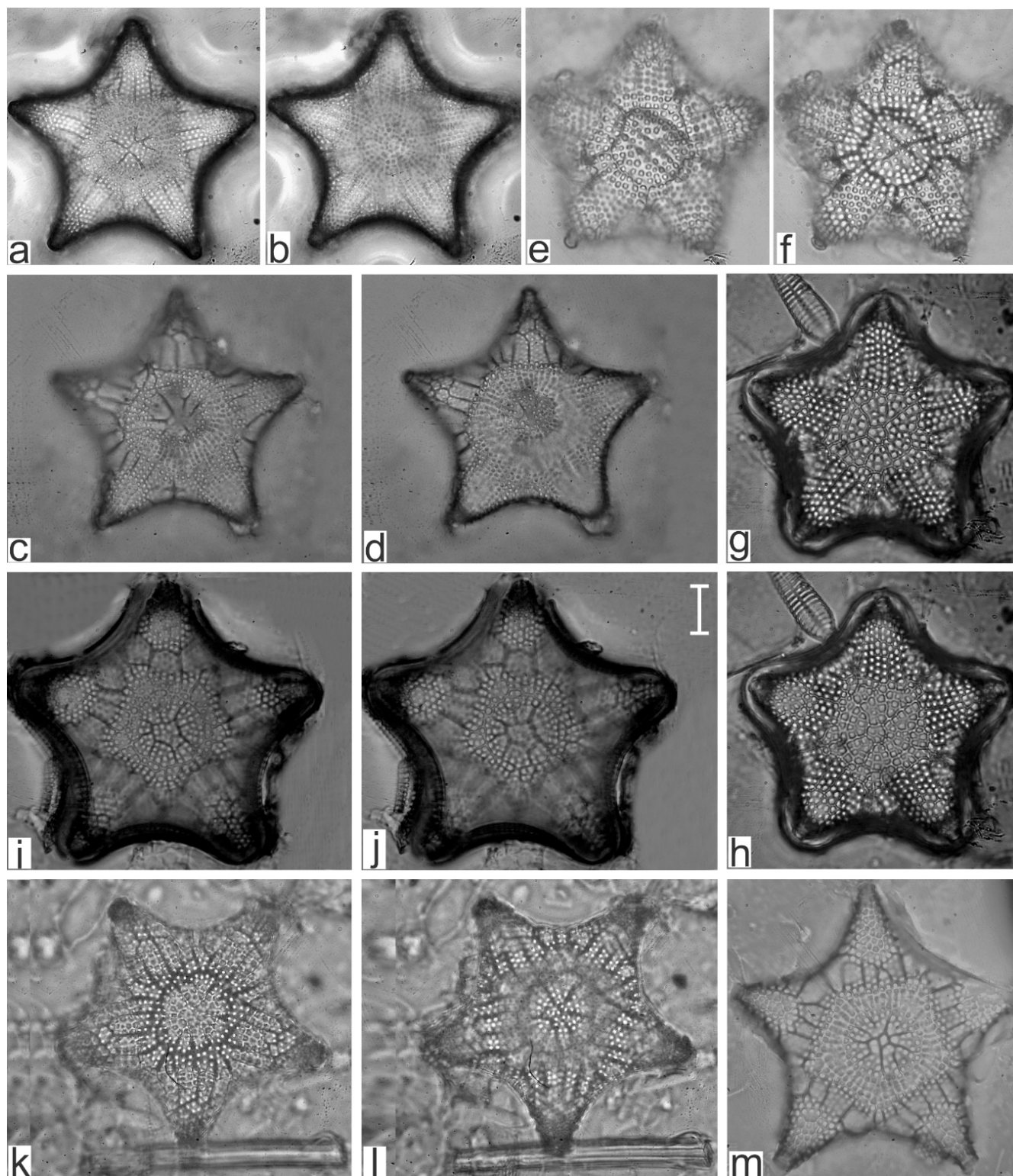


Figure A4. (a–d,g–j,m) *Amphipentastem pentacrinus*; bar= 20 μ m; (e,f,k,l) *Triceratium balearicum*. Bar = 10 μ m.

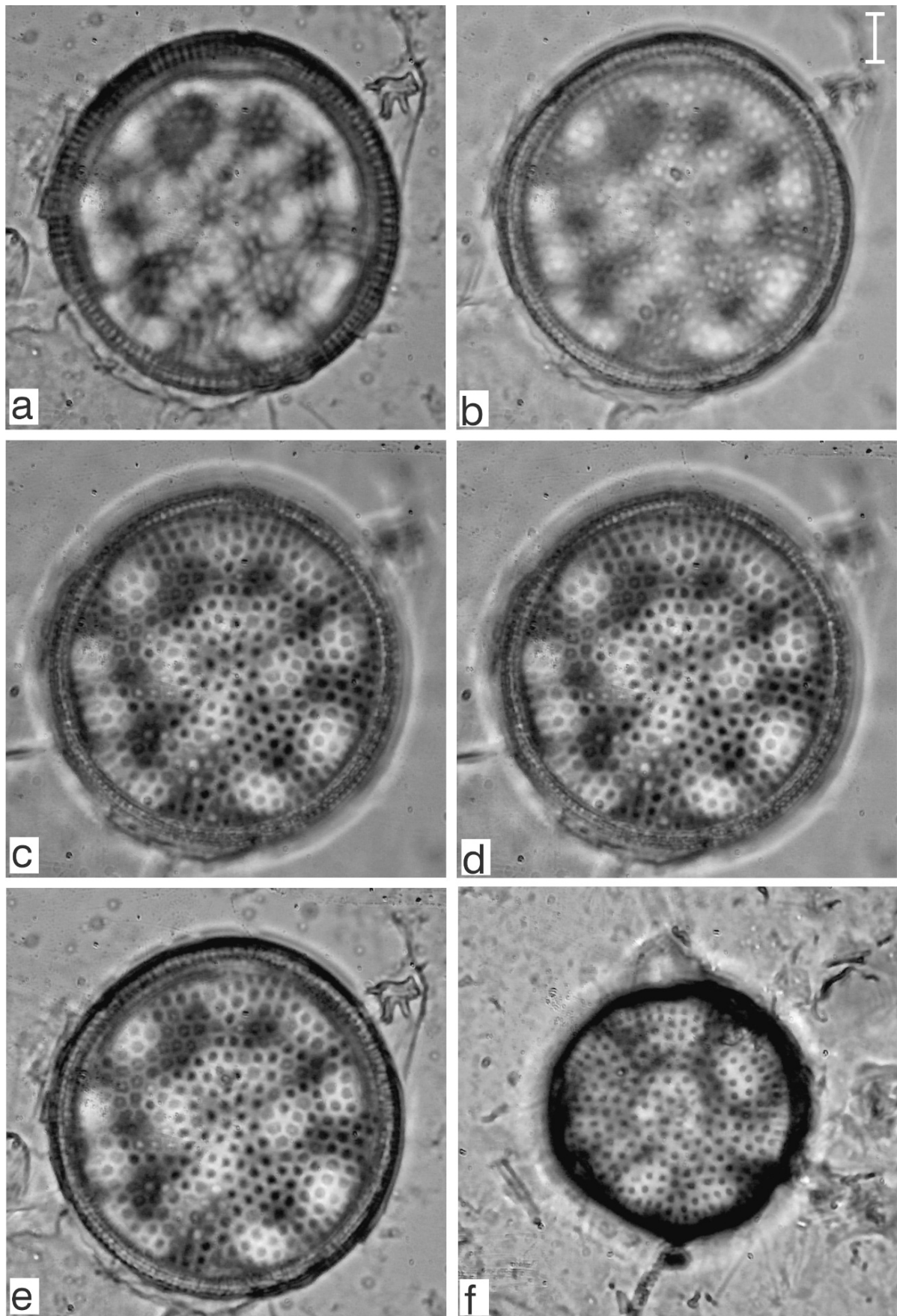


Figure A5. (a–f) Unidentified centric diatom species. Bar = 10 μm.

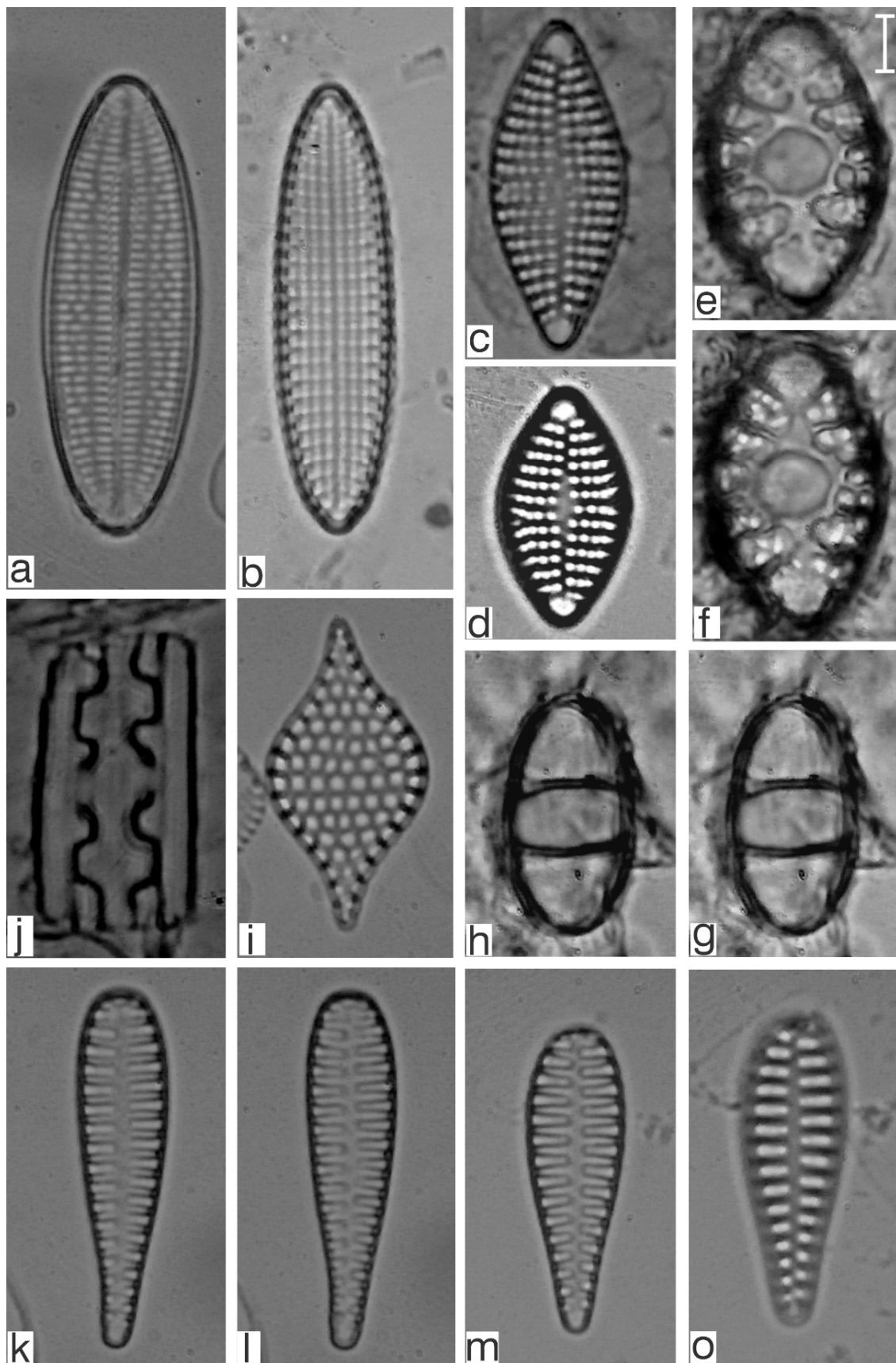


Figure A6. (a) *Cocconeis clandestina*; (b) *Hendeyella dubia*; (c,d) *Plagiogramma minus* var. *minus*; (e,f) *Glyphodesmis eximia*; (g,h) *Anaulus minutus*; (i) *Cymatosira lorenziana*; (j) *Grammatophora serpentina*; (k–m) *Opephora marina*; (o) *O. pacifica*. Bar = 10 μ m.

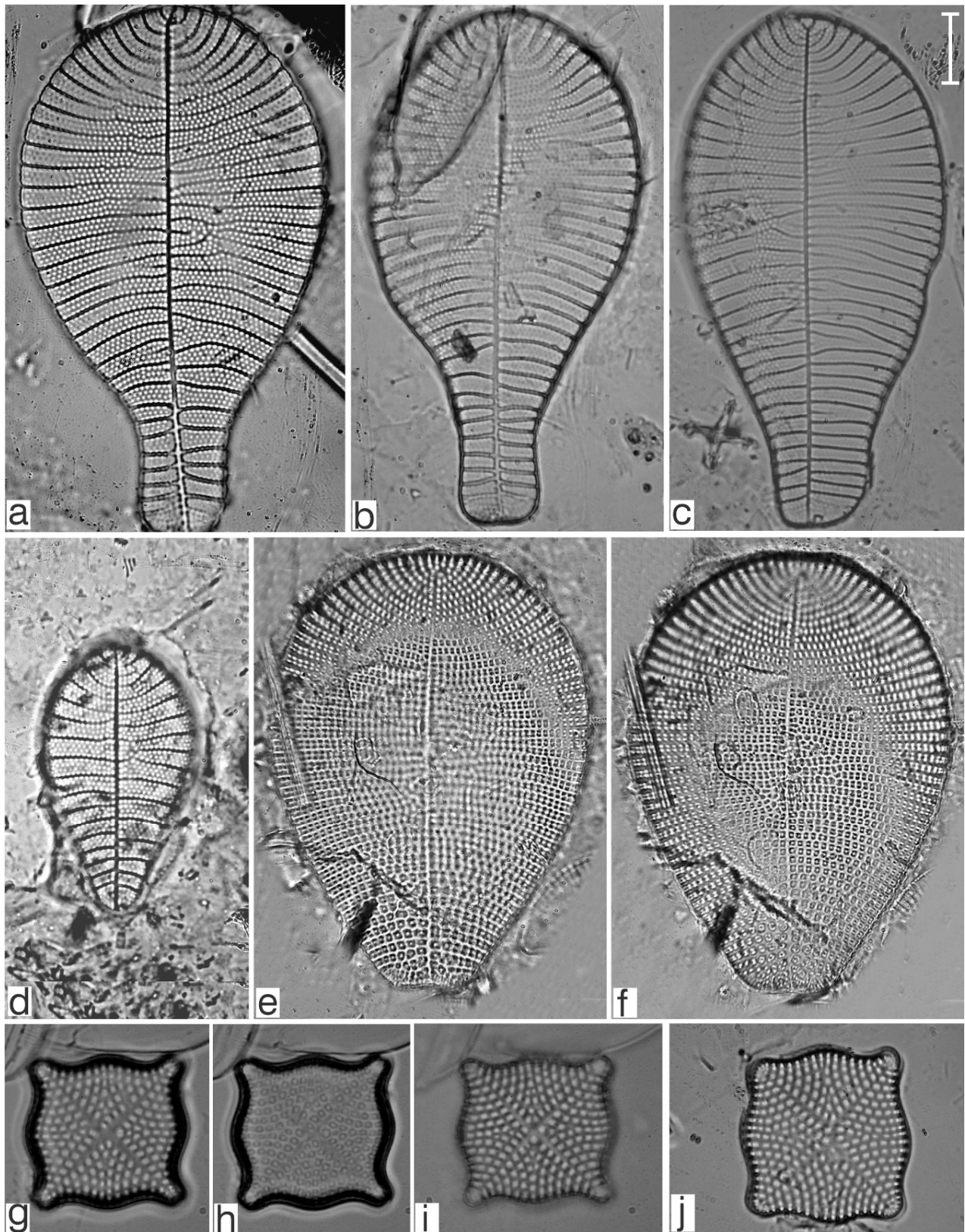


Figure A7. (a–d) *Podocystis adriatica*; (e,f) *P. spathulata*; bar = 20 μm; (g–j) *Perissonoe crucifera*. Bar = 20 μm.

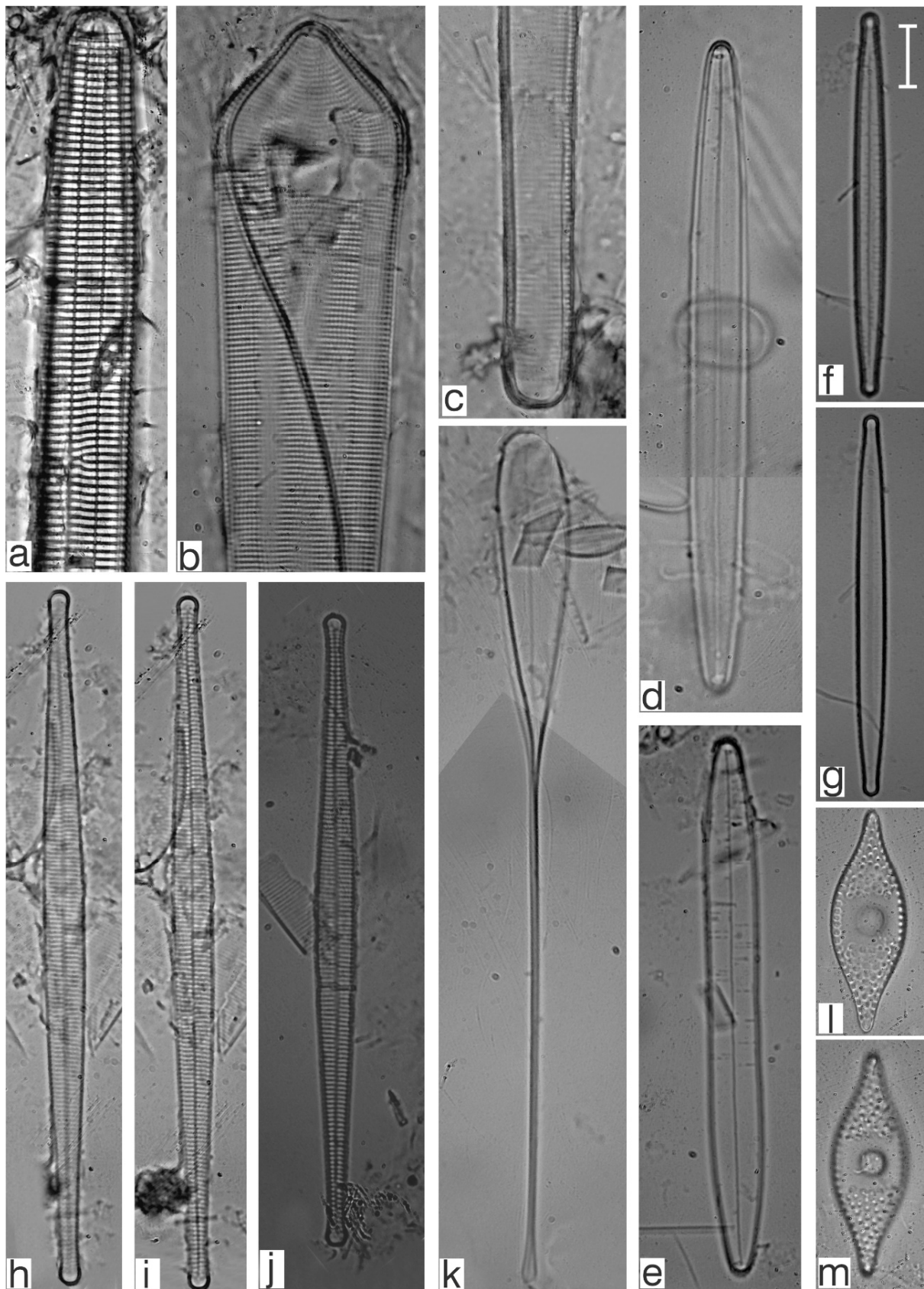


Figure A8. (a) *Ardissonaea formosa*; (b,c) *Synedrosphenia gomphonema*; (d,e) *Protorhaphis hustedtiana*; (f,g) *Hyalosynedra laevigata*; (h–j) *Catacombas gaillonii*; (k) *Licmophora remulus*; (l,m) *Rutilaria cf. obesa*. Bar = 10 μ m.

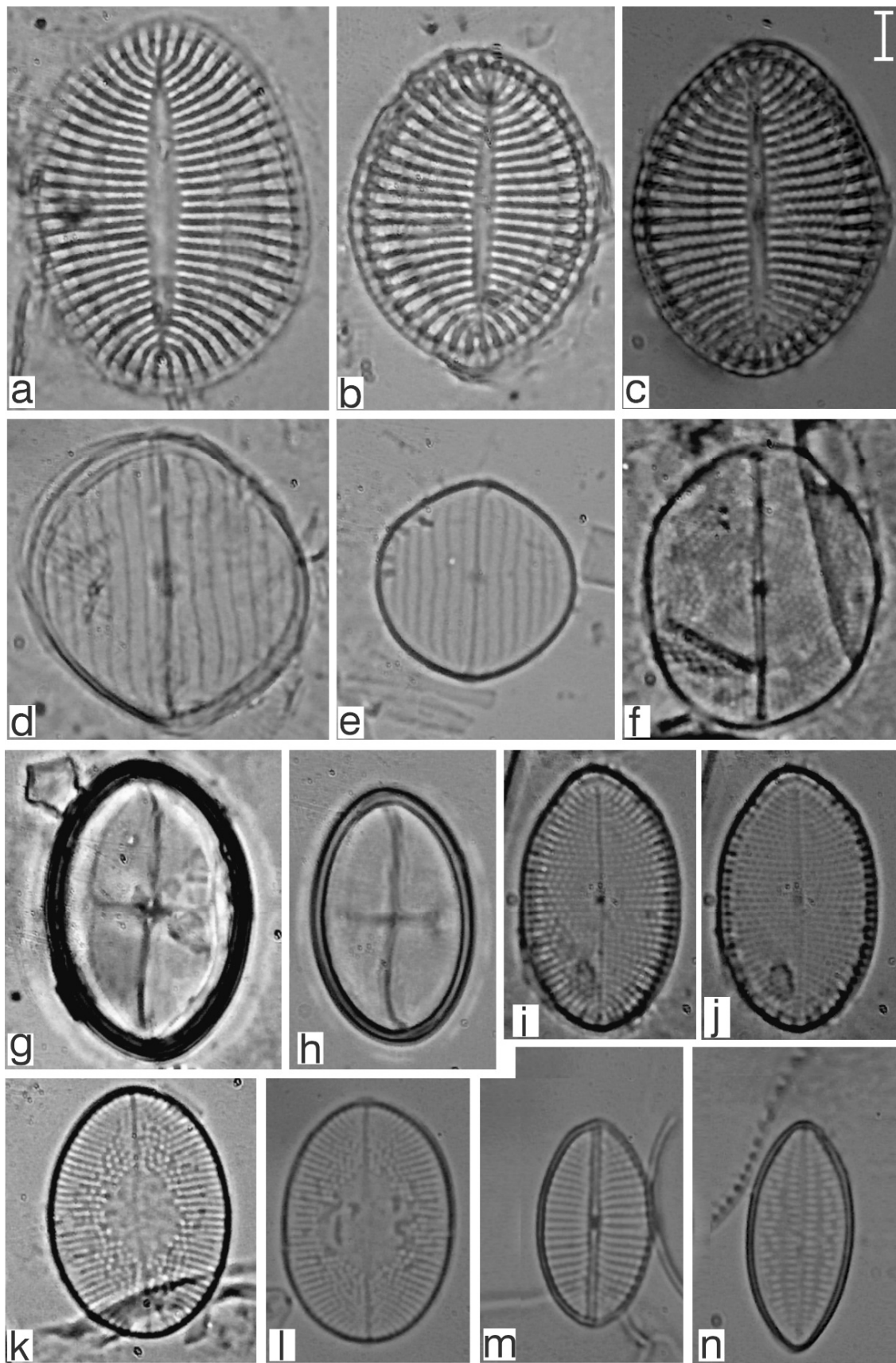


Figure A9. (a–c) *Cocconeis britannica*; (d,e) *Cocconeis singularis*; (f) *Cocconeopsis orthoneoides*; (g,h) *Cocconeis caribensis*; (i,j) *Cocconeis* sp. 1; (k,l) *Anorthoneis eurystoma*; (m) *Cocconeopsis* sp. 1; (n) *Amphicocconeis discrepans*. Bar = 10 μ m.

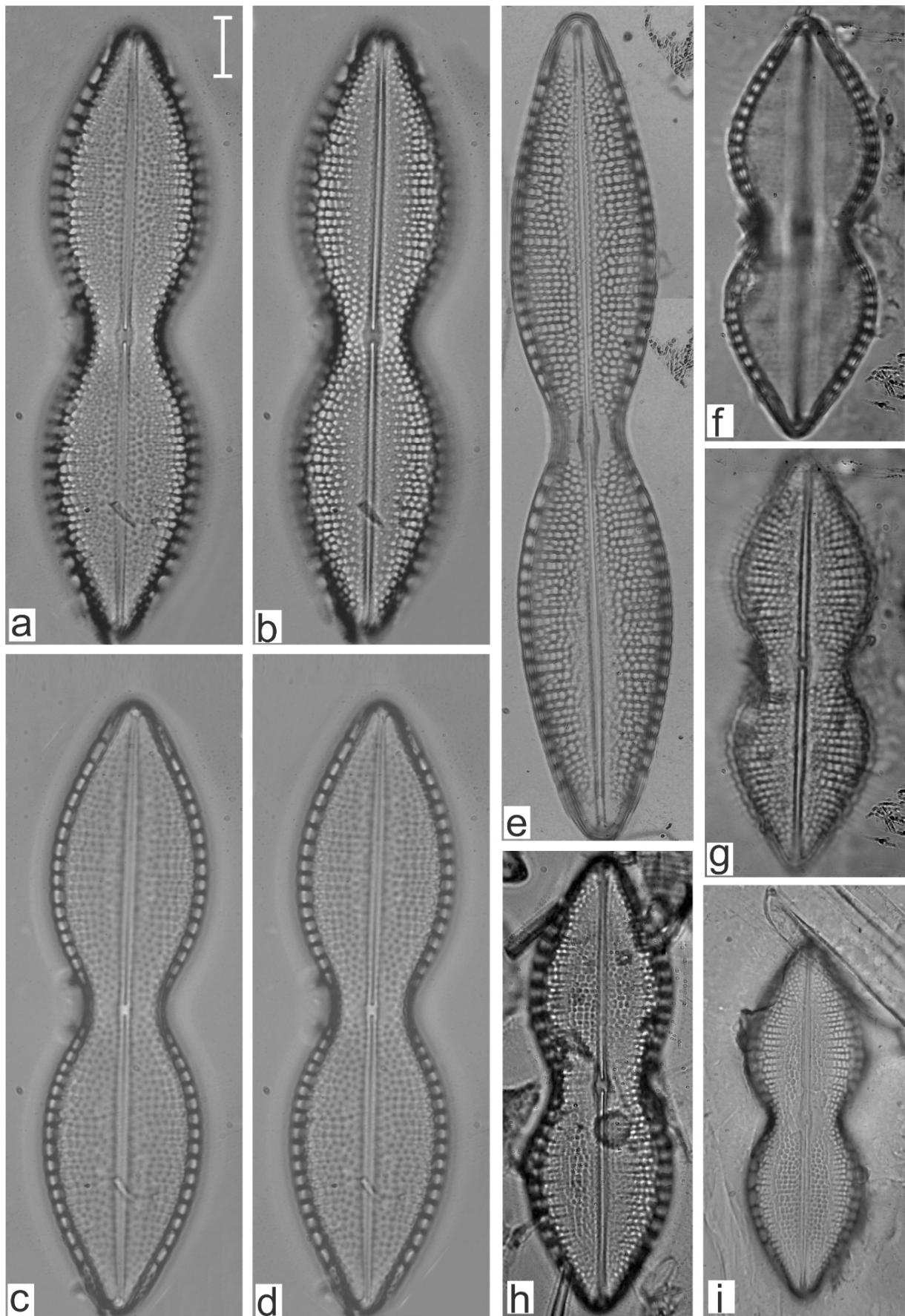


Figure A10. (a–d) *Dictyoneis marginata* var. *marginata*; (e) *D. marginata* var. *elongata*; (f–i) *D. marginata* var. *spectatissima*. Bar = 10 μ m.

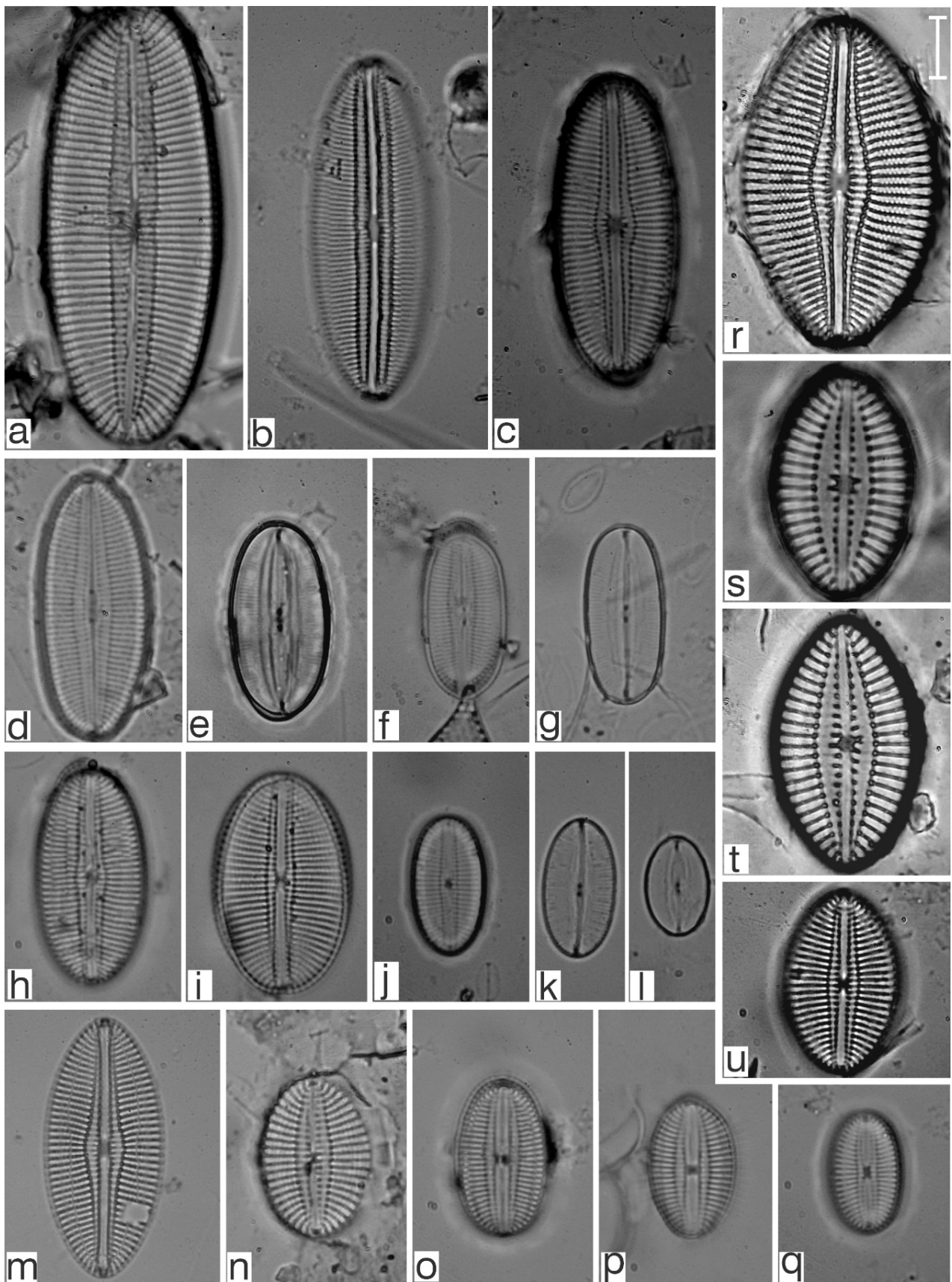


Figure A11. (a,b,j) *Diploneis littoralis* var. *clathrata*; (c,h) *D. vacillans*; (d) *Rossia linearis*; (e) *Fallacia ny*; (f,g,k) *F. oculiformis*; (i) *Diploneis parca*; (l) *Fallacia floriniae*; (m,n,u) *Diploneis smithii* var. *pumila*; (o–q) *D. papula*; (r) *D. smithii* var. *smithii*; (s,t) *D. nitescens*. Bar = 10 μ m.

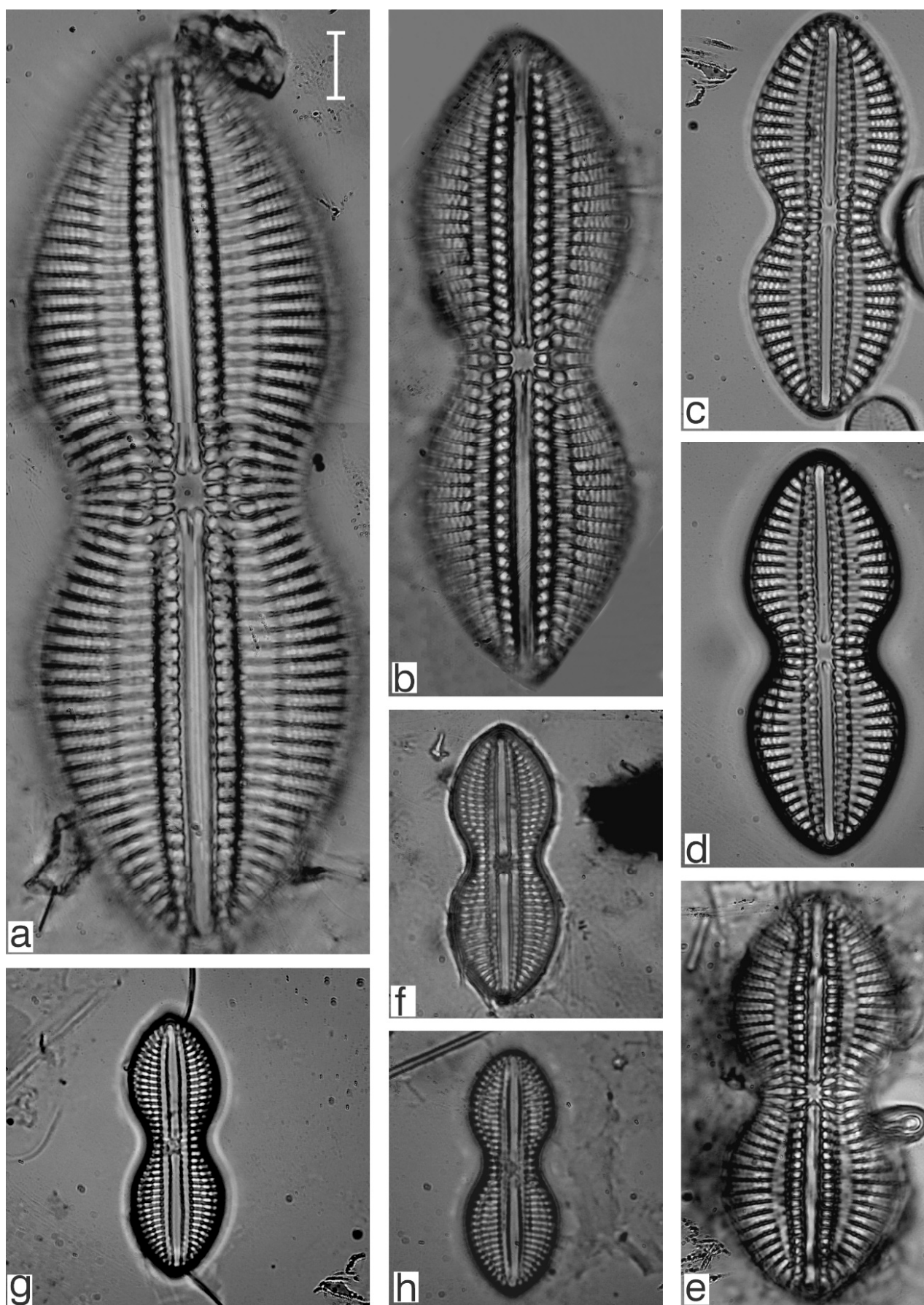


Figure A12. (a–e) *Diploneis crabro*; (f–h) *D. chersonensis*. Bar = 10 μm.

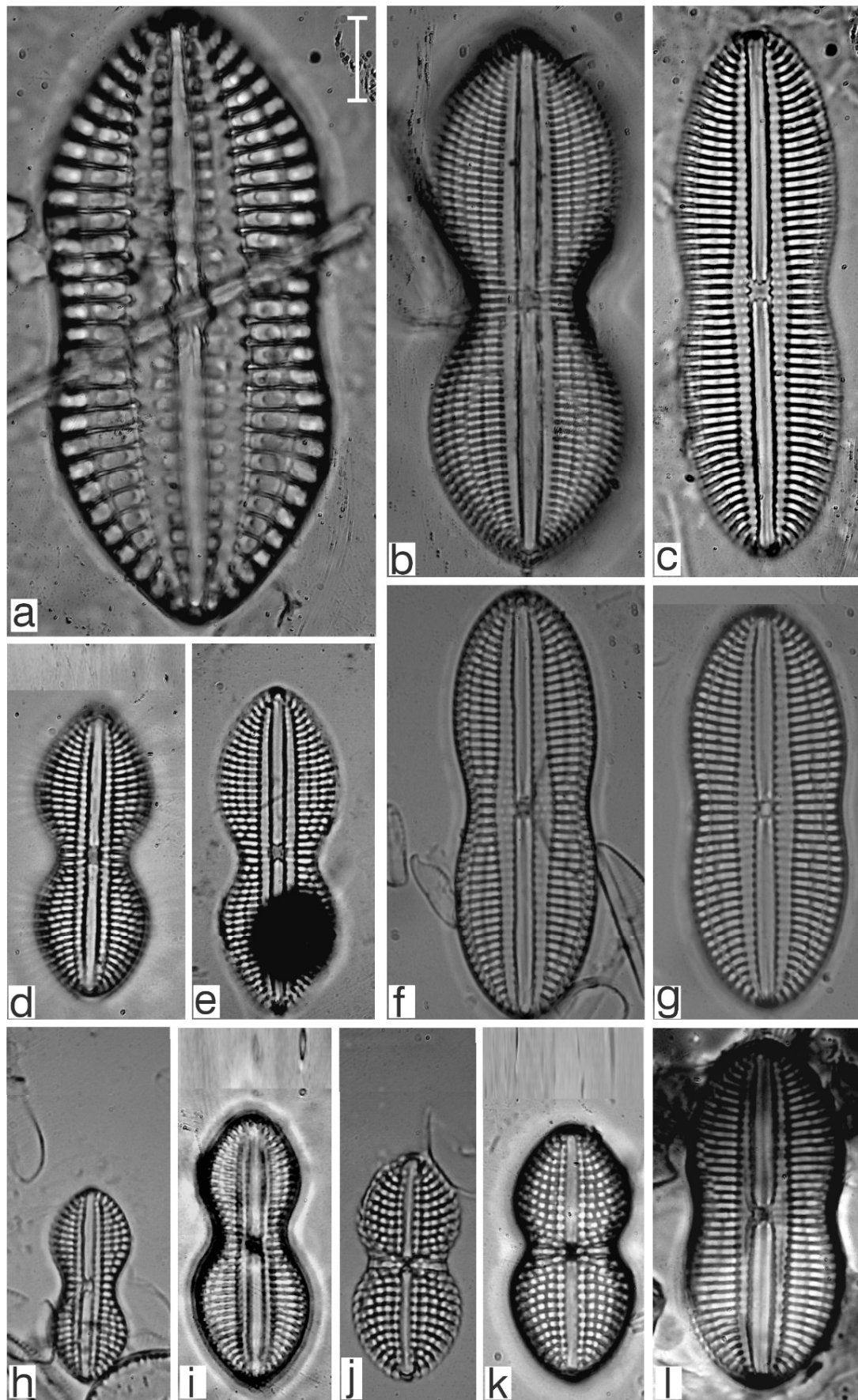


Figure A13. (a) *Diploneis gemmatula*; (b,d,e,h,i) *D. chersonensis*; (c) *D. advena*; (f,g,l) *D. papula* var. *constricta*; (h–k) *D. weissflogii*. Bar = 10 μ m.

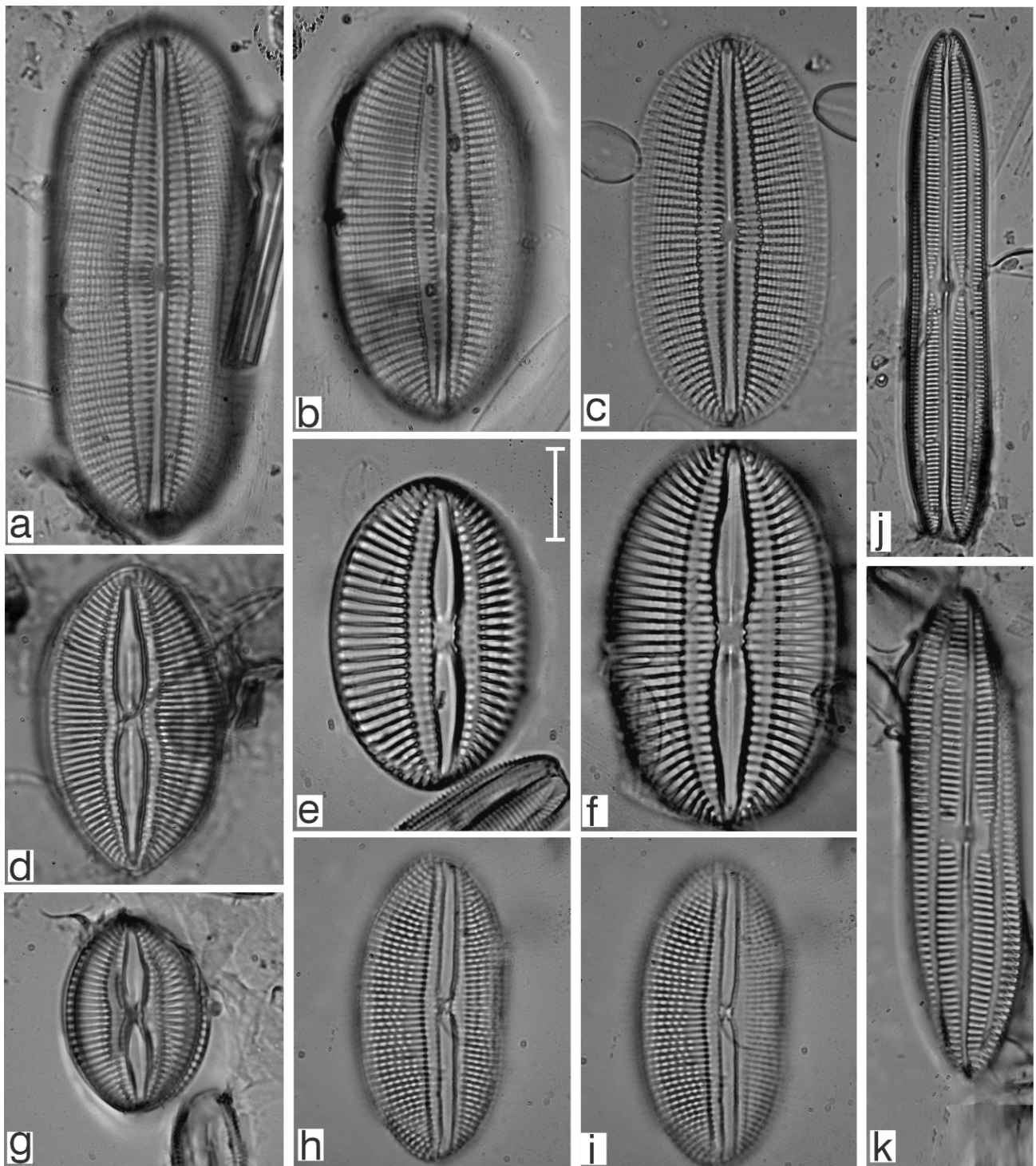


Figure A14. (a–c) *Diploneis fusca*; (d,g) *D. coffeiformis*; (e,f) *D. suborbicularis*; (h,i) *D. obliqua*; (j,k) *Oestrupia powellii*. Bar = 10 μm .

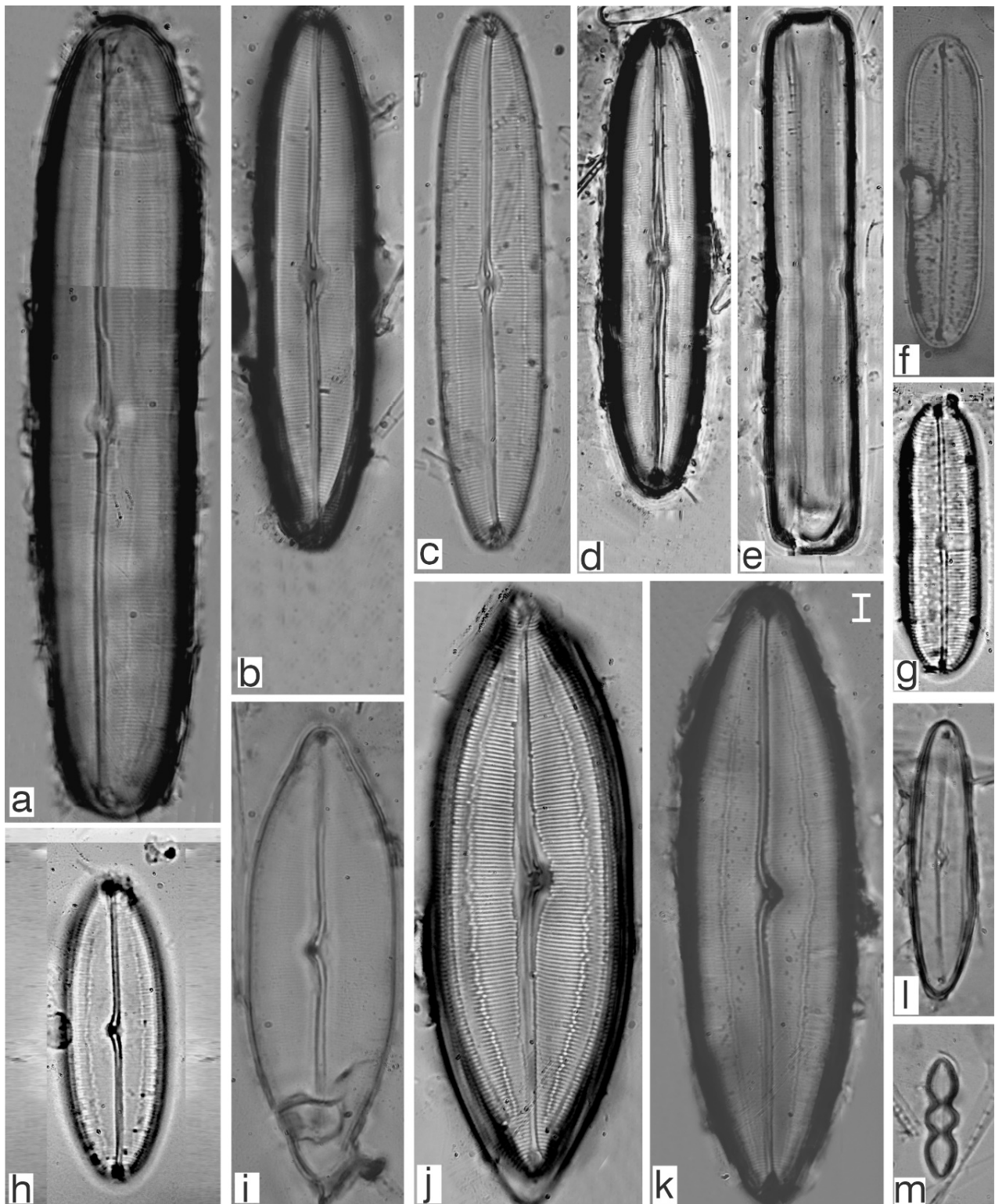


Figure A15. (a–e,h) *Caloneis liber*; (f,g) *Caloneis* sp. 1; (i,k) *C. sectilis*; (j) *C. excentrica*; (l) *C. linearis*; (m) *C. egena*. Bar = 10 μm.

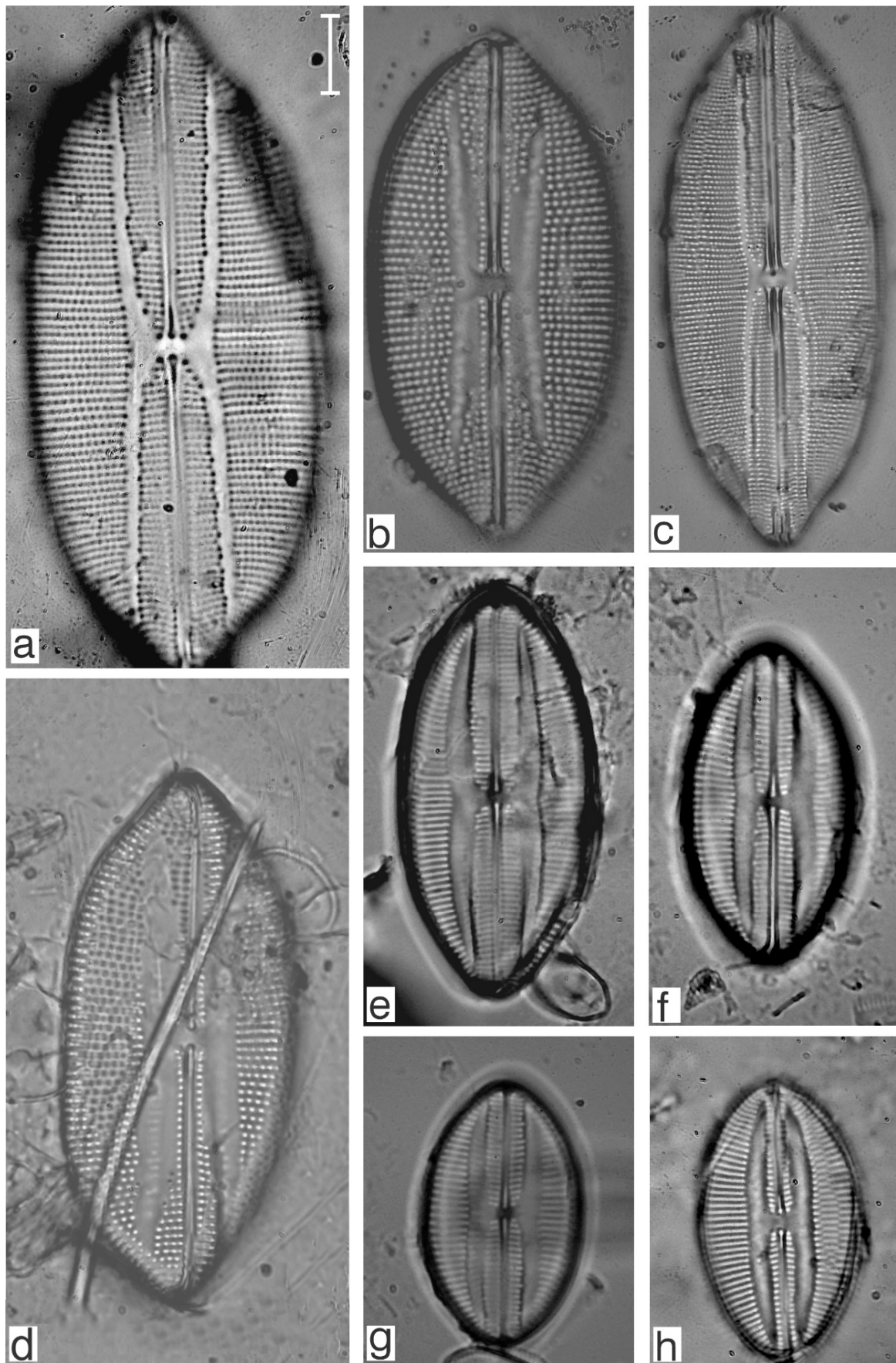


Figure A16. (a,c) *Lyrella lyra* var. *lyra*; (b,d) *Navicula (Lyrella) irrorata* f. *mexicana*; (e–h) *N. lyra* var. *elliptica*. Bar = 10 μ m.

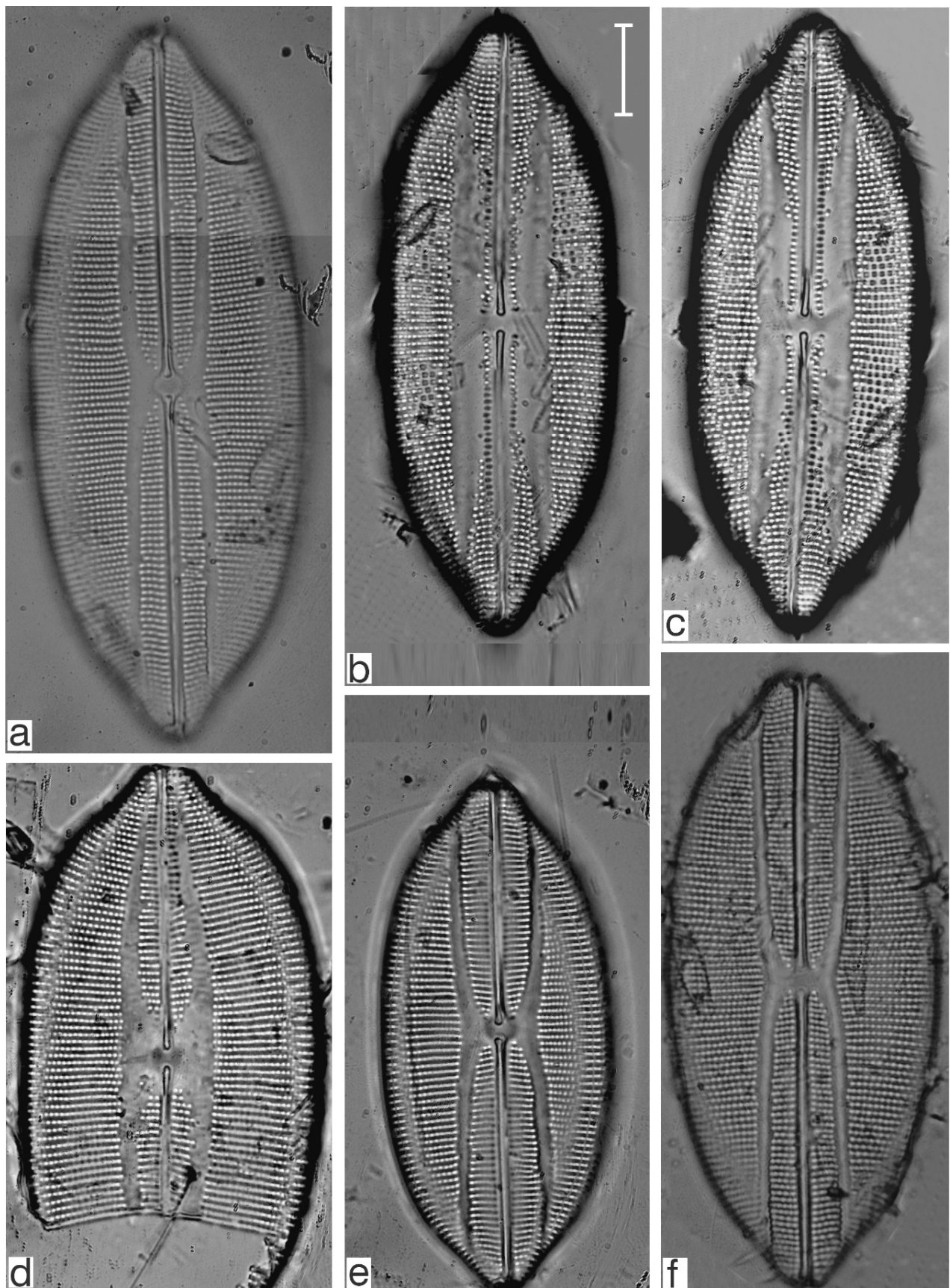


Figure A17. (a,d–f) *Lyrella lyra* var. *lyra*; (b,c) *Navicula (Lyrella) irrorata* f. *mexicana*. Bar = 10 μ m.

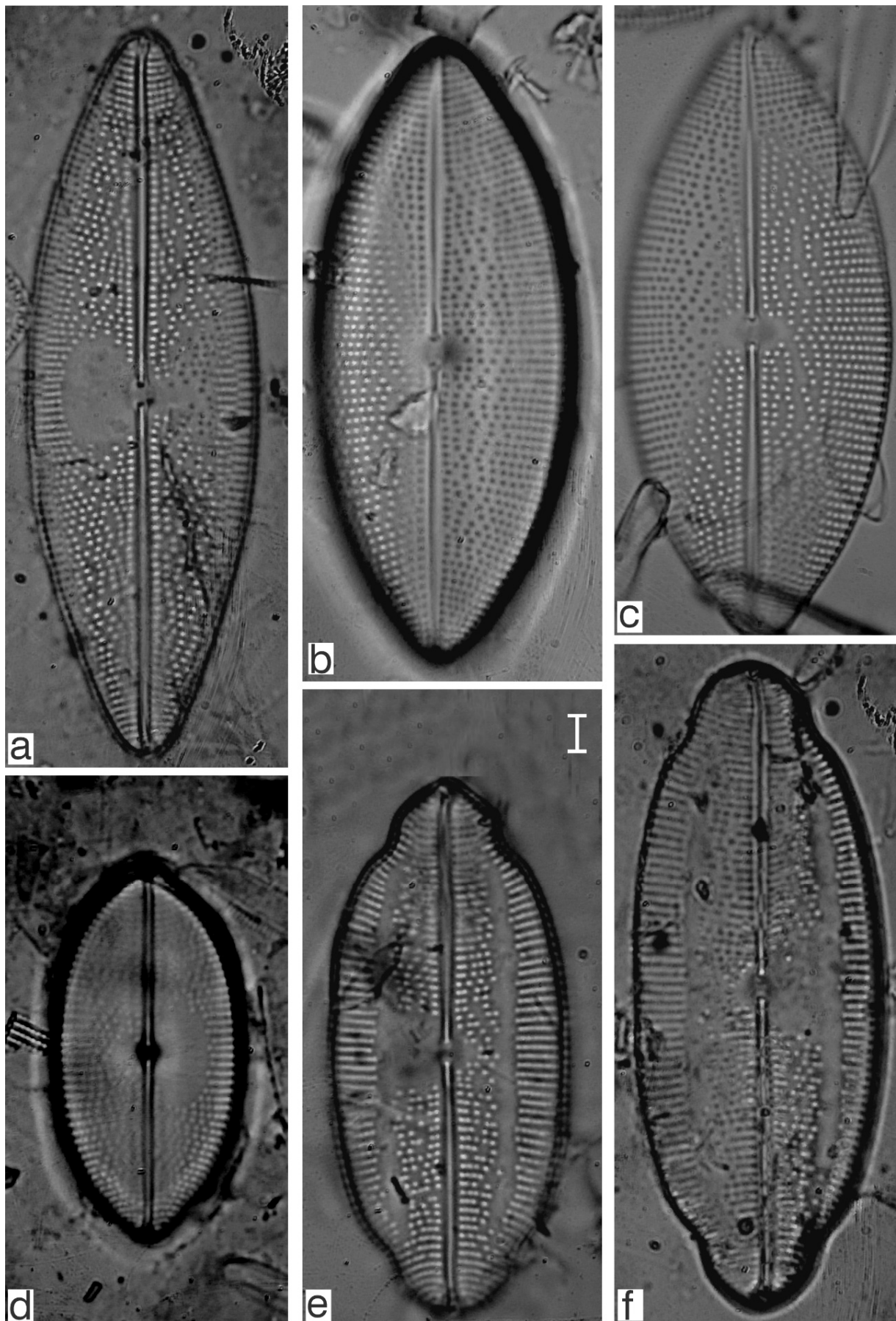


Figure A18. (a,d) *Petroneis plagiostoma*; (b,c) *P. granulata*; (e,f) *Lyrella diffluens*. Bar = 10 μm.

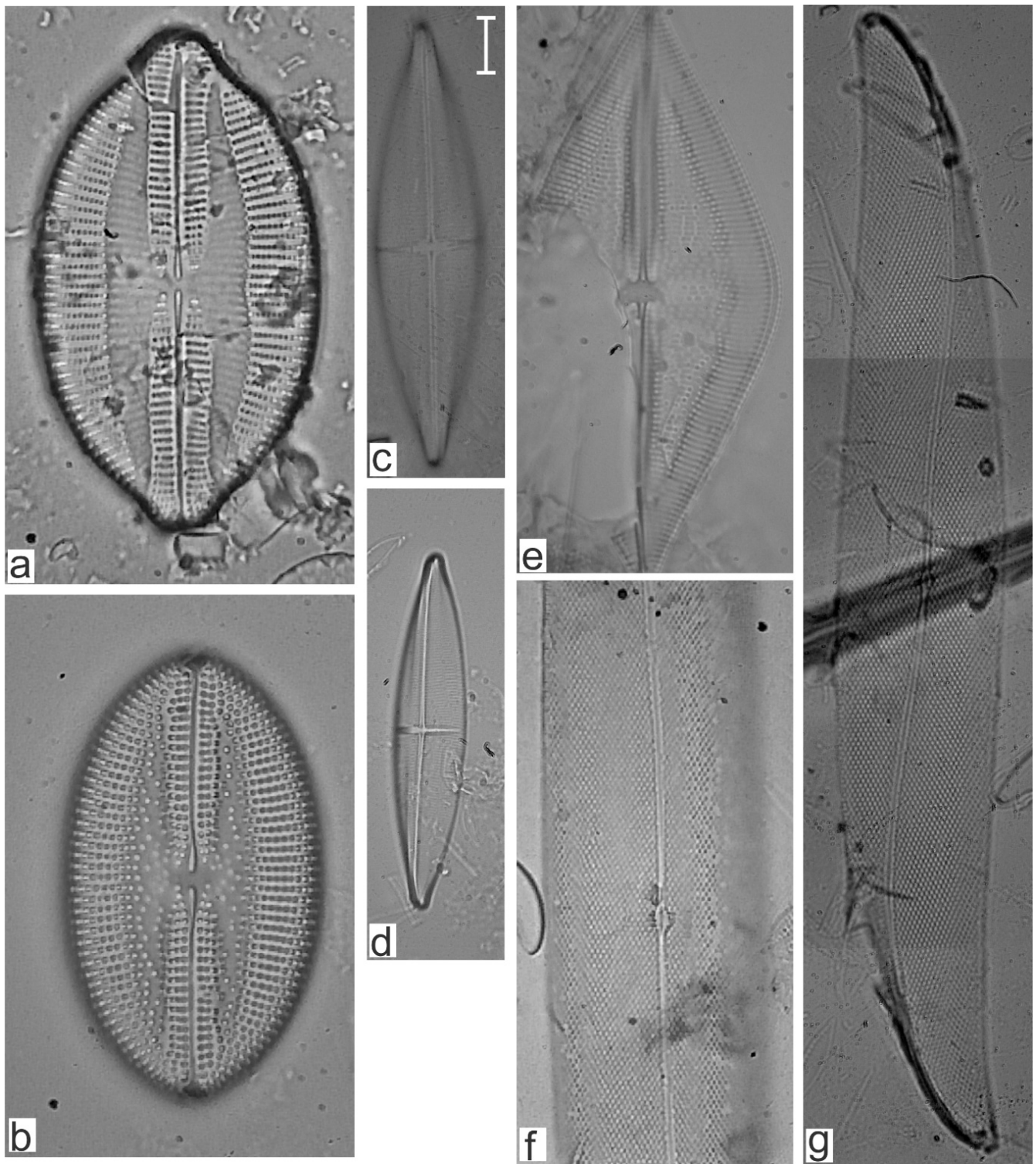


Figure A19. (a) *Lyrella clavata* var. *indica*; (b) *L. praetexta*; (c,d) *Staurophora salina*; (e) *Mastogloia jelineckii* var. *jelineckii*; (f,g) *Pleurosigma affine*. Bar= 10 μm.

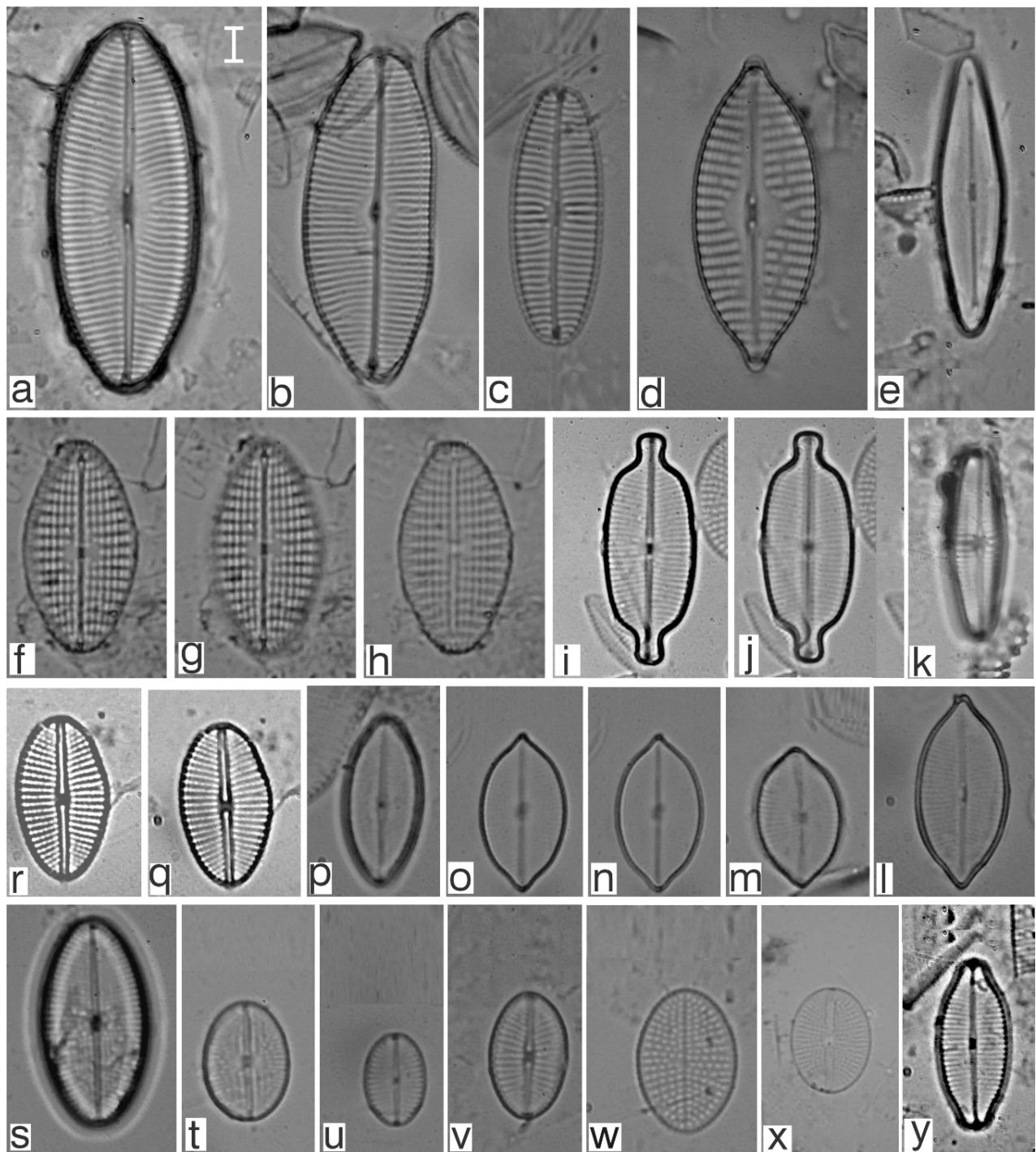


Figure A20. (a) *Navicula digitoradiata*; (b) *Cymbella* sp. 1; (c) *Navicula lusoria*; (d) *N. palpebralis*; (e) *Parlibellus phoebeae*; (f–h) *Navicula viminea*; (i,j) *Karayevia* sp. 1; (k) *Rhoikoneis* sp.; (l–p) *Navicula* cf. *sovereignae*; (q,r,v) *Cocconeopsis* sp. 1; (s) *Cocconeopsis* sp. 2; (t) *Navicula ponticula*; (u) *Cocconeopsis pullus*; (w,x) *C. patrickiae*; (y) *Achnanthes biasoletiana*. Bar = 10 µm.

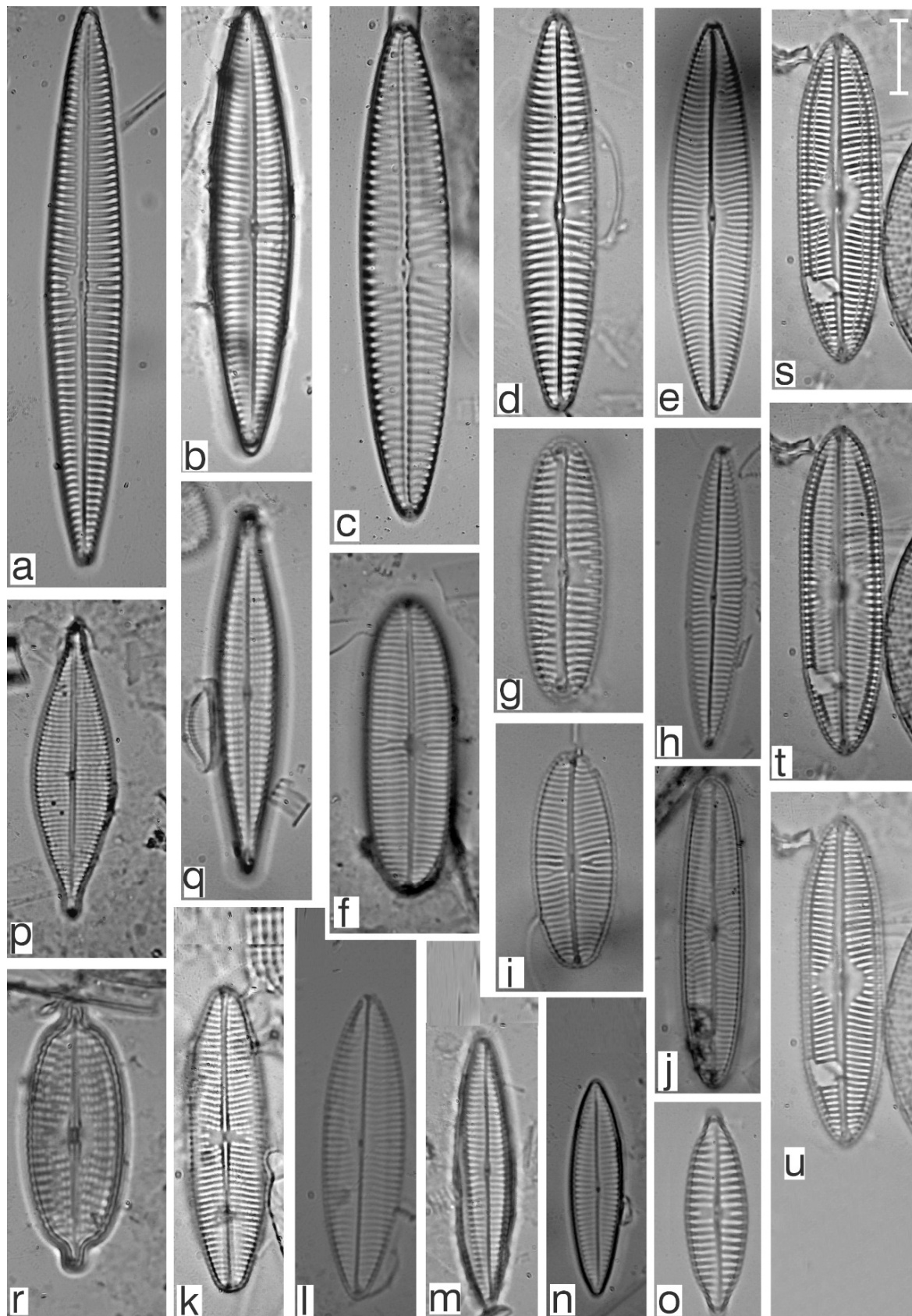


Figure A21. (a) *Navicula longa* var. *longa*; (b) *N. zosteretii*; (c,d) *N. longa* var. *irregularis*; (e) *N. johanrossii*; (f,i) *N. lusoria*; (g,s–u) *Oestrupia ergadensis*; (h,m,n) *Navicula agnita*; (j) *N. microdigitoradiata*; (k) *Navicula* sp. 2; (l) *N. apta*; (o) *N. cf. bipustulata*; (p) *Mastogloia lancetula*; (q) *Navicula abunda*; (r) *N. palpebralis*. Bar = 10 μ m.

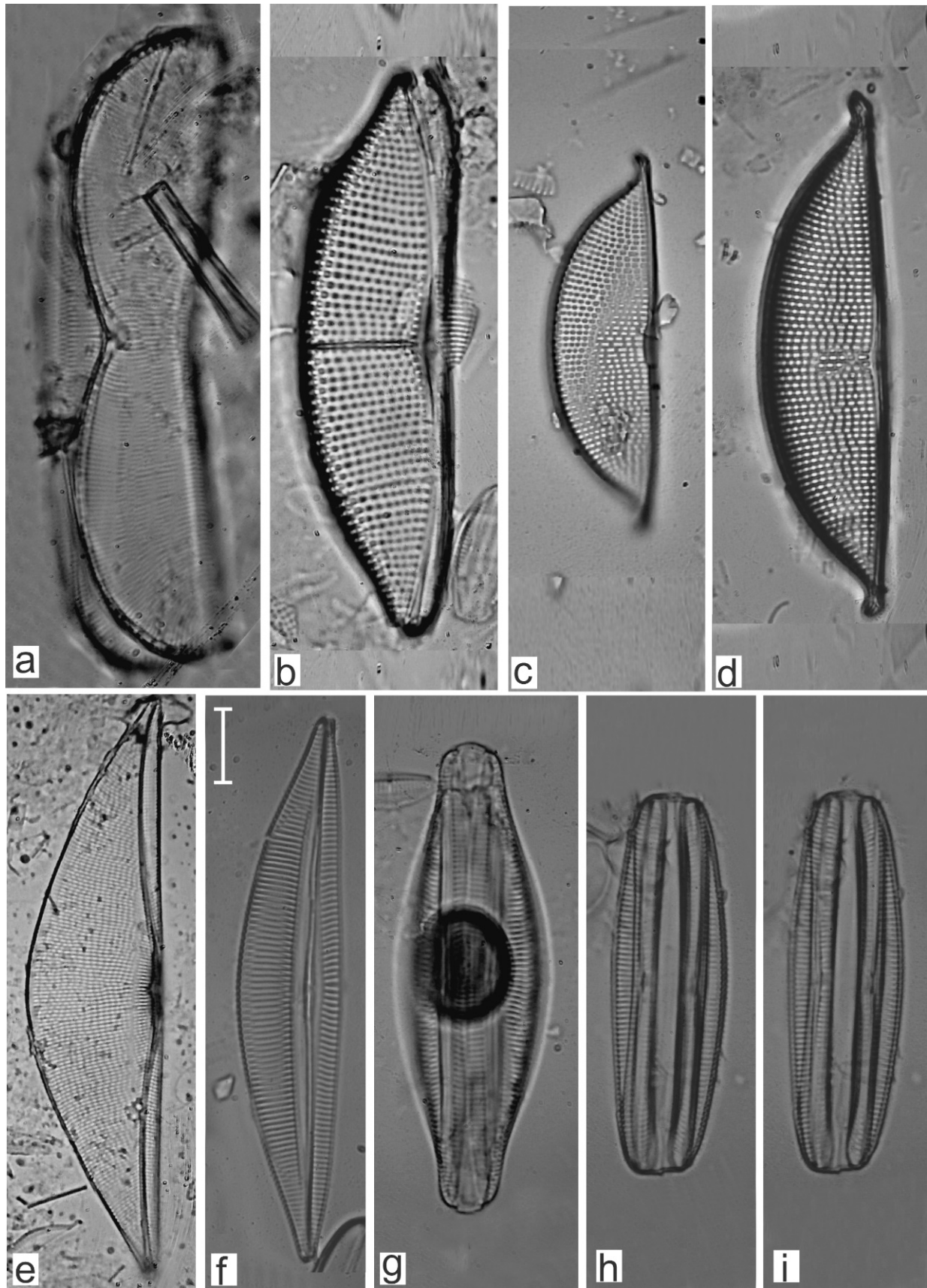


Figure A22. (a) *Auricula intermedia*; (b) *Tetramphora ostrearia*; (c) *Amphora corpulenta*; (d) *A. corpulenta* var. *capitata*; (e) *Tetramphora intermedia*; (f) *Seminavis latior*; (g) *S. robusta*; (h,i) *Amphora farcimen*. Bar = 10 μ m.

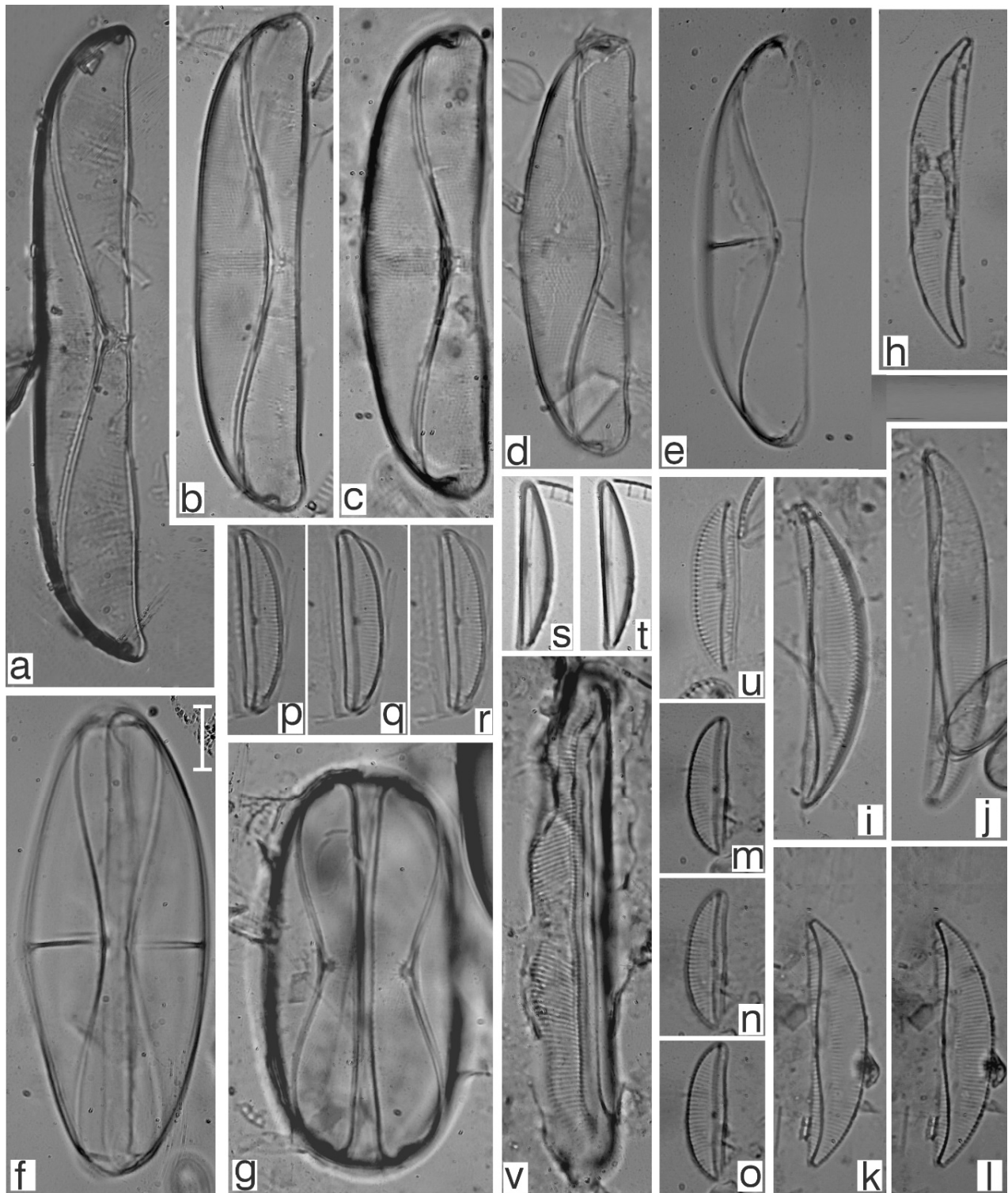


Figure A23. (a–d,g) *Amphora arenaria*; (e,f) *A. laevissima*; (h–l) *Seminavis lunulata*; (p–r,m–o,u) *Amphora* sp. 1; (s,t) *Seminavis delicatula*; (v) *Amphora floridiae*. Bar = 10 μ m.

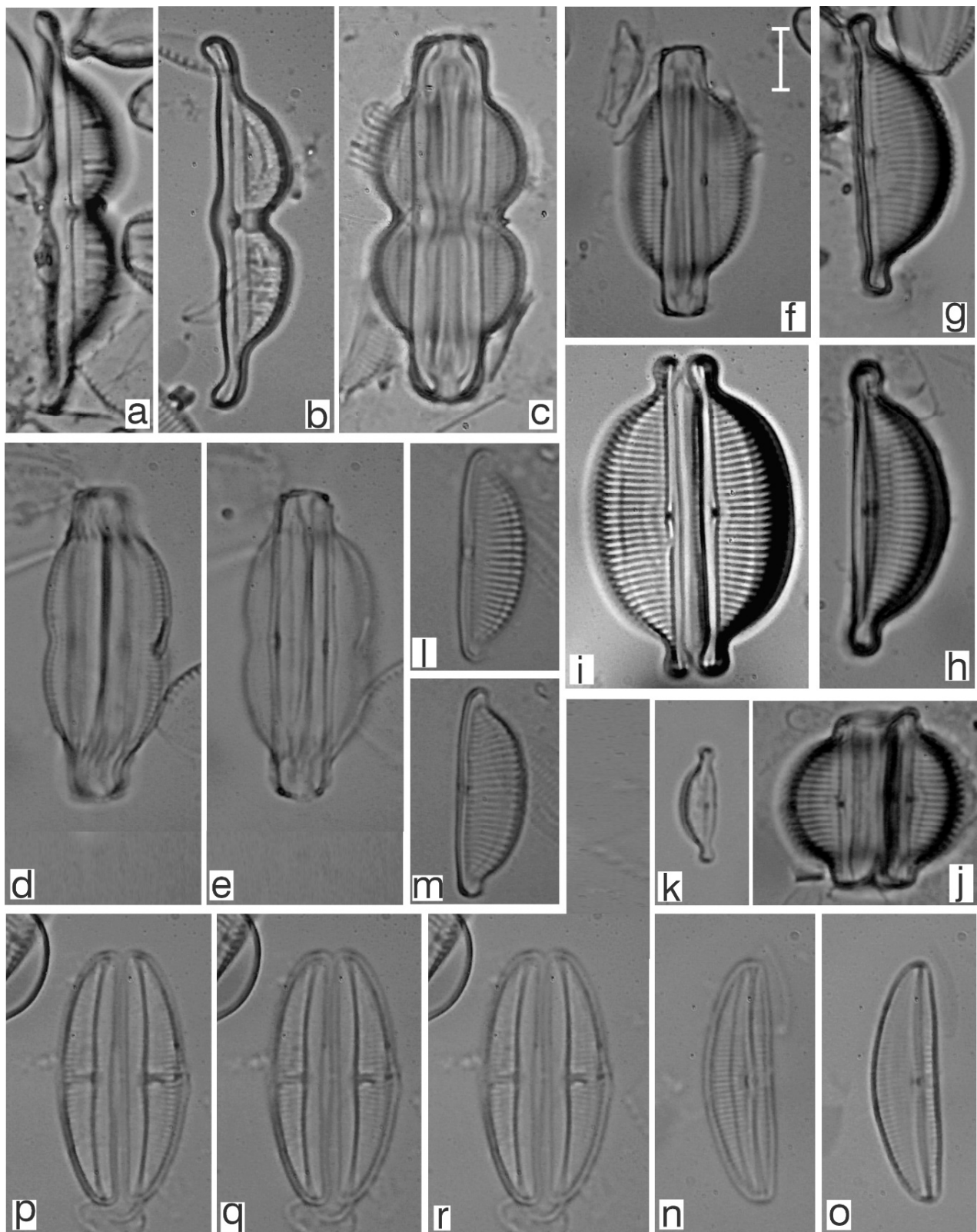


Figure A24. (a–c) *Amphora bigibba* var. *interrupta*; (d–j) *Halamphora turgida*; (k) *Amphora* sp. 2; (l,m) *Halamphora wisei*; (n,o) *Amphora graffeana* var.?; (p–r) *A. montgomeryi*. Bar = 10 μ m.

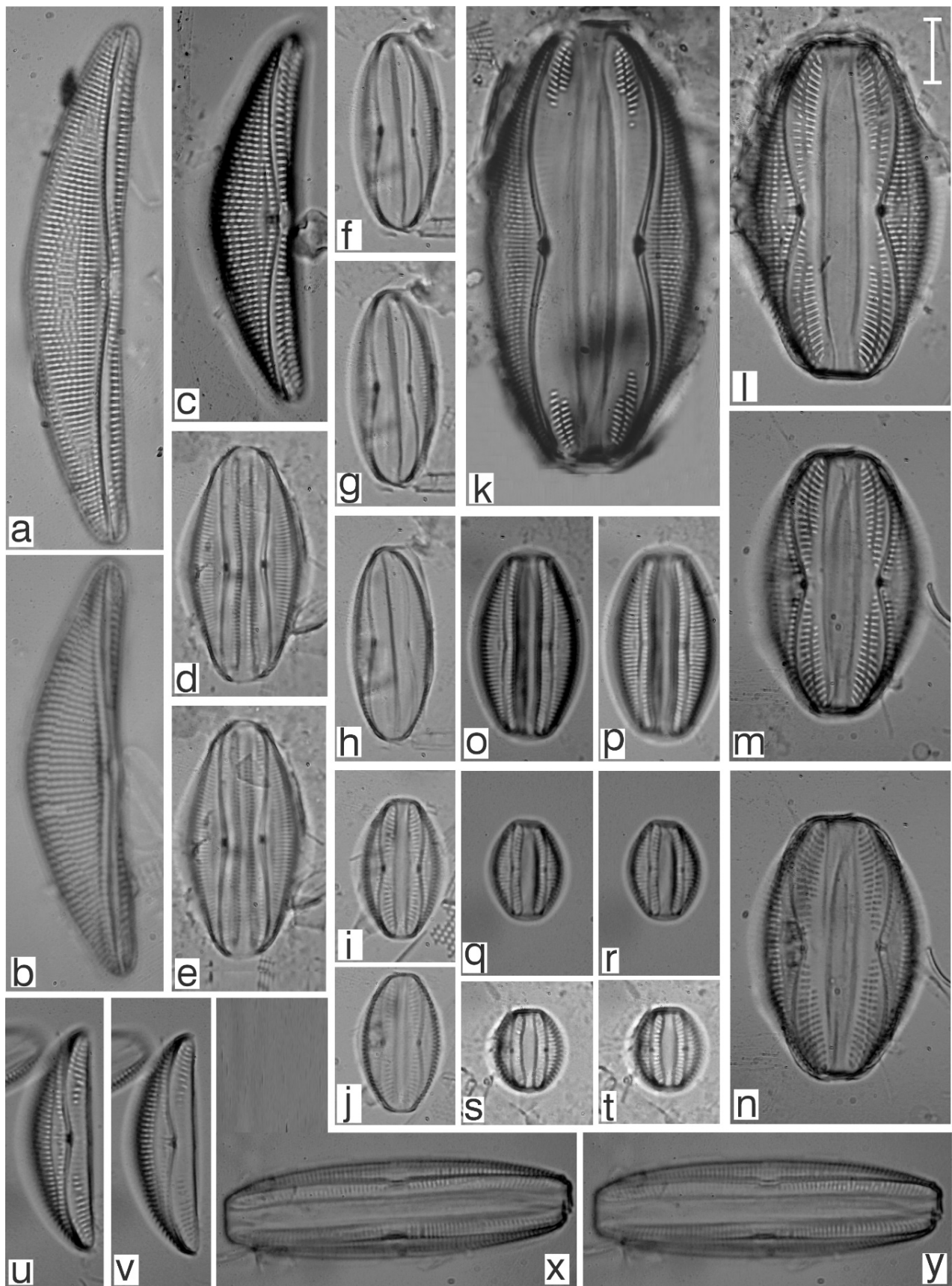


Figure A25. (a–c) *Amphora immarginata*; (d,e) *A. graeffei*; (f–h) *A. graeffeana*; (i,j) *A. proteus* var. *contigua*; (k) *A. gigantea* var. *fusca*; (l–n,u,v) *A. proteus*; (o–t) *A. cf. copulata*; (x,y) *Seminavis barbara*. Bar = 10 μ m.

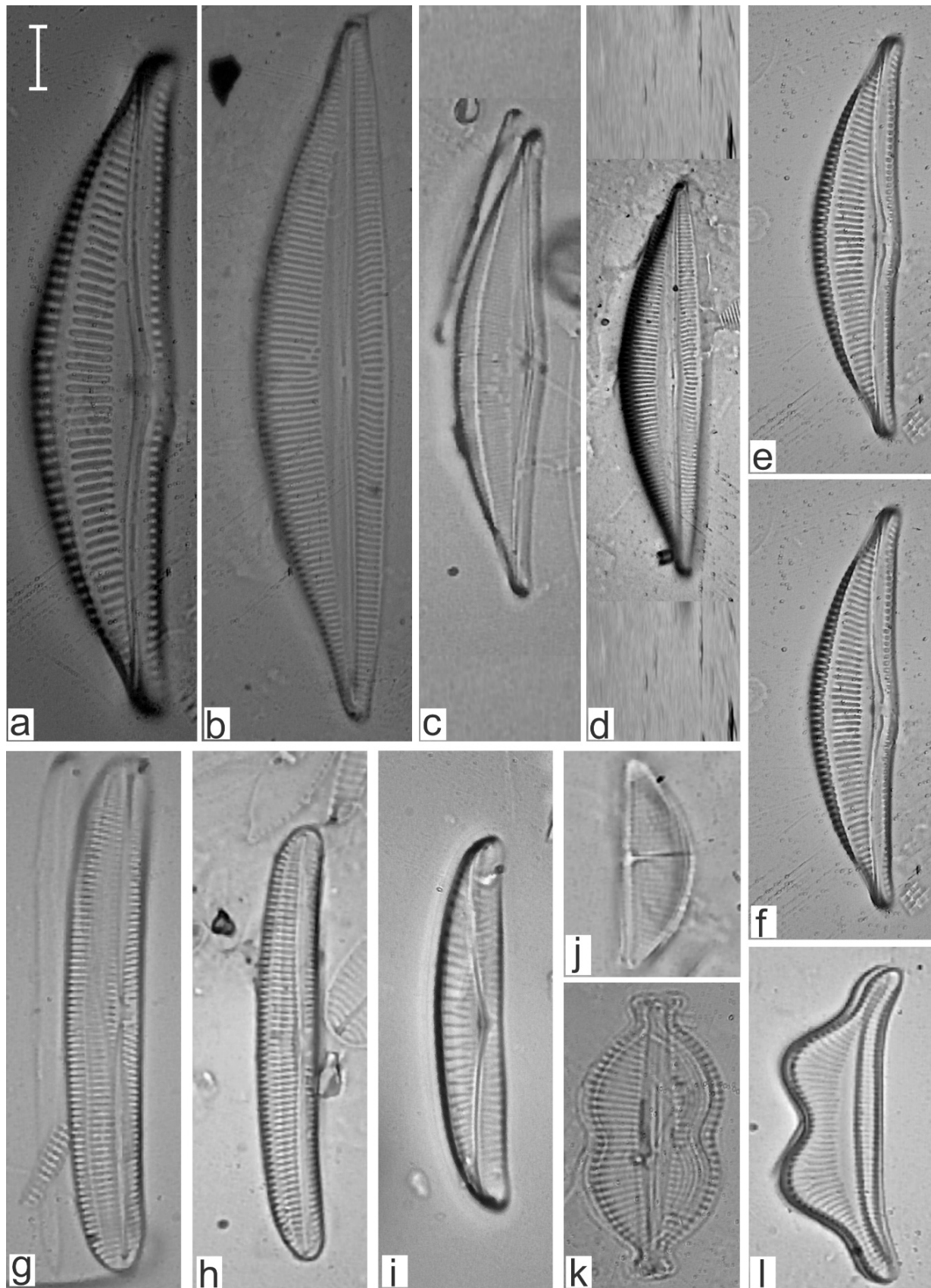


Figure A26. (a,e,f) *Amphora graeffi*; (b,d) *Seminavis robusta*; (c) *Amphora graeffeana*; (g,h) *A. farcimen*; (i) *A. spectabilis*; (j) *A. montgomeryi*; (k) *A. biundulata*; (l) *Brassiarea vivens*. Bar = 10 μm .

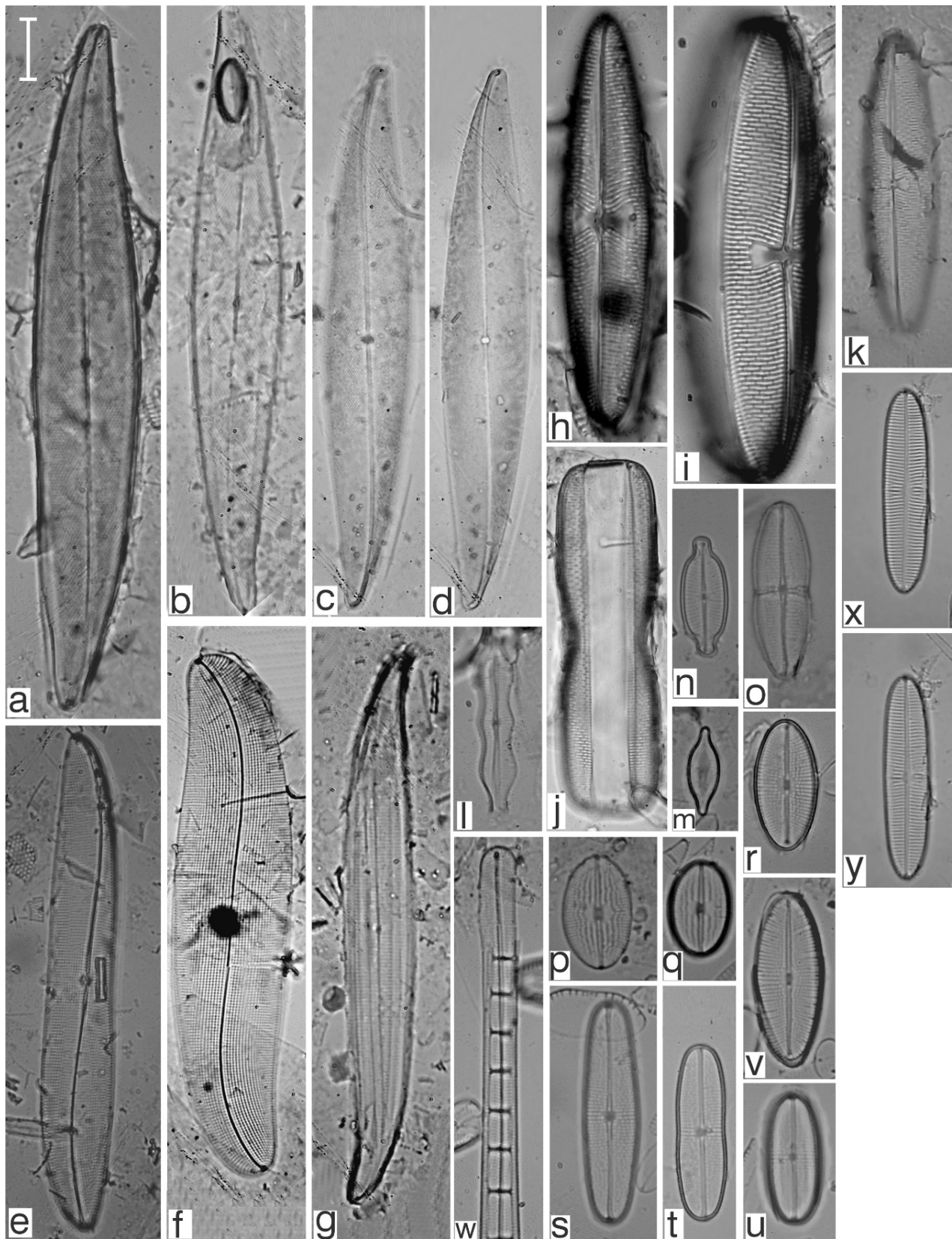


Figure A27. (a–d) *Pleurosigma salinarum*; (e) *Gyrosigma simile*; (f) *G. hummii*; (g) *G. beaufortianum*; (h) *Trachyneis aspera* var. *oblonga*; (i) *T. aspera* var. *elliptica*; (j) *T. aspera* var. *aspera*; (k) *T. velata*; (l) *Mastogloia staurophora*; (m) *Karayevia* cf. *carissima*; (n) *Karayevia* sp. 1; (o) *Staurophora* sp. 1; (p,q) *Navicula ponticula*; (r,v) *Cocconeopsis fraudulenta*; (s–u) *Navicula* sp. 3; (w) *Climaconeis lorenzii*; (x,y) *Navicula* sp. 1. Bar= 10 μ m.

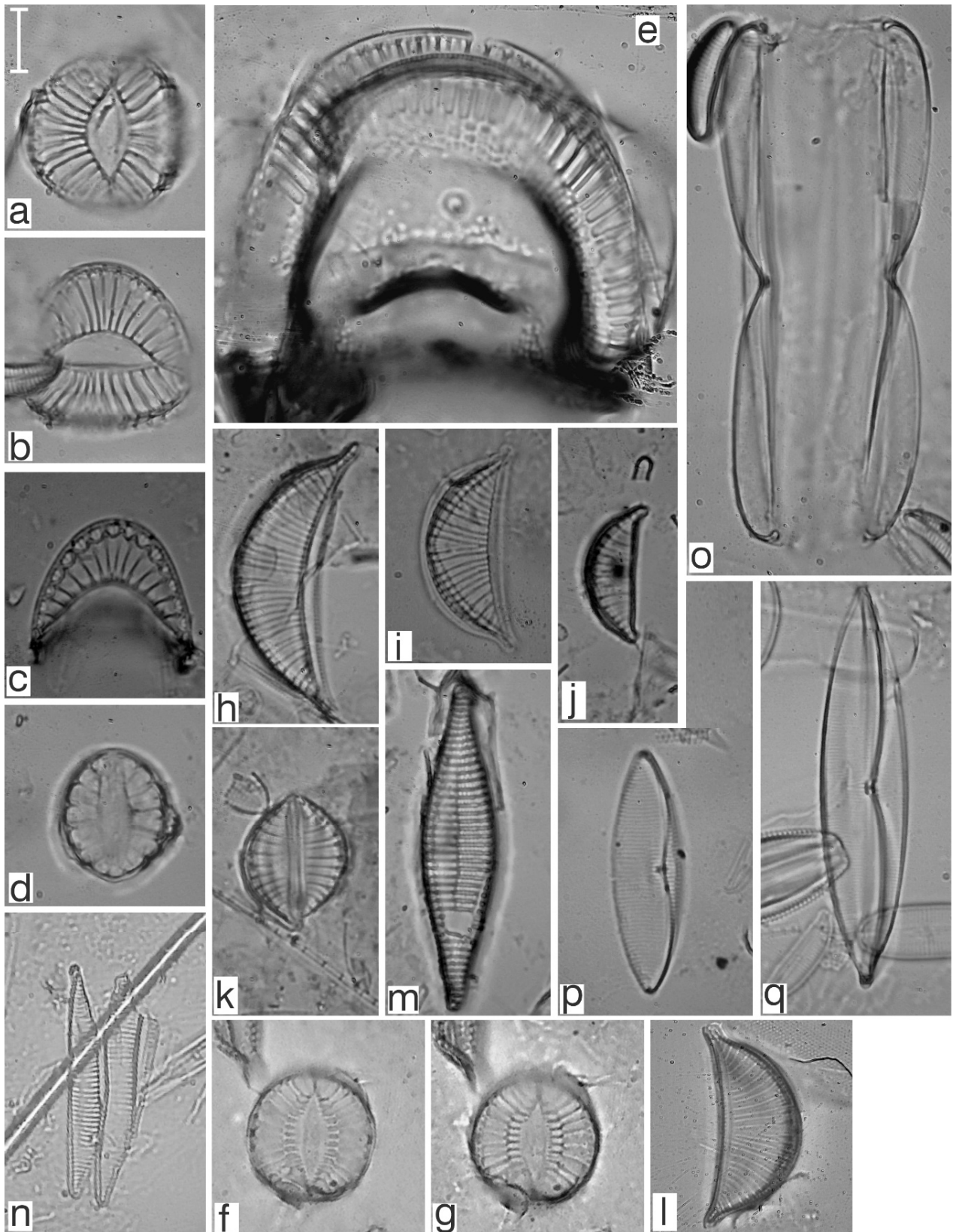


Figure A28. (a–c) *Campylodiscus subangularis*; (d) *C. giffeni*; (e) *C. hodgsonii*; (f,g) *Campylodiscus* sp. 1; (h,i) *Rhopalodia gibberula*; (j,k) *R. musculus* var. *producta*; (l) *Epithemia guetteringeri*; (m) *Nitzschia fusoides*; (n) *Hantzschia pseudomarina*; (o,q) *Plagiotropis vitrea*; (p) *P. pusilla*. Bar = 10 μ m.

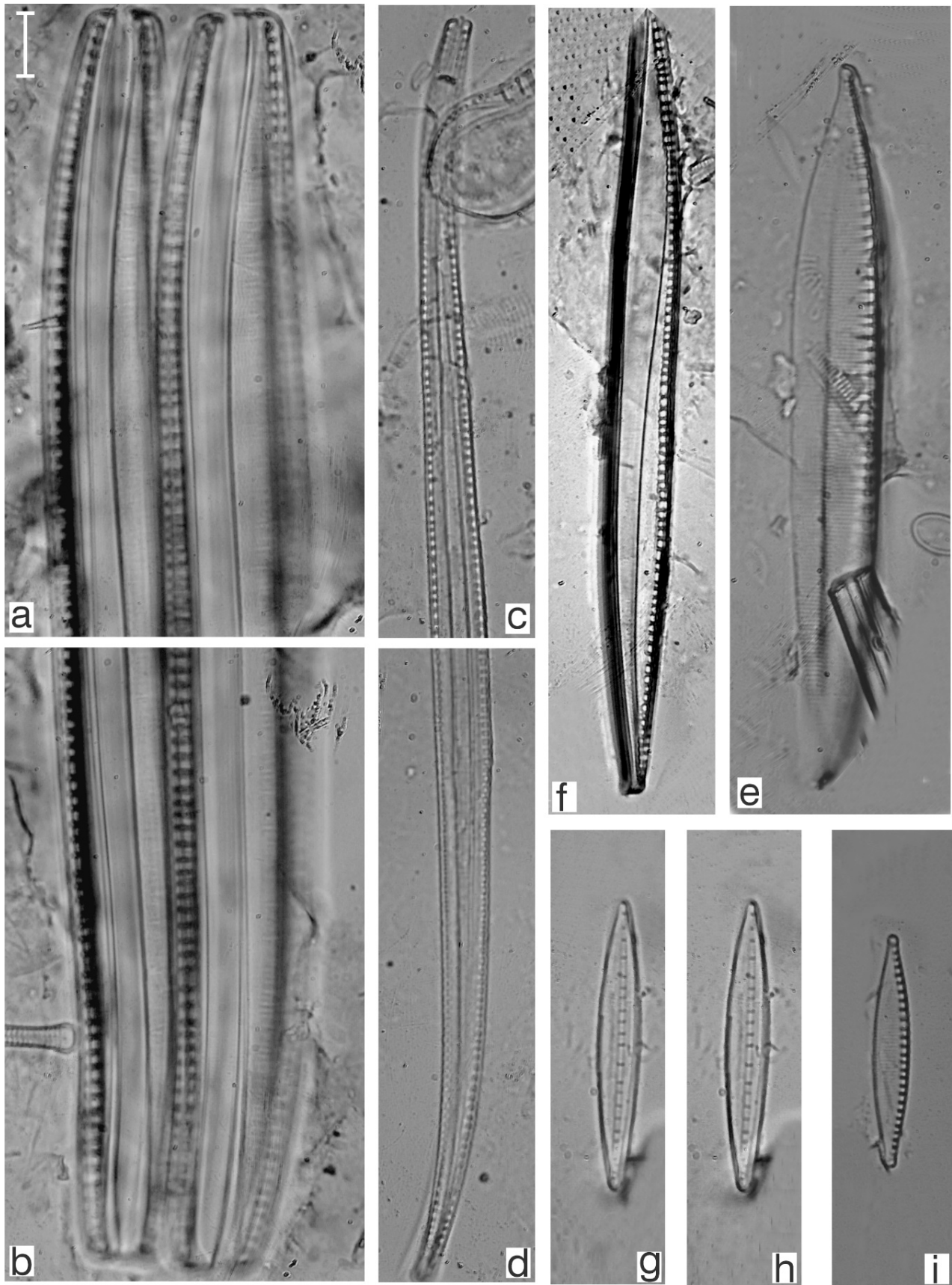


Figure A29. (a,b,f) *Nitzschia sigma*; (c,d) *N. scabra*; (e) *N. fluminensis*; (g,h) *Homoeocladia distans*; (i) *Nitzschia fusiformis*. Bar = 10 μm.

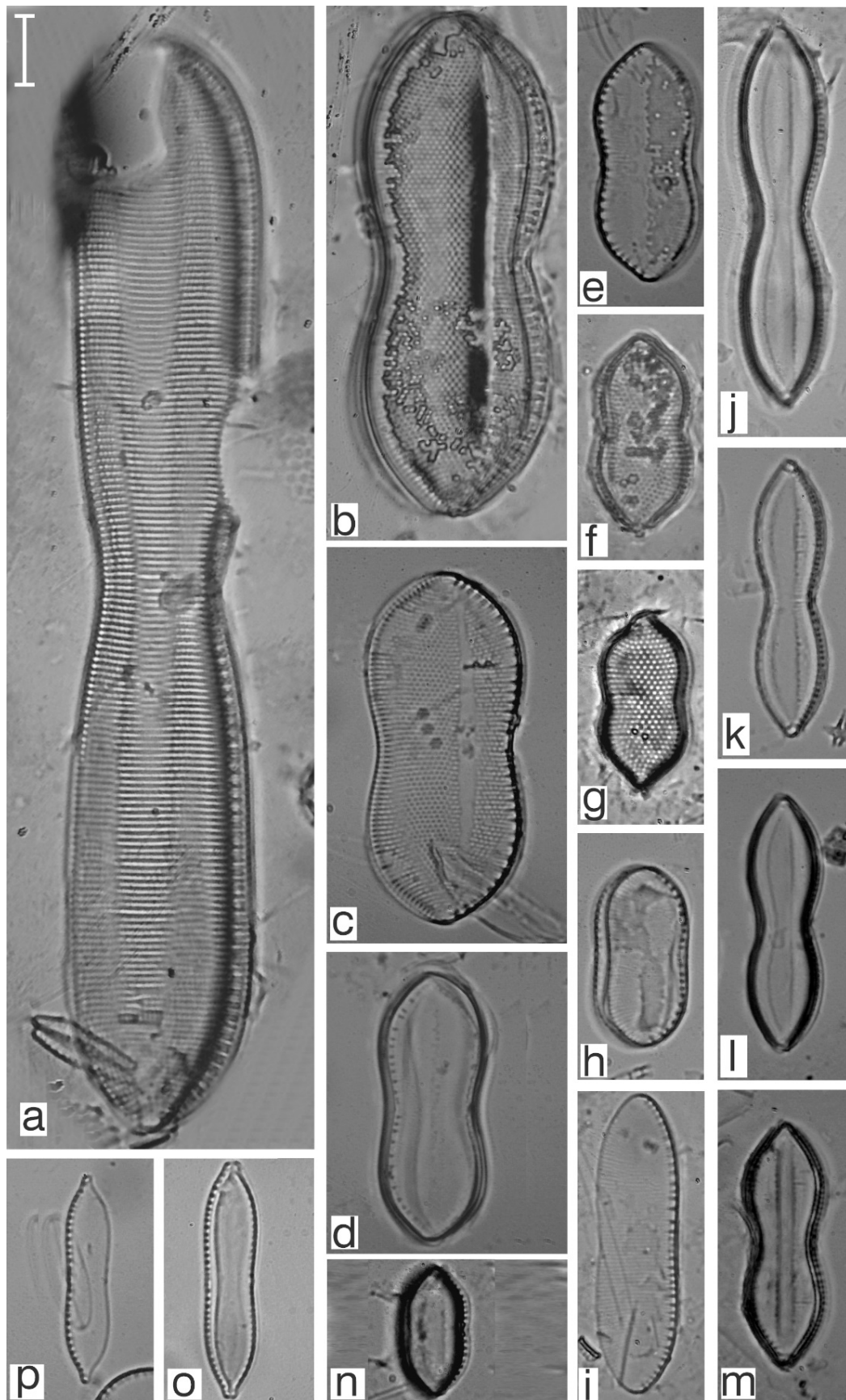


Figure A30. (a) *Tryblionella jelinecki*; (b,c) *Psammodictyon panduriforme*; (d,e,h) *Tryblionella persuadens*; (f,g) *T. coarctata*; (i) *T. cf. graeffei*; (j–m) *Nitzschia marginulata* var. *didyma*; (n) *Psammodictyon rudum*; (o,p) *Tryblionella parvula*. Bar= 10 μ m.

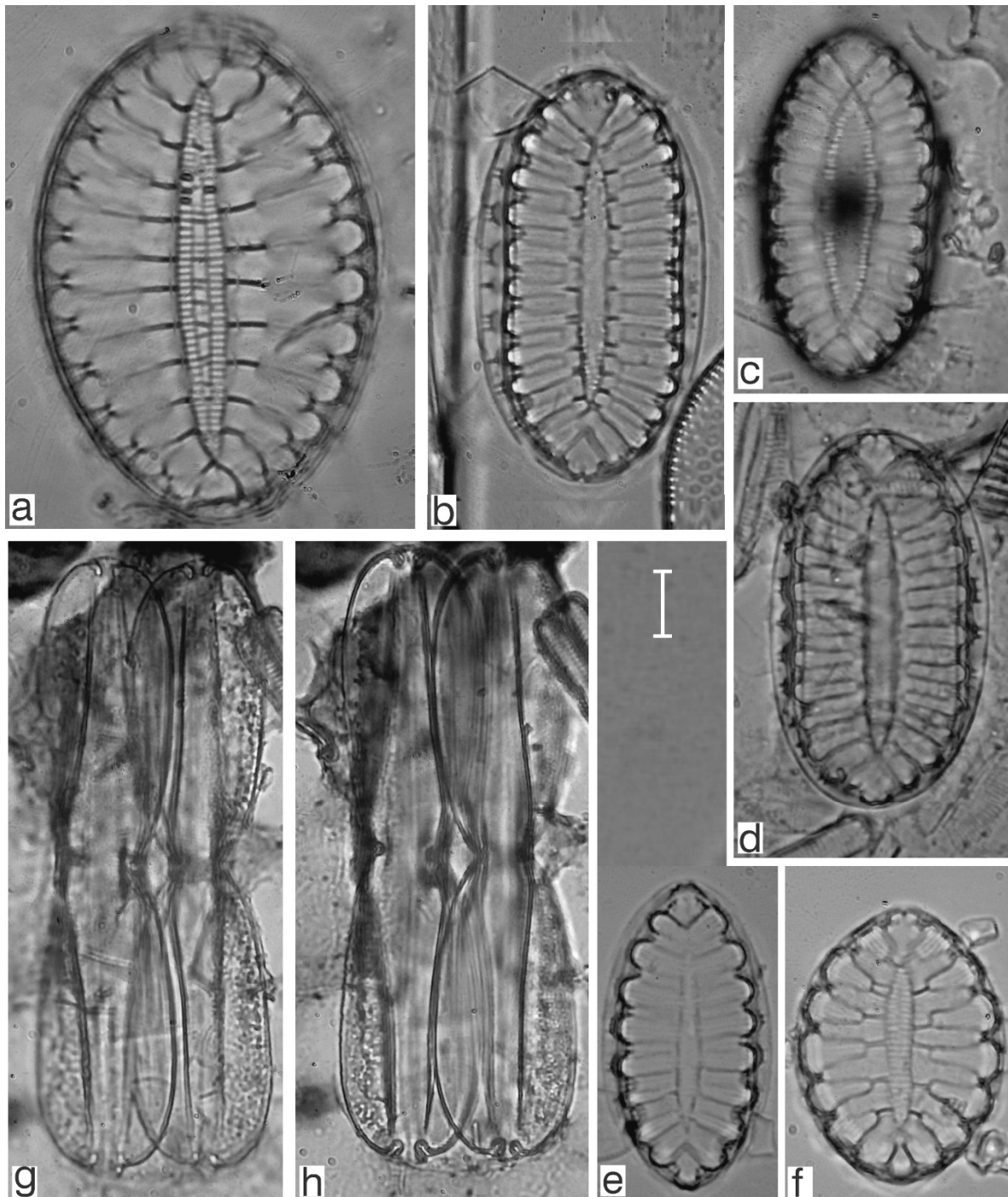


Figure A31. (a,c,e,f) *Campylodiscus neofastuosus*; (b,d) *Surirella platyloba*; (g,h) *Plagiotropis lepidoptera*. Bar = 10 μ m.

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