SPECIES

To Cite:
Bose R, Pal R. New reports on Monoraphid and Biraphid diatoms from India based on ultrastructure characteristics. *Species* 2023; 24: e65s1571
doi: https://doi.org/10.54905/disssi.v24i74.e65s1571

Author Affiliation:
Phycology and Algal Biotechnology Laboratory, Department of Botany, University of Calcutta, 35, Ballygunge Circular Road, Kolkata-700019, West Bengal, India

*Corresponding author
Phycology and Algal Biotechnology Laboratory, Department of Botany, University of Calcutta, 35, Ballygunge Circular Road, Kolkata-700019, West Bengal,
India
Email: rpalphyco@gmail.com

Peer-Review History
Received: 10 June 2023
Reviewed & Revised: 14/June/2023 to 20/July/2023
Accepted: 24 July 2023
Published: 27 July 2023

Peer-Review Model
External peer-review was done through double-blind method.

Species
pISSN 2319–5746; eISSN 2319–5754

DISCOVERY
SCIENTIFIC SOCIETY

New reports on Monoraphid and Biraphid diatoms from India based on ultrastructure characteristics

Rahul Bose, Ruma Pal*

ABSTRACT

The study aims at the taxonomic investigation of Raphid diatoms and reporting of some new taxa of Bacillariophyceae from the Indian subcontinent based on frustule ultrastructure. The diatoms are mainly from two groups, viz. Monoraphid and Biraphid were recorded as dominant genera from different eco-zones of Eastern India at regular intervals for five years. The study area includes, Darjeeling Himalayan hills, North Bengal Riverine Plain sand Rarh region (26º88′53″ N; 88º18′28″ E - 22º37′61″ N; 87º34′26″ E). From the investigation, a total of 27 taxa appeared as new records from all over India. Hilly regions of Darjeeling housed most of the new reports of diatom species followed by the foot-hills area of Jalpaiguri. The majority of the taxa belong to Biraphid groups, like *Eunotia*, *Pinnularia*, *Craticula*, *Navicula*, *Brachysira*, *Sellaphora*, *Placoneis*, *Cymbella* and *Gomphonema* closely followed by Monoraphid groups including the genera *Achnanthidium* and *Achnanthes*. In a word, Darjeeling Himalayan Hill Region of Eastern India showed maximum diversity of the recorded species. Detailed systematic accounts have also been included in the investigation.

Keywords: Diatom, ultrastructure, new report, Monoraphid, Biraphid

1. INTRODUCTION

Diatoms, being the members of the division Ochrophyta (Cavalier-Smith and Chao, 1996) are ubiquitous and ecologically important algae flourishing in freshwater, brackish water, and marine ecosystems. They account for almost 20% of the net primary productivity of marine ecosystems (Mann, 1999). Initially, around the globe, freshwater diatoms had been taxonomically identified based on European endemic species with the concept that 'Everything is everywhere'. During that period only light microscopic observation was considered. With the advent of scanning electron microscope application in diatom taxonomy and systematics from the 1960 onwards has been revised totally by Hasle and Syvertsen, (1997).

They, for the first-time bridged light microscope and scanning electron microscopic illustrations of marine diatoms and dinoflagellates for better comprehension of the systematics studies. In course of time, several authors

proposed systematics of freshwater diatoms around the globe (Kociolek and Spaulding, 2000; Vanormelingen et al., 2007; Vyverman et al., 2007). Kociolek, (2018) documented 249 freshwater diatom genera and gave a prelude of their distributions based on endemism and phylogenetic perspective.

In India, extensive and noteworthy documentation of diatom diversity had been initiated by Gandhi covering almost every part of Western India. Afterward, in few of his series of publications, based on light microscopy 127 new Indian taxa were published, among them, 31 species were reported new to science along with 9 new forms and 17 new varieties (Gandhi, 1955; Gandhi, 1958; Gandhi, 1959a; Gandhi, 1959b; Gandhi, 1959c; Gandhi, 1961a; Gandhi, 1961b).

After Gandhi, Karthick along with his group surveyed the regional distribution of endemic diatom taxa from the Western Ghats to northern Himalayans. They have employed a scanning electron microscope for the first time to illustrate the ultrastructural pattern and formation of diatom frustule based on valve shape and orientation, the existence of raphe system on either valve, raphe orientation, the pattern of striae and areolae, etc. The group had contributed 209 taxa including 200 species altogether which enriched the diatom catalogue of India (Karthick et al., 2013). Later on, Joseph and Francis, (2019) reported 2 new taxa from the southwest coast of India.

Few other reports are available from Eastern India as well. Keshri et al., (2016) reported 4 diatom taxa from Eastern India of which 3 were new records from India. Later on, Samanta and Bhadury, (2018) surveyed the Indian part of Sundarban Biosphere Reserve and reported 15 diatom species out of which 7 were the first record from Sundarbans mangrove water from India. Of late Mandal et al., (2020) established an illustrative database of 40 diatoms taxa from sediment cores of Holocene deposits in the Indian part of Sundarbans.

The present group-initiated exploration, survey, and documentation of diatom assemblages from Eastern India including coastal West Bengal where 32 planktonic diatom taxa were being investigated and detailed structural morphology was studied (Chowdhury and Pal, 2008). In addition to that, in our previous study, we have surveyed some pristine habitats of the lower part of Gangetic West Bengal and documented 50 diatom species alongside elaboration with a detailed ultrastructural pattern using SEM of the dominant genera (Bose et al., 2017).

Later on, the same group reported *Cocconeis gracilariensis* being epiphytic on *Gracilaria* sp., a red alga as a new species from the brackish water region of Indian Sundarbans (Satpati et al., 2017). Recently Bose and Pal, (2020) recorded for the first time nearly 51 diatom taxa from the foot-hills region of Eastern Himalayas along with *Gomphonema contraturris* being newly reported from India. In the present investigation ultrastructural patterns of 27 diatoms, further newly recorded taxa from India have been represented and discussed based on their nature and site of occurrence, habitat condition, etc.

2. MATERIALS AND METHODS

Sampling sites

A thorough field survey was carried out for a period of two years (2016-2020) from different parts of West Bengal, India. Three different geographical regions had been surveyed and explored.

Darjeeling Himalayan hill region

The region constituted both the Himalayas and Sub-Himalayan fans; situated to the north of the state and belongs to the Eastern Himalaya range. The altitude ranged from 100-4000 m above sea level. Pristine habitats of Darjeeling (26º88′53″ N; 88º18′28″ E) and foothill region like Jalpaiguri (26º75′13′′ N, 88º58′0013′′ E; 26º88′55′′ N, 88º47′44′′ E; 26º66′66′′ N, 88º41′60′′ E) districts were examined for diatom sampling. Few natural and abandoned channels, ponds, and mostly artificial lakes formed by dams present there.

North Bengal Plains

The Himalayan origin sediments deposited in the Himalayan foreland basin and formed the North Bengal Plain also geographically known as the Barind upland. This region is a lowland area covered with swamps, beels, and small streams occupying valleys with average altitude ranged from 20-50 m. Malda (24º98′38″ N; 88º13′81″ E), Dakshin Dinajpur (25°37′15″ N; 88°55′65″ E) districts fall under this zone.

Rarh region

This region lies between Chota Nagpur Plateau on the west and the flow of the Ganges in the east and geographically known as Plateau-fringe fans. The average altitude of the region ranged from 10-150 m above sea level. West Midnapore (22º37′61″ N; 87º34′26″ E) district formed the southern part of the region.

Voucher preparation and frustules cleaning for identification

Geographical locations have been recorded using GPSMAP 76CSx. Epilithic, Epipelic, and Epiphytic diatoms had been scraped with a very fine scalpel from the rocky surface, moist stones and pebbles, and submerged aquatic stalk respectively followed by immediate storage within an icebox. At the laboratory, the voucher number was assigned with the acronym (CUH/AL-DIA) and deposited in Calcutta University Herbarium (CUH/AL) with accession no. for proper documentation and enlistment of the flora in the aforesaid places. As for detailed ultrastructural observations, an aliquot of 1 ml of each voucher sample was subjected to acid digestion as per the standardized protocol of Bose and Pal, (2020). Electron microscopic images were taken with Carl Zeiss EVO 18 (EDS 8100) microscope with Zeiss Inca Penta FETX 3 (Oxford instruments) attachment.

3. RESULTS

The survey was conducted from different physiographical locations of West Bengal. From all the sites pennales genera of diatoms were encountered upon examination. The identification was carried out based on the ultrastructural pattern and orientation of the siliceous frustules (Figure 1-6). The site of collection, nature of occurrence, and habitat of all the taxa were enlisted following the figure plates through respective herbarium accession numbers (Table 1). 27 taxa were documented from the present investigation, belonging to 10 families and 5 orders (Table 2).

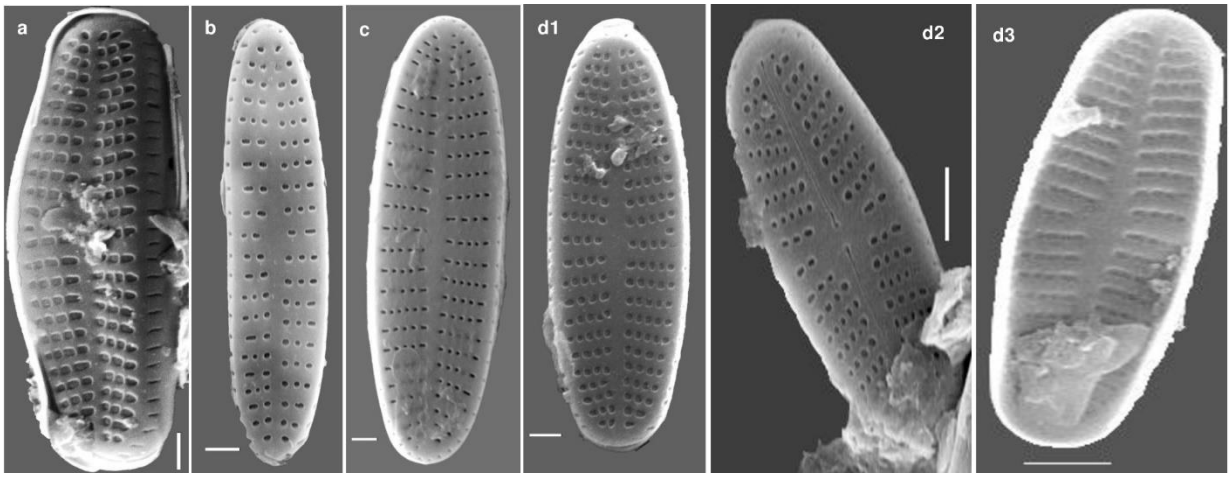

Figure 1 a: *Achnanthidium nanum*; b: *Achnanthidium subatomus*; c: *Achnanthidium atomus*; d1-d3: *Achnanthidium duriense*; (Scale bar: a, b, c= 2 μm; d1-d3= 1 μm)

The identification was authenticated from several pieces of literature, relevant monographs, and verified from Algaebase and Diatombase. The classification was based on Cavalier-Smith and Chao, (1996) and Cox, (2015). Amongst 27 taxa, all of them have been recorded as new reports from the Indian subcontinent especially from Eastern India. Detailed SEM investigation has been done for the recorded taxa for better taxonomic interpretation.

Systematic enumeration of the collected taxa:

Achnanthidium nanum (F.Meister) M.H.Novais & I.Jüttner (Figure 1 c)

Novais et al., (2015, p. 120, fig. 267)

Frustules heterovalvar with concave raphe valve and convex rapheless valve, frustules in girdle view bent; valves linear to linear-elliptic with broadly rounded, sometimes subrostrate ends, valve length 5-12.5 μm and breadth 1.7-3 μm; central area inconspicuous; striae mainly composed of 3–4 rounded to transapically elongated areolae, slightly radiate, more strongly radiate towards the apices, almost equidistant throughout the valve, striae density 23/10 μm.

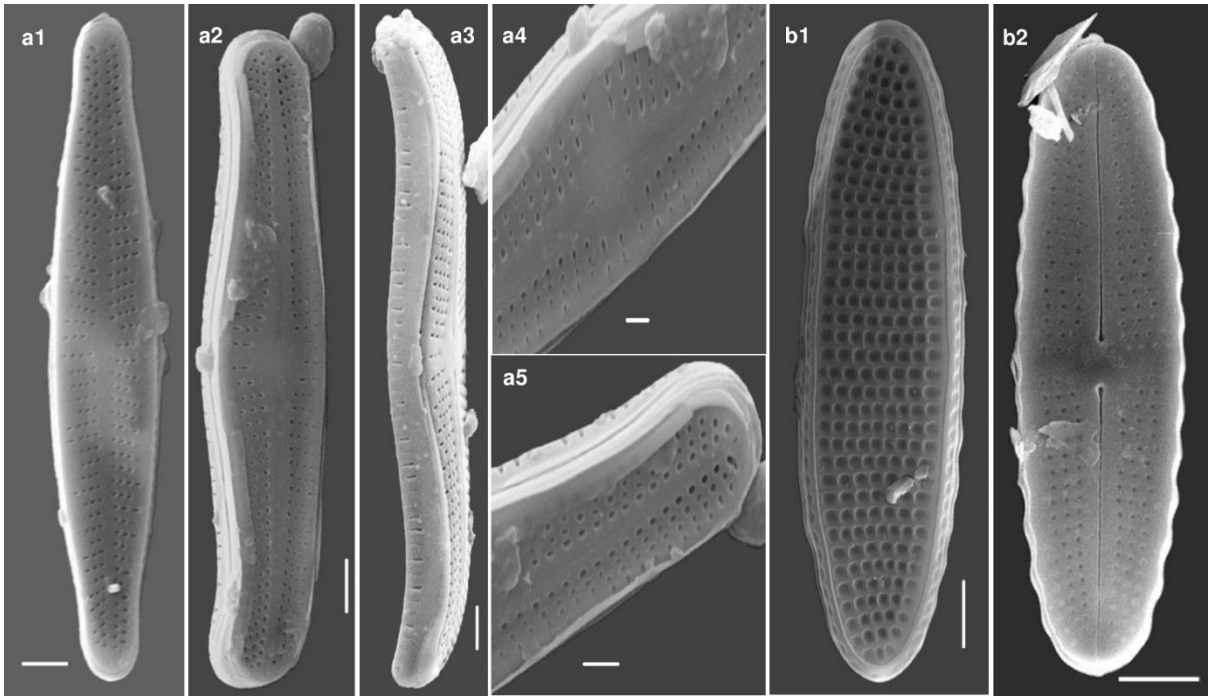

Figure 2 a1-a5: *Achnanthidium catenatum*; b1-b2: *Achnanthes crenulate* (Scale bar: a1-a3 = 2 µm; a4-a5= 1 µm; b1-b2= 5 µm)

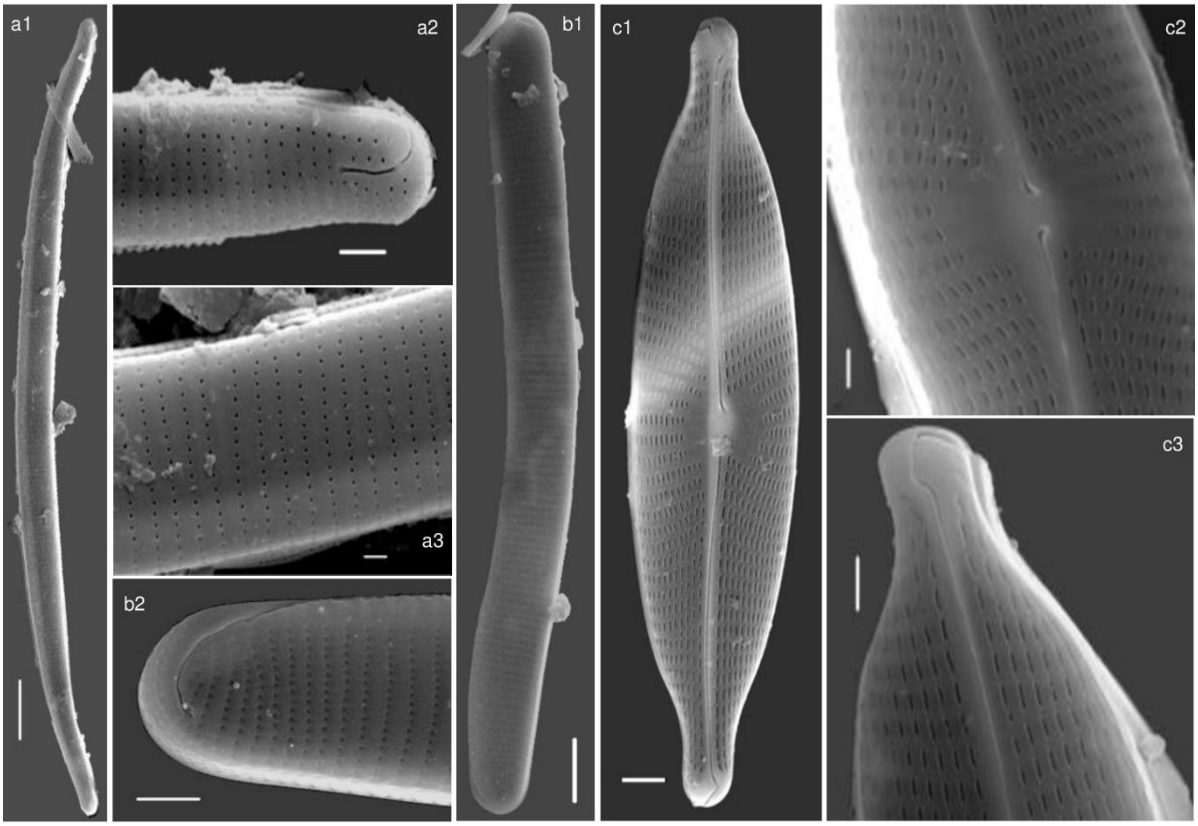

Figure 3 a1-a3: *Eunotia genuflexa*; b1-b2: *Eunotia glacialispinosa*; c1-c3: *Craticula buderi* (Scale bar: a1= 10 µm; b1= 5 µm; c1= 2 µm; a2-a3, b2= 1 µm; c2-c3= 500 nm)

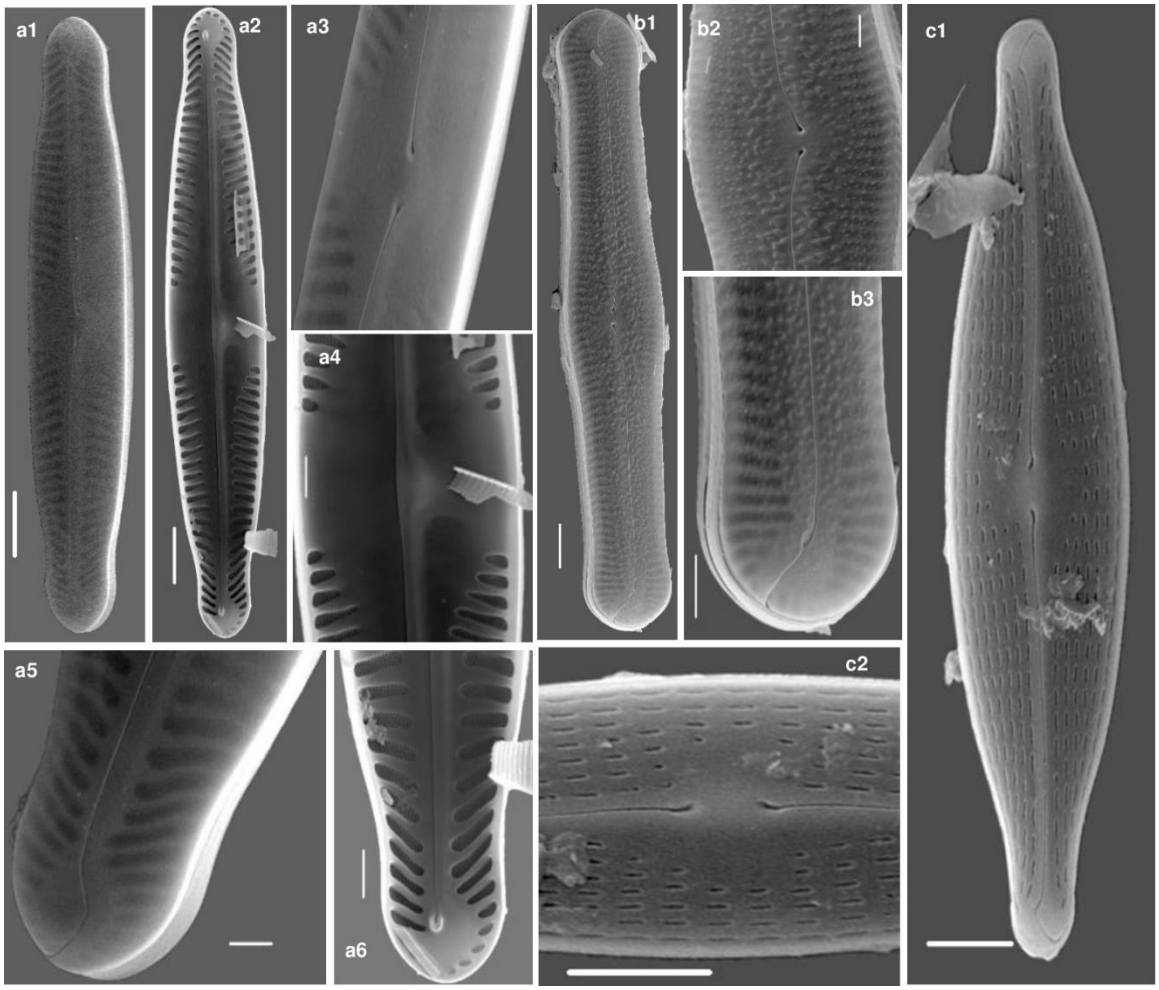

Figure 4 a1-a6: *Pinnularia subcapitata*; b1-b3: *Pinnularia alabamae*; c1-c3: *Navicula viridula* (Scale bar: b1= 10 µm; c1= 5 µm; a1-a2= 3 µm; a3-a6, b2-b3, c2= 1µm; f2= 500 nm)

Achnanthidium subatomus (Hustedt) Lange-Bertalot (Figure 1 e)

Monnier et al., (2007, p. 148, fig. 37-42)

Frustules heterovalvar with concave raphe valve and convex rapheless valve, valves linear to linear-elliptic with rounded, rarely slightly subrostrate ends, valve length 10-23 µm and breadth 3-6 µm; striae almost equidistant throughout on the rapheless valve, striae density 11/ 10 µm; central area inconspicuous on the rapheless valve.

Achnanthidium atomus (Hustedt) Monnier, Lange-Bertalot & Ector (Figure 1 f)

Ponader and Potapova, (2007, p. 230, pl. 2, fig. 6-8); Monnier et al. (2004, p. 131, fig. 124-130)

Frustules heterovalvar with concave raphe valve and convex rapheless valve, valves are elliptical to linear-elliptical, valve length 10-20.8 µm and breadth 3.5-5.4 µm; striae radiate with a straight raphe on the raphe valve and parallel throughout the rapheless valve becoming slightly radiate at the apices, striae density 21-26/10 µm in rapheless valve.

Achnanthidium duriense M.H.Novais & L.Ector (Figure 1 g1-g3)

Novais et al., (2015, pp. 127–128, fig. 395-402)

Valves elliptic to linear-elliptic, valve length 9.7-13.09 µm and breadth 2.7-4.3 µm; both raphe and rapheless valve with narrow linear axial area slightly expanded towards the centre; raphe straight, filiform, externally with slightly expanded drop-like proximal raphe pores; transapical striae almost parallel (raphe valve) and equidistant (rapheless valve) near the valve centre elsewhere slightly radiate, striae composed of 4-5 rounded areolae, striae density 36/10 µm.

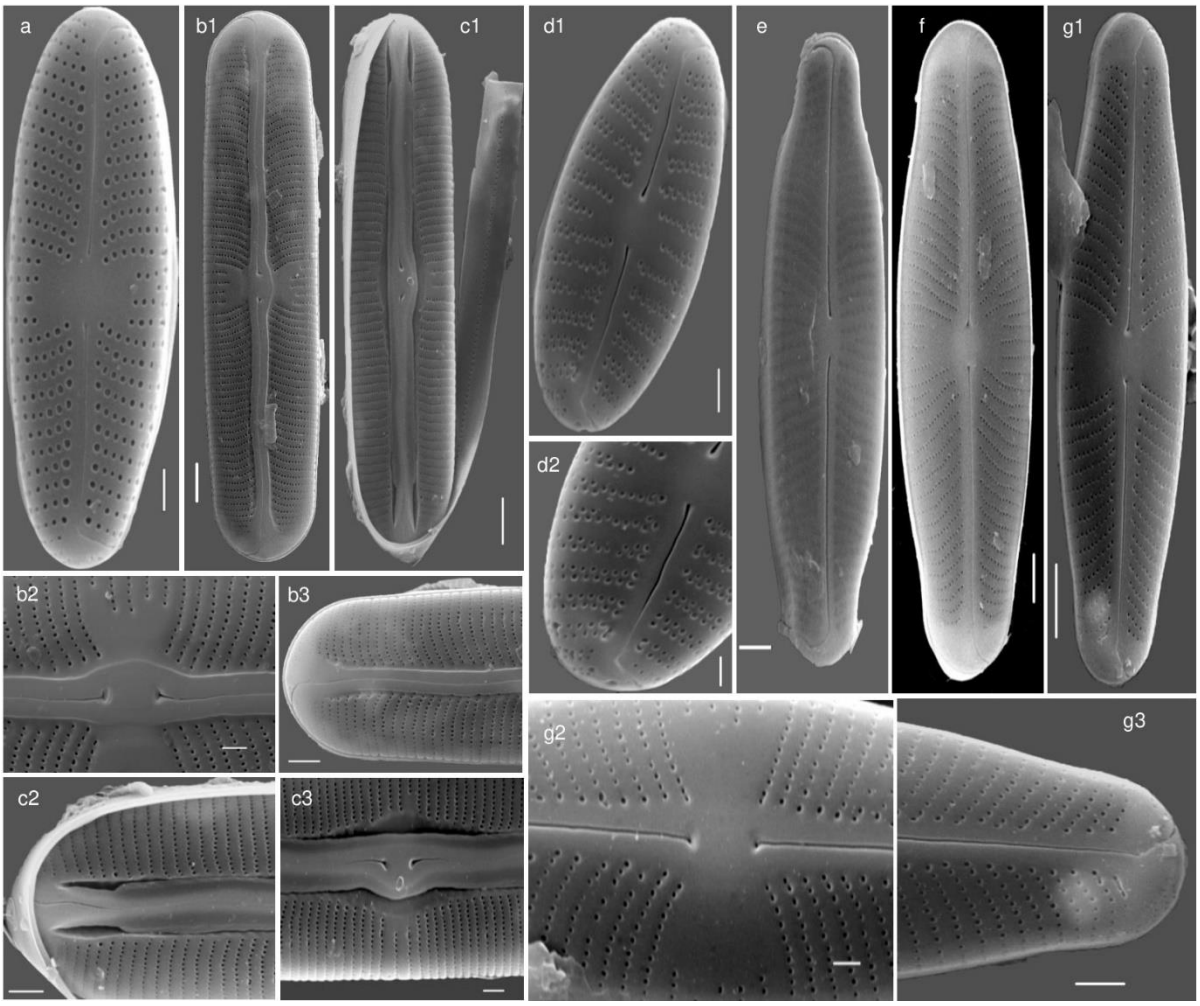

Figure 5 a: *Sellaphora nigri*; b1-b3: *Sellaphora laevissima*; c1-c3: *Sellaphora stroemii*; d1-d2: *Sellaphora saugerresii*, e: *Sellaphora absoluta*; f: *Sellaphora caput*; g1-g3: *Sellaphora seminulum* (Scale bar: b1, c1= 2 μm; a, d1-d2, e, f, g1= 1 μm; b2-b3, c2-c3, g2-g3= 500 nm)

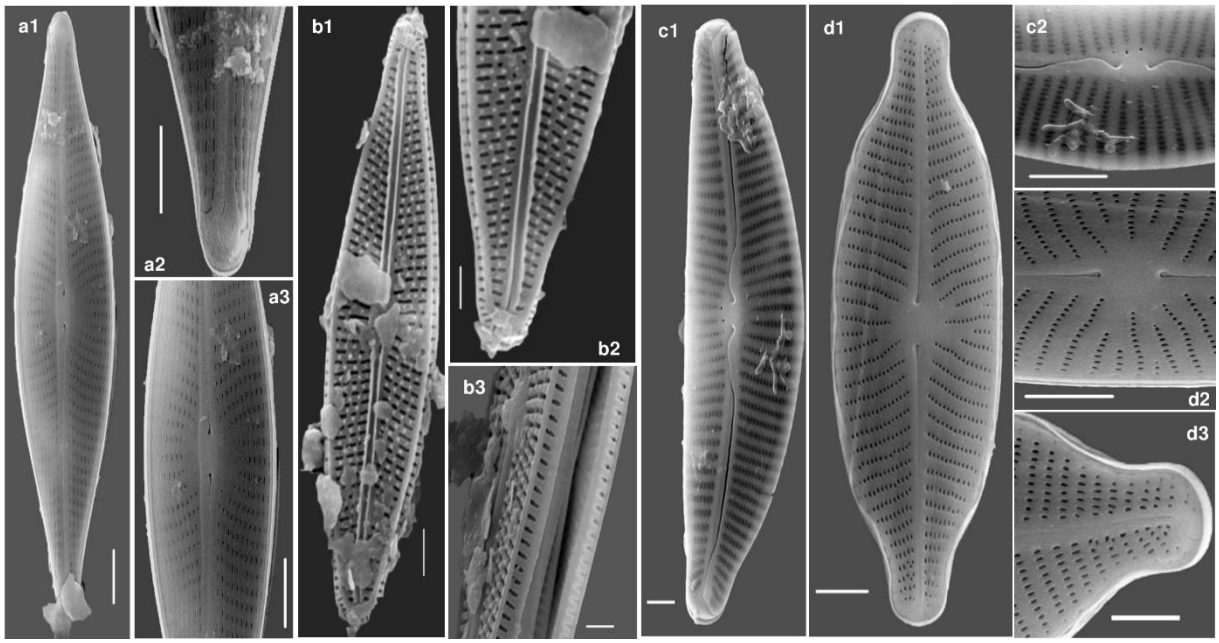

Figure 6 a1-a3: *Navicula pseudoreinhardtii*; b1-b3: *Brachysira brebissonii*; c1-c2: *Cymbella subturgidula*; d1-d3: *Placoneis elginensis* (Scale bar: b1, d1= 3 μm; a1, c1= 2 μm; a2-a3, b2-b3, c2, d2-d3= 1 μm)

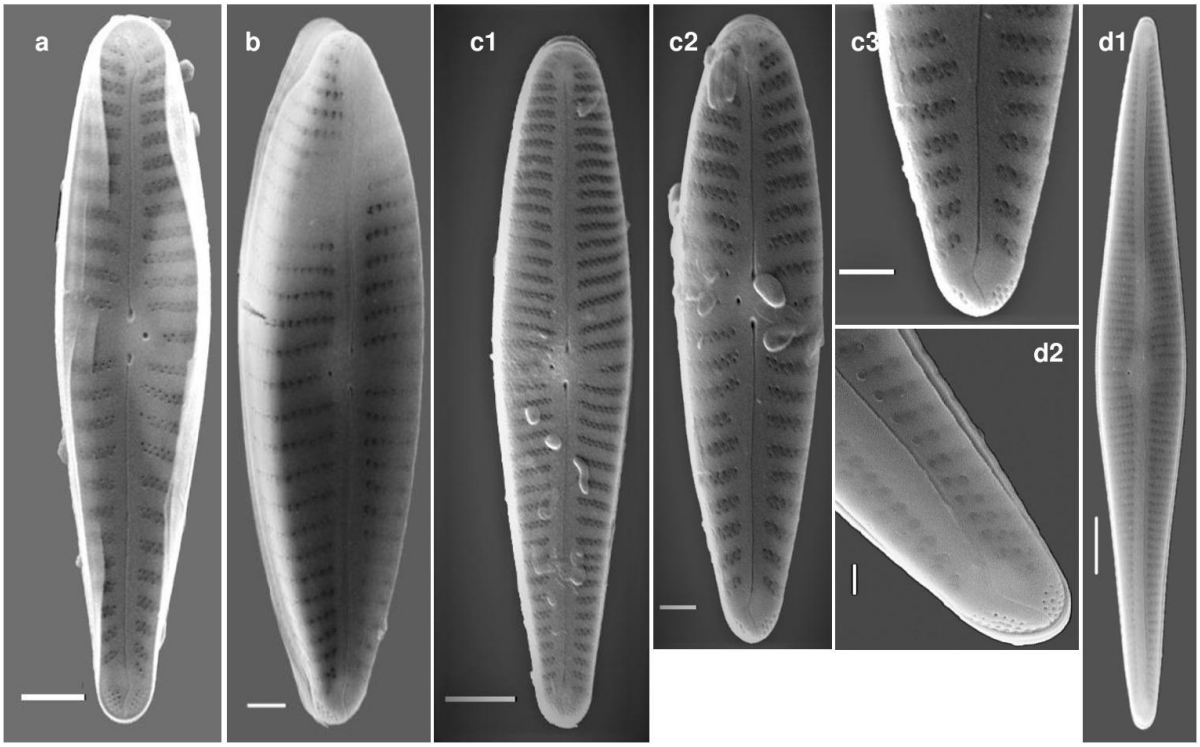

Figure 7 a: *Gomphonema pumilum* var. *rigidum* f. *biseriatum*; b: *Gomphonema punae*; c1-c2: *Gomphonema guaraniarum*; d1-d3: *Gomphonema rhombiciforme* (Scale bar: c1, d1= 5 μm; a, b= 2 μm; d2= 1 μm; c2, d3= 500 nm)

Table 1 Floristic details of the Newly recorded Taxa from the Eastern part of the Indian subcontinent

Name of the Taxa recorded	Site of collection	Habitat	Voucher no. of the specimen
Achnanthidium nanum	Darjeeling	Epipelic	CUH/AL-DIA 131
Achnanthidium subatomus	Darjeeling	Epilithic	CUH/AL-DIA 119
Achnanthidium atomus	Jalpaiguri	Epiphytic	CUH/AL-DIA 68
Achnanthidium duriense	Darjeeling	Epipelic	CUH/AL-DIA 132
Achnanthidium catenatum	Jalpaiguri	Epiphytic	CUH/AL-DIA 112
Achnanthes crenulated	Darjeeling	Epilithic	CUH/AL-DIA 120
Eunotia glacialispinosa	Malda	Epipelic	CUH/AL-DIA 138
Eunotia genuflexa	Dakshin Dinajpur	Epiphytic	CUH/AL-DIA 145
Craticula buderi	Jalpaiguri	Epiphytic	CUH/AL-DIA 113
Pinnularia subcapitata	Malda	Epipelic	CUH/AL-DIA 139
Pinnularia alabamae	Dakshin Dinajpur	Epiphytic	CUH/AL-DIA 147
Navicula pseudoreinhardtii	Darjeeling	Epipelic	CUH/AL-DIA 133
Navicula viridula	Darjeeling	Epilithic	CUH/AL-DIA 122
Brachysira brebissonii	West Midnapore	Epiphytic	CUH/AL-DIA 152
Sellaphora nigri	Jalpaiguri	Epiphytic	CUH/AL-DIA 114
Sellaphora laevissima	Dakshin Dinajpur	Epiphytic	CUH/AL-DIA 148
Sellaphora stroemii	Malda	Epipelic	CUH/AL-DIA 140
Sellaphora saugerresii	Dakshin Dinajpur	Epiphytic	CUH/AL-DIA 149
Sellaphora absoluta	Darjeeling	Epilithic	CUH/AL-DIA 123
Sellaphora caput	Jalpaiguri	Epiphytic	CUH/AL-DIA 115
Sellaphora seminulum	Malda	Epipelic	CUH/AL-DIA 141
Cymbella subturgidula	Jalpaiguri	Epilithic	CUH/AL-DIA 71
Placoneis elginensis	Darjeeling	Epilithic	CUH/AL-DIA 124
Gomphonema pumilum var.	Jalpaiguri	Epilithic	CUH/AL-DIA 73

rigidum f. *biseriatum*			
Gomphonema punae	Darjeeling	Epipelic	CUH/AL-DIA 134
Gomphonema guaraniarum	Jalpaiguri	Epiphytic	CUH/AL-DIA 94
Gomphonema rhombiciforme	Darjeeling	Epipelic	CUH/AL-DIA 136

Table 2 Systematic position of the recorded taxa in the present study, systematic follows Cox (2015)

Phylum	Class	Order	Family	Species
Ochrophyta	Bacillariophyceae	Cocconeidales	Achnanthidiaceae	*Achnanthidium nanum, Achnanthidium subatomus, Achnanthidium atomus, Achnanthidium duriense, Achnanthidium catenatum*
		Mastogloiales	Achnanthaceae	*Achnanthes crenulata*
		Eunotiales	Eunotiaceae	*Eunotia glacialispinosa, Eunotia genuflexa*
		Naviculales	Stauroneidaceae	*Craticula buderi*
			Pinnulariaceae	*Pinnularia subcapitata, Pinnularia alabamae*
		Cymbellales	Naviculaceae	*Navicula pseudoreinhardtii, Navicula viridula*
			Brachysiraceae	*Brachysira brebissonii*
			Sellaphoraceae	*Sellaphora nigri, Sellaphora laevissima, Sellaphora stroemii, Sellaphora saugerresii, Sellaphora absoluta, Sellaphora caput, Sellaphora seminulum*
			Cymbellaceae	*Cymbella subturgidula*
			Gomphonemateceae	*Placoneis elginensis, Gomphonema pumilum* var. *rigidum* f. *biseriatum, Gomphonema punae, Gomphonema guaraniarum, Gomphonema rhombiciforme*

Achnanthidium catenatum (Bily & Marvan) Lange-Bertalot (Figure 2 a1-a5)

Joh, (2012, p. 27, fig. 15)

(Homotypic synonym: *Achnanthes catenata* Bily & Marvan)

Valve linear to linear-lanceolate in outline, valve length 16-24.12 µm and breadth 3.5-4.3 µm, transapically wide in middle area with rostrate or capitate ends; in raphe valve, axial area narrowly linear, central area developed with a few short striae or widely distant striae in central portion, raphe filiform, in rapheless valve, axial area narrowly linear, slightly lanceolate in middle portion, striae parallel, striae density 23-28/10 µm.

Achnanthes crenulata Grunow (Figure 2 c1-c2)

Toyoda et al., (2006, pp. 175–176, fig. 5-7)

Valves lanceolate with an undulate margin in valve view, 39–50 µm in length and 10.8–14.2 µm in breadth; on the raphe valve (RV), raphe extends the length of valve with a central area forming a distinct, reasonably wide stauros reaching the valve margin; striae uniseriate, occurring opposite each other on either side of raphe on RV, striae density 8–13/10 µm on RV and 7–8/10 µm on araphid valve (ARV).

Eunotia genuflexa Nörpel-Schempp (Figure 3 a1-a3)

Bukhtiyarova, (2019, p. 11, fig. 4-6b)

Valves slightly dorsiventral, with narrowed rounded poles, valve length 135-160 μm and breadth 3-5 μm; Striae basal, uniserial, distant, uniformly spaced along the valve; raphe contains two short filiform slits on ventral valve mantle; terminal raphe fissures long, broadly curved and end up by round lacunae; striae density 18-22/10 μm.

Eunotia glacialispinosa Lange-Bertalot & Cantonati (Figure 3 b1-b2)

Luo et al., (2019, p. 143, fig. 80-81, 105); Cantonati and Bertalot, (2010, p. 269, fig. 68-71, 73-85)

Valve length 68-90 μm and 5-6.5 μm breadth; long terminal raphe fissures in valve facade approaches the dorsal margin; striae density 14-15/10 μm; areolae difficult to discriminate on the valve surface, 27-30/10 μm, wider spaced in distal parts of the valve mantle.

Craticula buderi (Hustedt) Lange-Bertalot (Figure 3 c1-c3)

Taylor et al., (2007, pl. 49); Cichon, (2016, p. 303, fig. 2-14)

Valves elliptic-lanceolate, with rostrate to subcapitate protracted apices, valves length 28 μm and breadth 6.8 μm; central area slightly wider than axial area and elliptic in shape; raphe filiform with near-straight proximal ends, distal ends hooked in same direction; striae parallel to very weakly radiate at valve centre, convergent at apices, striae density 17/ 10 μm.

Pinnularia subcapitata W.Gregory (Figure 4 a1-a6)

Noga et al., (2014, p. 80, fig. 36-37); Bahls et al., (2018, p. 70, pl. 33, fig. 4)

Valves linear, almost straight or very slightly convex margin, subcapitate ends, valve length 26.7–32 μm and breadth 5.1-5.25 μm; striae parallel, rarely slightly radiate in central part of valve, convergent towards the ends, striae alveolate and multiseriate, striae density: 16-21/10 μm.

Pinnularia alabamae Krammer (Figure 4 b1-b3)

Krammer, (2000, p. 185, pl. 212, fig. 1-3)

Valve linear, gibbous in the middle, ends swollen and broadly rounded, valve length 158.4-250 μm and breadth 26.6-42 μm; raphe system broadly lateral, outer raphe fissure slightly curved; striae radiate in the middle and convergent towards the ends, striae density 4-6/10 μm.

Navicula pseudoreinhardtii Patrick (Figure 4 c1-c3)

Potapova, (2013, fig. 62-68)

Valve length 23-28 μm and breadth 6.4-6.8 μm; slightly attenuate apices; sternum raised above the valve surface; raphe slightly lateral and proximal raphe endings are almost straight; striae density 12-17/10 μm.

Navicula viridula (Kützing) Ehrenberg (Figure 6 a1-a2)

Lee, (2012, p. 49, fig. 10A); Potapova, (2011). *Navicula viridula*. In Diatoms of North America, (https://diatoms.org/species/navicular_viridula)

Valves lanceolate to linear-lanceolate with subrostrate apices, valve length 41.6-60 μm and 10.4-12 μm; axial area narrow and straight; raphe straight, external proximal raphe ends slightly dilated and bent toward primary side of the valve; striae radiate in the centre, becoming convergent at the apices, striae density 10-15/10 μm.

Brachysira brebissonii R.Ross (Figure 6 b1-b3)

Kennedy and Allott, (2017, p. 15, fig. 81-91, 96-98)

Valves small, rhombic-lanceolate to elliptical-lanceolate with narrow rounded apices, valve length 12.8-25 μm and breadth 3.4-8 μm; raphe filiform, straight, positioned within two ribs lie on external face of valve; areolae typically elongate; striae weakly radiate from centre to apex, small papillae (silica nodules) scattered across the external valve face, striae density 35-42/10 μm.

Sellaphora nigri (De Notaris) C.E.Wetzel & L.Ector (Figure 5 a)

Wetzel et al., (2015, p. 221, fig. 319-393)

Valves small, elliptical to oval, with broadly rounded apices, valve length 13.5 μm and breadth 5.8 μm; striae uniseriate, radiate throughout, striae density 22-32/10 μm, striae bordering central area slightly curved, with shorter striae (usually 4); raphe straight with tear–drop proximal fissures and distal fissures bend strongly to same side of valve.

Sellaphora laevissima (Kützing) D.G.Mann (Figure 5 b1-b3)

Mann et al., (2008, p. 62, fig. 51); Slate and Steveson, (2007, p. 377, fig. 59)

Valves linear, rounded poles slightly subcapitate or broadly rostrate, valve length 26.5-49 μm and breadth 6-8.5 μm; raphe filiform, with broad curve halfway between centre and end of valve, raphe-sternum bordered by shallow groove externally; central area expanded, rectangular to weakly bow-tie shaped, bordered by 3-4 shortened stria of similar lengths; striae straight or curved, slightly radiate, striae density 19.8-29/10 μm.

Sellaphora stroemii (Hustedt) H.Kobayasi (Figure 5 c1-c3)

Falasco et al., (2009, p. 253, fig. 118-120); Wetzel et al., (2015, p.211, fig. 85-86)
Valves linear with rounded ends, sometimes slightly sub-capitate, valve length 18-23.2 μm and breadth 5-7.1 μm; raphe filiform, straight, with the external ends bent towards the primary side of the valve, the raphe sternum flanked by parallel furrows, continuous or interrupted at central area; striae uniseriate slightly punctuated, striae density 25/10 μm.
Sellaphora saugerresii (Desmazières) C.E.Wetzel & D.G.Mann (Figure 5 d1-d2)
Wetzel et al., (2015, p. 216, fig. 251-269)
Valves linear-elliptic to linear-lanceolate with rounded ends, valve length 9.88-12.3 μm and breadth 3.8-4.56 μm; central area wide, symmetric, bow-tie shaped with two or three shorter uneven striae; raphe straight with tear–drop–shaped proximal fissures, slightly curved, distal fissures bend strongly to same side of valve mantle; striae uni– to biseriate. radiate throughout, striae density 18-22/10 μm.
Sellaphora absoluta (Hustedt) Wetzel, Ector, Van de Vijver, Compère & D.G.Mann (Figure 5e)
Wang et al., (2010, p. 233, fig. 3 H)
(Homotypic synonym: *Navicula absoluta* Hustedt)
Valves lanceolate, ends rostrate, valve length 13.09-20 μm and breadth 4-6 μm; axial area narrow; raphe filiform, proximal ends expended, distal ends hooking in the same direction; central area small, ovoid to elliptical formed by 4-6 shortening median striae. striae uniseriately punctuate, radiate, striae density 24-31/10 μm.
Sellaphora caput K.M.Evans & D.G.Mann (Figure 5 f)
Evans and Mann, (2009, p. 72, fig. 4-5)
Valves linear-elliptical with broad capitate poles, sometimes subcapitate or rostrate, valve length 27-38 μm and breadth 7.3-8.25 μm; striae radiate, slightly curved, with shorter ones intercalated at the centre, 18–25/ 10 μm; axial area very narrow; central area neither ornamented nor ridged, transversely rectangular to bow-tie-shaped; polar bars parallel to slightly radiate.
Sellaphora seminulum (Grunow) D.G.Mann (Figure 5 g1-g3)
Wetzel et al., (2015, p. 217, fig. 297)
Valves linear–lanceolate to broadly lanceolate, with clearly convex margins and protracted, broadly rounded, slightly rostrate ends, valve length 16.5-28 μm and breadth 4.4-8 μm; striae radiate and arcuate, uniseriate at apices, striae density 12-16/10 μm; central area bordered by three-four shorter striae, butterfly–shaped, proximal raphe ends curves gently towards primary side externally.
Cymbella subturgidula Krammer (Figure 6 c1-c2)
Krammer, (2002, figs 44: 19-21); Da-Silva et al., (2015, p. 18, fig. 71-89)
Valve slightly lanceolate to lanceolate, dorsiventral, dorsal margin broadly convex and ventral margin straight to convex; ends subrostrate to broadly subcapitate, valve length 30.16-40 μm and breadth 9.1-13 μm; proximal raphe ends have central pores which curve to ventral margin; central area small, elliptical; 2 to 3 stigmata present at the middle striae, striae radiate, striae density 11-15/10 μm.
Placoneis elginensis (W.Gregory) E.J.Cox (Figure 6 d1-d3)
Cox, (2003, p. 64, fig. 56-72)
(Heterotypic synonym: *Placoneis anglica* (Ralfs) E.J.Cox)
Valves elliptical, length 20-27.96 μm and breadth 8–9.5 μm, valve apices rostrate to subcapitate; striae density 11–15/10 μm, gently radiate over throughout the valve, shorter opposite the central raphe endings forming a transverse area occupying about half the valve width and more rounded.
Gomphonema pumilum var. *rigidum* f. *biseriatum* E.A.Morales et M.L Vis (Figure 7 a)
Morales and Vis, (2007, p. 146, fig. 230)
Valves clavate with filiform raphe and a distinct stigma in the central area, valve length 13-16 μm and breadth 3.6-4.3 μm; striae with two rows of areolae, striae density 14-16/10 μm.
Gomphonema punae Lange-Bertalot & U.Rumrich (Figure 7 b)
Rumrich et al., (2000, pl. 129, fig. 1-14); Sala et al., (2008, p. 1173, fig. 34-36)
Valves heteropolar, ovate with subrostrate ends, valve length 21-28.8 μm and breadth 5-7.8 μm; stigma with an external circular opening, placed near one of the central striae; striae uniseriate, parallel to slightly radiate; raphe gently undulated with external proximal ends slightly dilated and terminal ones bent to the same side; striae density 11-13/10 μm.
Gomphonema guaraniarum Metzeltin & Lange-Bertalot (Figure 7 c1-c2)
Medeiros et al., (2018, p. 12, fig. 108-111); Metzeltin and Lange-Bertalot, (2007, pl. 212, fig. 9-14)

Valves rhombic-lanceolate, apical and basal ends attenuate rounded, valve length: 61.3–70 μm and breadth 8.75–10 μm; raphe-sternum narrow and linear, stigma at the end of central stria; striae are uniseriate, striae density12–14/10 μm; raphe ends are dilated into pores, apical pore field formed by rounded poroids disposed in both sides of terminal raphe fissure.

Gomphonema rhombiciforme Metzeltin & Lange-Bertalot (Figure 7 d1-d3)

Kociolek and Kingston, (1999, p. 692, fig. 34-39)

(Heterotypic Synonym: *Gomphonema stoermeri* Kociolek & J.C.Kingston)

Valves lanceolate–clavate, headpole rounded, footpole narrow; smaller specimens broadly rounded, footpole narrow, valve length 21.5–45 μm and breadth 7–8.75 μm; striae biseriate, striae density 10-13/ 10 μm; dilated proximal raphe ends with a rounded stigma, while distal raphe ends deflected before apices onto valve mantle; prominent apical pore field composed of large porelli.

4. DISCUSSION & CONCLUSION

The survey was conducted from various physiographic locations of West Bengal. Among 27 taxa that have been recorded for the first time from India are from Darjeeling Himalayan Hill region with maximum diversity which is closely followed by North Bengal Plains region. In the Biraphid group of diatoms Sellaphoraceae family appeared to be most dominant with 7 members of which 4 were epiphytic in habitat, 2 were epipelic in habitat and rest epilithic in nature. Whereas in the survey altogether 6 species were encountered in the monoraphid group of which epiphytic, epilithic and epipelic habitat comprised 2 species each. Moreover, all the members of the monoraphid diatoms were reported from the Darjeeling Himalayan Hill Region.

Authors' contribution

RB has drafted and written the full manuscript; RP has edited the manuscript.

Acknowledgements

The authors are obliged to the Centre of Advanced Study (CAS), Department of Botany, University of Calcutta, Fund for Improvement of S & T Infrastructure (FIST) of the Department of Science & Technology (DST), Government of India (DST– FIST) and Promotion of University Research and Scientific Excellence, Department of Science & Technology, Government of India (DSTPURSE) program for supportive with the infrastructural facilities. The authors would like to show their gratitude towards Centre for Research in Nano science and Nanotechnology (CRNN), University of Calcutta for providing instrumental support. Nonetheless, Mr Rahul Bose would like to acknowledge the Government of West Bengal for providing the Swami Vivekananda Merit Cum Means Scholarship to continue his research work.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Ethical approval & declaration

In this article, as per the algae regulations in Phycology and Algal Biotechnology Laboratory, Department of Botany, University of Calcutta, India, the authors observed the Monoraphid and Biraphid diatoms from India based on ultrastructure characteristics. The Algae ethical guidelines are followed in the study for species observation, identification & experimentation.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Bahls L, Boynton B, Johnston B. Atlas of diatoms (Bacillariophyta) from diverse habitats in remote regions of western Canada. PhytoKeys 2018; 105:1–186.
2. Bose R, Bar R, Pal R. Floristic assortment of planktonic and epipsammic diatoms from Eastern India with new reports. J Algal Biomass Util 2017; 8:51–68.
3. Bose R, Pal R. New reports of epilithic and epiphytic diatom flora from foot-hills areas of Eastern Himalayas. Phytomor phology 2020; 69:81–94.
4. Bukhtiyarova LN. The genus *Eunotia* Ehrenb. (Bacillariophyta) in the Cheremsky Nature Reserve, Ukrainian Polissya, and refined terminology relevant to the raphe system morphology. PhytoKeys 2019; 128:1–31.

5. Cantonati M, Bertalot H. Diatom biodiversity of springs in the Berchtesgaden National Park (north-eastern Alps, Germany), with the ecological and morphological characterization of two species new to science. Diatom Res 2010; 25:251–280.
6. Cavalier-Smith T, Chao EE. 18S rRNA sequence of *Heterosigma carterae* (Raphidophyceae), and the phylogeny of heterokont algae (Ochrophyta). Phycologia 1996; 35:500–510.
7. Chowdhury AK, Pal R. Diversity of planktonic diatoms from West Bengal coast with special reference to taxonomic Accounts. Phytomorphology 2008; 58:29–41.
8. Cichon S. *Craticula buderi* (Bacillariophyceae) in Poland. Pol Bot J 2016; 61:301–305.
9. Cox EJ. Diatoms, diatomeae (Bacillariophyceae s.l., Bacillariophyta). In: Syllabus of Plant Families, Frey W (Editor), Borntraeger, Stuttgart 2015; 64–103.
10. Cox EJ. *Placoneis* Mereschkowsky (Bacillariophyta) revisited: Resolution of several typification and nomenclatural problems, including the generitype. Bot J Linn Soc 2003; 14:53 –83.
11. Da-Silva WJ, Jahn R, Ludwig TAV, Hinz F, Menezes M. Typification and taxonomic status re-evaluation of 15 taxon names within the species complex *Cymbella affinis/tumidula/turgidula* (Cymbellaceae, Bacillariophyta). PhytoKeys 2015; 53:1–25.
12. Evans KM, Mann DG. A proposed protocol for nomenclaturally effective DNA barcoding of microalgae. Phycologia 2009; 48:70–74.
13. Falasco E, Blanco-Lanza S, Bona F, Goma J, Hlubikova D, Novais MH, Hoffmann L, Ector L. Taxonomy, morphology and distribution of the *Sellaphora stroemii* complex (Bacillariophyceae). Fottea 2009; 9:243–256.
14. Gandhi HP. A contribution to our knowledge of the freshwater diatoms of Partabgarh Rajasthan. J Indian Bot Soc 1955; 34:307–338.
15. Gandhi HP. Fresh-water diatoms from Sagar in the Mysore State. Indian Botanical Society. J Indian Bot Soc 1959b; 38:305–331.
16. Gandhi HP. Freshwater diatoms of Panhalgarh hill fort in the Kolhapur district. Hydrobiologia 1959a; 14:93–129.
17. Gandhi HP. Notes on the diatomaceae of Ahmedabad and its environs. Hydrobiologia 1961b; 17:218–236.
18. Gandhi HP. The diatom flora of the Bombay and Salsatte Islands-II. Nova Hedwigia 1961a; 3:469–506.
19. Gandhi HP. The freshwater diatom flora from Mugad, Dharwar District with some ecological notes. Ceylon J Sci Biol Sci 1959c; 2:98–116.
20. Gandhi HP. The freshwater diatoms flora of the Hirebhasgar Damarea, Mysore State. J Indian Bot Soc 1958; 37:249–265.
21. Hasle GR, Syvertsen EE. Marine diatoms. In: Identifying marine phytoplankton (Ed. by C.R. Tomas), Academic Press, San Diego 1997; 5–385.
22. Joh G. Algal Flora of Korea. Chrysophyta; Bacillariophyceae: Pennales: Raphidineae: Acanthaceae. Freshwater diatoms V, National Institute of Biological Resources, Incheon 2012; 3(7): 134.
23. Joseph G, Francis MS. First new record of two diatoms (*Caloneis africana* (Giffen) Stidolph and *Luticola nivalis* (Ehrenberg) DG Mann) from South West Coast of India (Cochin backwaters). Oceanologia 2019; 61:395-399.
24. Karthick B, Hamilton PB, Kociolek JP. An illustrated guide to common diatoms of Peninsular India. Gubbi Labs, Gubbi 2013; 206.
25. Kennedy B, Allott N. A review of the genus *Brachysira* in Ireland with the description of *Brachysira praegeri* and *Brachysira conamarae*, new raphid diatoms (Bacillariophyceae) from high status waterbodies. Phytotaxa 2017; 326:1–27.
26. Keshri JP, Ghosh AK, Roy S. On the occurrence of four diatom taxa from Eastern India with a taxonomic note. J Bot 2016; 1–5.
27. Kociolek JP, Kingston JC. Taxonomy, ultrastructure, and distribution of some gomphonemoid diatoms (Bacillariophyceae: Gomphonemataceae) from rivers in the United States. Canad. J Bot 1999; 77:686–705.
28. Kociolek JP, Spaulding SA. Freshwater diatom biogeography. Nova Hedwigia 2000; 71:223–241.
29. Kociolek JP. A worldwide listing and biogeography of freshwater diatom genera: A phylogenetic perspective. Diatom Res 2018; 33:509–534.
30. Krammer K. The genus *Cymbella*. Diatoms of Europe. Diatoms of the European Inland Waters and Comparable Habitats. Diatoms of Europe 2002; 3:1–584.
31. Krammer K. The genus *Pinnularia*. In: Diatoms of the European Inland Waters and Comparable Habitats, Lange-Bertalot H (Editor), Gantner Verlag KG: Berlin/Heidelberg, Germany 2000; 703.
32. Lee JH. Algal flora of Korea. *Chrysophyta: Bacillariophyceae: Pennales: Raphidineae: Naviculaceae.* Freshwater diatoms *VI*. National Institute of Biological Resources, Incheon 2012; 3(8): 56.
33. Luo F, Qingmin Y, Yu P, Pang W, Wang Q. *Eunotia* (Bacillariophyta) biodiversity from high altitude, freshwater habitats in the Mugecuo Scenic Area, Sichuan Province, China. Phytotaxa 2019; 394:133–147.
34. Mandal M, Żelazna-Wieczorek J, Sen-Sarkar N. New diatom taxa for the Indian Sundarbans found in short sediment cores. Diatom Res 2020; 35:17–35.
35. Mann DG, Thomas SJ, Evans KM. Revision of the diatom genus *Sellaphora*: A first account of the larger species in the British Isles. Fottea 2008; 8:15–78.

36. Mann DG. The species concept in diatoms. Phycologia 1999; 38:437–495.
37. Medeiros G, Amaral MWW, Ferreira PC, Ludwig T, Bueno N. *Gomphonema* Ehrenberg (Bacillariophyceae, Gomphonemataceae) of the São Francisco Falso River, Paraná, Brazil. Biota Neotrop 2018; 18:e20170495.
38. Metzeltin D, Lange–Bertalot H. Tropical diatoms of South America II. Special remarks on biogeography disjunction. Iconogr Diatomol 2007; 18:1–877.
39. Monnier O, Lange-Bertalot H, Hoffmann L, Ector, L. The genera *Achnanthidium* Kützing and *Psammothidium* Bukhtiyarova et Round in the family Achnanthidiaceae (Bacillariophyceae): A reappraisal of the differential criteria. Cryptogam Algol 2007; 28:41–158.
40. Morales EA, Vis ML. Epilithic diatoms (Bacillariophyceae) from cloud forest and alpine streams in Bolivia, South America. Proc Acad Nat Sci Phila 2007; 156(1):123–155.
41. Noga T, Peszek Ł, Stanek-Tarkowska J, Pajączek A. The *Pinnularia* genus in south-eastern Poland with consideration of rare and new taxa to Poland. Oceanol Hydrobiol Stud 2014; 43:77–99.
42. Novais MH, Jüttner I, Hoffmann L, Ector L. Morphological variability within the *Achnanthidium minutissimum* species complex (Bacillariophyta): Comparison between the type material of *Achnanthes minutissima* and related taxa, and new freshwater *Achnanthidium* species from Portugal. Phytotaxa 2015; 224:101–139.
43. Ponader K, Potapova M. Diatoms from the genus *Achnanthidium* in flowing waters of the Appalachian Mountains (North America): Ecology, distribution and taxonomic notes. Limnologica 2007; 37:227–241.
44. Potapova M. *Navicula viridula*. In: Diatoms of North America 2011. https://diatoms.org/species/navicula_viridula
45. Potapova M. The types of 22 *Navicula* (Bacillariophyta) species described by Ruth Patrick. Proc Acad Nat Sci Phila 2013; 162: 1–23.
46. Rumrich U, Lange–Bertalot H, Rumrich M. Diatomeen der Aden. Von Venezuela bis Patagonien (Feuerland). Iconogr Diatomol 2000; 9:1–649.
47. Sala SE, Ramirez JJ, Plata-Diaz Y. Diatoms from lentic and lotic systems in Antioquia, Chocó and Santander Departments in Colombia. Rev Biol Trop 2008; 56:1159–1178.
48. Samanta B, Bhadury P. Study of diatom assemblages in Sundarbans mangrove water based on light microscopy and rbcL gene sequencing. Heliyon 2018; 4:e00663.
49. Satpati GG, Gorain PC, Sengupta S, Pal R. *Cocconeis gracilariensis* sp. nov. (Cocconeidaceae, Bacillariophyta) from India: A new brackish water diatom, epiphytic on invasive red seaweed *Gracilaria* sp. NeBio 2017; 8:88–93.
50. Slate JE, Stevenson RJ. The diatom flora of phosphorus-enriched and unenriched sites in an Everglades marsh. Diatom Res 2007; 22:355–386.
51. Taylor JC, Harding WR, Archibald CGM. An illustrated guide to some common diatom species from South Africa. Water Research Commission, Pretoria 2007; 1-225.
52. Toyoda K, Williams DM, Tanaka J, Nagumo T. Morphological investigations of the frustule, perizonium and initial valves of the freshwater diatom *Achnanthes crenulata* Grunow (Bacillariophyceae). Phycol Res 2006; 54:173–182.
53. Vanormelingen P, Verleyen E, Vyverman W. The diversity and distribution of diatoms: From cosmopolitanism to narrow endemism. Biodivers. Conserv 2007; 17:393–405.
54. Vyverman W, Verleyen E, Sabbe K, Vanhoutte K, Sterken M, Hodgson DA, Mann DG, Juggins S, Vijver B, Jones V, Flower R, Roberts D, Chepurnov VA, Kilroy C, Vanormelingen P, De-Wever A. Historical processes constrain patterns in global diatom diversity. Ecology 2007; 88:1924–1931.
55. Wang LC, Lee TQ, Chen SH, Wu JT. Diatoms in Liyu Lake, eastern Taiwan. Taiwania 2010; 55:228–242.
56. Wetzel CE, Ector L, Vijver B, Compere P, Mann D. Morphology, typification and critical analysis of some ecologically important small naviculoid species (Bacillariophyta). Fottea 2015; 15:203–234.