Annexure 1:

Checklist of Epilithic diatoms of Rivers of Uttara Kannada, Karnataka

TAXA	KALI	BEDTHI	AGHANASHINI	SHARAVATHI	VENKATAPURA
ACHNANTHES sp J.B.M. Bory de St. Vincent		+			
Achnanthes minutissima Kützing *v.minutissima* Kützing *(Achnanthidium)*	+	+	+	+	+
Achnanthes sp.		+			
Achnanthidium sp.	+	+	+	+	+
Actinocyclus sp.	+				
Amphora montana Krasske	+				
Amphora pediculus (Kützing) Grunow	+				+
Amphora species		+			
Aulacoseira ambigua (Grunow) Simonsen	+	+		+	
*Aulacoseira granulata (*Ehr.*)* Simonsen		+			
*Aulacoseira granulata (*Ehr.*)* Simonsen morphotype *curvata*		+			
Bacillaria paradoxa Gmelin	+				
Brachysira neoexilis Lange-Bertalot	+	+	+	+	+
Brachysira sp.	+	+	+	+	+
Brachysira wygaschii Lange-Bertalot	+		+	+	+
BRASSIEREA sp Hein & Winsborough		+			
*Caloneis bacillum (*Grunow*)* Cleve	+	+		+	
Caloneis hyalina Hustedt	+				
*Caloneis silicula (Ehr.)*Cleve	+	+			+
Caloneis species		+			
Cocconeis placentula Ehrenberg *var.euglypta (*Ehr.*)* Grunow	+	+	+		+
CRATICULA sp A. Grunow		+			
Craticula accomodiformis Lange-Bertalot		+			
Craticula molestiformis (Hustedt) Lange-Bertalot		+			
Craticula submolesta (Hust.) Lange-Bertalot	+	+			+
Craticula vixnegligenda Lange-Bertalot		+			
CYCLOSTEPHANOS sp F.E. Round		+			

Cyclostephanos species	+	+			+
CYCLOTELLA sp F.T. Kützing ex A de Brébisson		+			
Cyclotella meneghiniana Kützing	+	+			
Cyclotella ocellata Pantocsek		+			
Cyclotella species		+			
Cymbella kolbei Hustedt *var.* kolbei	+	+		+	+
Cymbella species	+	+	+	+	+
*Cymbella tumida (*Brebisson*)*Van Heurck	+	+			
CYMBOPLEURA (Krammer) Krammer					+
Cymbopleura sp.	+			+	+
Diadesmis contenta (Grunow ex V. Heurck) Mann	+	+			+
*Diploneis elliptica (*Kützing) Cleve		+			
*Diploneis oblongella (*Naegeli) Cleve-Euler		+			
Diploneis ovalis (Hilse) Cleve		+			
Diploneis subovalis Cleve	+	+			+
Encyonema mesianum (Cholnoky) D.G. Mann	+				+
*Encyonema minutum (*Hilse in Rabh.) D.G. Mann	+	+			+
Encyonema species	+				+
Entomoneis alata Ehrenberg		+			
Eolimna subminuscula (Manguin) Moser Lange-Bertalot & Metzeltin	+	+			
EUNOTIA sp. C.G. Ehrenberg		+			
Eunotia bilunaris (Ehr.) Mills var. *bilunaris*					+
Eunotia incisa Gregory var.*incisa*	+	+			
*Eunotia minor (*Kützing*)* Grunow	+	+	+	+	+
Eunotia rhomboidea Hustedt	+		+	+	+
Eunotia sp.	+	+		+	
Fallacia insociabilis (Krasske) D.G. Mann		+			
Fallacia pygmaea (Kützing) Stickle & Mann *ssp.pygmaea* Lange-Bertalot	+	+			
Fallacia tenera (Hustedt) Mann in Round		+			
Fragilaria biceps (Kützing) Lange-Bertalot	+	+	+	+	+
Fragilaria species		+			
Fragilaria ulna (Nitzsch.) Lange-Bertalot var. *ulna*	+	+	+	+	+

Fragilaria ungeriana Grunow	+				
Frustulia saxonica Rabenhorst				+	
Frustulia species	+			+	+
Geissleria decussis(Ostrup) Lange-Bertalot & Metzeltin		+			
Gomphonema acuminatum Ehrenberg	+				
Gomphonema difformum Karthick and Kociolek		+	+	+	
Gomphonema diminutum Karthick and Kociolek	+	+	+		
Gomphonema gandhii Karthick and Kociolek	+	+	+	+	+
Gomphonema parvulum (Kützing) Kützing var. *parvulum f. parvulum*	+	+	+	+	+
Gomphonema pseudoaugur Lange-Bertalot		+			
Gomphonema species	+	+	+	+	+
*Gyrosigma acuminatum (*Kützing)Rabenhorst	+	+			
Gyrosigma scalproides (Rabenhorst)Cleve	+				
Gyrosigma species		+			
Hantzschia distinctepunctata Hustedt in Schmidt & al.				+	
Hippodonta avittata (Cholnoky) Lange-Bert.Metzeltin & Witkowski	+				+
Luticola species	+	+			
Luticola species (aff. mutica)	+				
Navicula species		+			
Navicula antonii Lange-Bertalot		+		+	
Navicula cincta (Ehr.) Ralfs in Pritchard	+				
Navicula cryptocephala Kützing	+	+	+	+	+
Navicula cryptotenella Lange-Bertalot	+				
Navicula elginensis (Gregory) Ralfs in Pritchard					+
Navicula erifuga Lange-Bertalot	+	+			
Navicula gracilis Ehrenberg	+			+	
Navicula hustedtii Krasske					
Navicula hustedtii Krasske var.*obtusa* Hustedt	+			+	
Navicula leptostriata Jorgensen	+	+	+	+	+
*Navicula peregrina (*Ehr.) Kützing	+				
Navicula reinhardtii (Grunow) Grunow in Cl. & Möller				+	

Navicula riediana Lange-Bertalot & Rumrich	+			+	+
Navicula rostellata Kützing	+	+		+	+
Navicula sp.	+	+	+	+	+
Navicula symmetrica Patrick	+	+	+	+	+
Navicula viridula (Kützing) Ehrenberg	+				
Navigiolum species.					
Neidium affine(Ehrenberg)Pfitzer	+				+
NITZSCHIA sp. A.H. Hassall		+			
Nitzschia amphibia Grunow f.*amphibia*	+	+			+
Nitzschia clausii Hantzsch	+	+		+	+
Nitzschia compressa (J.W.Bailey) Boyer		+			
*Nitzschia dissipata(*Kützing*)Grunow var.media (*Hantzsch.*)* Grunow				+	
Nitzschia fonticola Grunow in Cleve et Möller	+	+			
Nitzschia frustulum(Kützing)Grunow var.frustulum	+	+			
Nitzschia gracilis Hantzsch				+	
Nitzschia linearis(Agardh) W.M.Smith var.*linearis*					
Nitzschia nana Grunow in Van Heurck	+				
Nitzschia obtusa W.M.Smith *var. kurzii* (Rabenhorst) Grunow	+	+		+	+
Nitzschia palea (Kützing) W.Smith	+	+		+	+
Nitzschia reversa W.Smith	+	+		+	+
Nitzschia sigma(Kützing)W.M.Smith		+		+	+
Nitzschia species	+	+			+
*Nitzschia umbonata(*Ehrenberg*)*Lange-Bertalot		+			
Pinnularia acrospheria W. Smith var. *acrospheria*		+			+
Pinnularia brebissonii (Kütz.) Rabenhorst *var.* brebissonii	+	+		+	
Pinnularia divergens W.M.Sm. var.*undulata* (M.Perag. & Herib.) Hustedt				+	
Pinnularia gibba Ehrenberg				+	
Pinnularia species		+		+	+
Placoneis sp.	+	+		+	
Planothidium frequentissimum(Lange-Bertalot)Lange-Bertalot	+	+	+	+	+
Planothidium rostratum (Oestrup) Round & Bukhtiyarova	+	+			+

PLANOTHIDIUM sp. Round & Bukhtiyarova		+	+	+	
Pleurosigma salinarum (Grunow) Cleve & Grunow	+				
Pseudostaurosira brevistriata (Grun.in Van Heurck) Williams & Round		+			
Rhopalodia gibba (Ehr.) O.Muller var.gibba					+
*Rhopalodia operculata (*Agardh) Hakansson	+				+
Sellaphora species	+	+			
Sellaphora americana (Ehrenberg) D.G. Mann	+			+	+
Sellaphora laevissima (Kützing) D.G. Mann				+	
Sellaphora nyassensis (O.Muller) D.G. Mann	+	+			
*Sellaphora pupula (*Kützing) Mereschkowksy	+	+		+	+
SEMINAVIS sp. D.G. Mann		+			
Seminavis species		+			
Skeletonema species					
Stauroneis species	+	+			+
Surirella angusta Kützing	+	+		+	+
Surirella species	+	+		+	+
Synedra sp.		+			
Tryblionella calida (grunow in Cl. & Grun.) D.G. Mann	+	+			
Tryblionella levidensis Wm. Smith		+			
TOTAL	**83**	**95**	**22**	**51**	**55**
TOTAL NUMBER OF TAXA REPORTED FROM ALL RIVER BASINS	**140**				

Nova Hedwigia Vol. 93 issue 1–2, 211–236 **Article**
Stuttgart, August 2011

The diatom genus *Gomphonema* Ehrenberg in India: Checklist and description of three new species

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With 51 figures and 2 tables

Karthick, B., J.P. Kociolek, M.K. Mahesh & T.V. Ramachandra (2011): The diatom genus *Gomphonema* Ehrenberg in India: Checklist and description of three new species. – Nova Hedwigia 93: 211–236.

Abstract: We have compiled a checklist of *Gomphonema* Ehrenberg taxa reported previously from India. From forty-nine references, over 100 *Gomphonema* taxa have been reported, including 39 new taxon descriptions. In addition to these previous reports of *Gomphonema* taxa, we describe three new species, *G. gandhii* Karthick & Kociolek, sp. nov., *G. difformum* Karthick & Kociolek, sp. nov. and *G. diminutum* Karthick & Kociolek, sp. nov., all from hill streams of Western Ghats, India. Frustule morphology, as studied in light and scanning electron microscopy, is compared with that of other recently described *Gomphonema* species from Africa and Asia. All three Indian species have distinctly dilated proximal raphe ends, in addition to differentiated apical pore fields, septa, pseudosepta and a round external stigmal opening. *Gomphonema gandhii* is linear-lanceolate-clavate, has a wide axial area, and is 19–51 µm long, 3–7 µm broad. *Gomphonema difformum* is smaller than *G. gandhii*, and has a hyaline area around the headpole. *Gomphonema diminuta* is much smaller and narrower than the other two species. These species are distinct from their closest congeners by their sizes, shape and structure of the head pole, and striae densities. All these species were described from low nutrient, neutral, low ionic content streams of Western Ghats. As most other species described from tropical region these three species appear to be endemic to India. Moreover, within India they have hitherto only been found in Western Ghats, one of the twelve biodiversity hotspots of the World.

Key words: Bacillariophyceae, diatoms, Gomphonema, India, new species, taxonomy, valve ultrastructure.

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 www.borntraeger-cramer.de
DOI: 10.1127/0029-5035/2011/0093-0211 0029-5035/2011/0093-0211 $ 6.50

Introduction

The diatom genus *Gomphonema* Ehrenberg is large, including over 500 taxa worldwide (Fourtanier & Kociolek 2009). While its members are almost exclusively freshwater in terms of habitats, and many species are associated with impacted trophic levels (e.g. Patrick in Patrick & Reimer 1966), the genus is quite diverse morphologically. Variation in valve ultrastructure includes presence or absence of stigmata, areolar structure, structure and position of the apical pore fields, and presence/absence of spines to name a few (Kociolek & Stoermer 1993, but also see Metzeltin & Lange-Bertalot 1998, Reichardt 1999). While some species of *Gomphonema* appear to be cosmopolitan in their distribution (for example, it appears that *G. parvulum* (Kützing) Kützing has been reported from all continents on earth), there are many reports of endemic species of *Gomphonema* from South America (Fricke 1904; Metzeltin & Lange-Bertalot 2007), Africa (Compère 1995, Hustedt 1949, Kociolek & Stoermer 1991), Madagascar (Spaulding & Kociolek 1998), North America (Kociolek & Kingston 1999, Thomas et al. 2009), Europe (Hustedt 1945, Reichardt 1999, 2005), Asia (Lange-Bertalot & Genkal 1999, Li et al. 2006) and Australia and environs (Hustedt 1942, Kociolek et al. 2004).

India is a large, geographically complex country with ten different biogeographic zones covering over 3 million sq. km, about a third the size of all of Europe, but with nearly 50% greater human population (World Population Prospects, 2008). The country shares borders with Bangladesh, Bhutan, Myanmar, China, Nepal and Pakistan. The complexity of India's freshwater environments includes three major, complex watersheds (Himalayas and the Karakoram ranges; Vindhya, Satpura ranges and the Chota Nagpur Plateau; and the Western Ghats) that cut across the country, related to their sources in the mountains. Freshwater environments range in elevation from sea level at the coast to over 8000 m above sea level.

The diatom genus *Gomphonema* in India has been documented for over 160 years. First report of the genus in India was by Ehrenberg (1845), who reported *G. clavatum*, *G. gracile* and *G. turris* from "Kolkatta" (then Calcutta) and River Ganges. Since then, 49 separate papers have identified 130 taxa of *Gomphonema* from India, mostly from lowland habitats. Of these, about 30% have been newly described taxa. In the region around India, gomphonemoid diatoms have been considered by Hustedt (1922), Jüttner et al. (2004) from Nepal, and Mereschkowsky (1906), Kociolek (1992), and Li et al. (2006, in press) from China. Though many species of *Gomphonema* have been described from India, there are extensive parts of the country that have not been investigated. The Western Ghats mountain range in Southern India, one of the Gondwanaland breakup landmasses, is amongst the most important hotspots of biodiversity. Western Ghats is a chain of mountains that runs parallel with the west coast of India for over 1600 km from 8°15'N to 21°00'N. Due to its distinct physiographic, edaphic and climatic gradients, this region harbors a wide array of habitats with unique geographic position and that support unique sets of flora and fauna. The Western Ghats harbors approximately 5000 species of vascular plants belonging to nearly 2200 genera; about 1700 species (34%) are endemic. There are also 58 endemic plant genera, while nearly three-quarters of the endemic genera

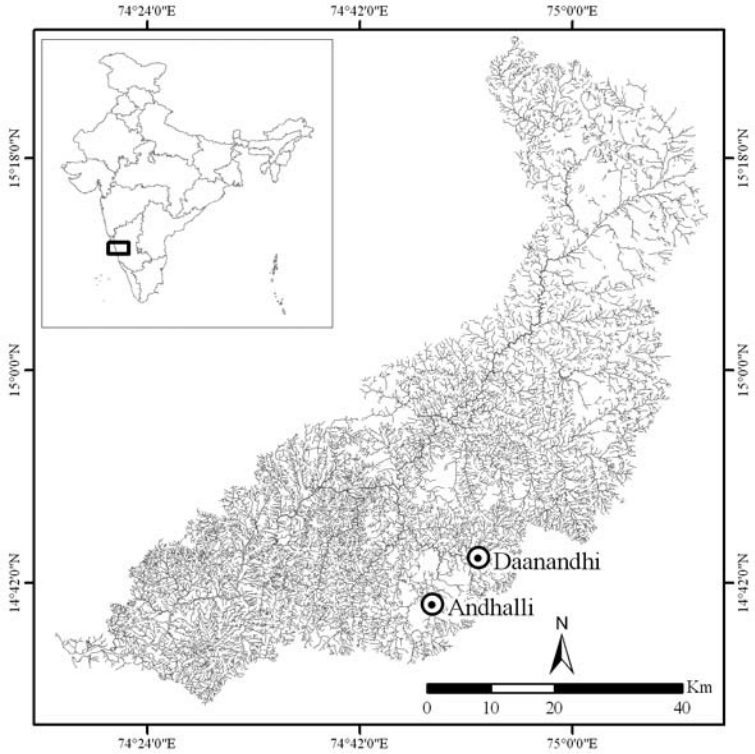


Fig 1. Map showing the area of investigation (inset India with Bedthi River basin highlighted).

have only a single species (Conservation International, 2008). The fauna and flora of this region has attracted attention of systematic and evolutionary biologists because of the mixture of high-level endemism (Inger, 1999; Myers et al. 2000) and various affinities with other biogeographic regions (Bossuyt & Milinkovitch, 2001).

In the present report we have compiled a checklist of the *Gomphonema* taxa previously reported and described from India (Table 1). We also document and describe with light and scanning electron microscopy three new species of *Gomphonema* from Central Western Ghats, Karnataka State, India. We also present information about each species' autecology, with particular attention paid to water chemistry and seasonality.

Materials and methods

Ten first to fourth order streams were surveyed for diatoms and water quality assessment in the Bedthi River Basin, Central Western Ghats, Karnataka (Fig. 1) from January to December, 2006. Diatom samples were collected by vigorously scrubbing 3–5 stones from the substratum with a toothbrush and the resultant suspension was preserved in ethanol. A portion of sample was oxidized by the hot HCl and $KMnO_4$ method (Taylor et al. 2007). Cleaned material was mounted onto glass slides with

Table 1. Listing of *Gomphonema* taxa for India and references that have reported each taxon. (Note: * denotes the species described from Indian administrative boundary; † indicates the studies on fossil material)

	Species name	Reference
1	*Gomphonema abbreviatum* Kütz.	Abdul-Majeed 1935; Srinivasan 1965; Suxena and Venkateshwarlu 1970
2	*Gomphonema abbreviatum* Kütz. f. *minor*? Krishnamurthy*	Krishnamurthy 1954; Kumawat et al. 2008
3	*Gomphonema abbreviatum* Kütz. v. *pulneyensis*? Krishnamurthy*	Krishnamurthy 1954
4	*Gomphonema acuminatum* Ehr.	Carter 1926; Biswas 1936; Krishnamurthy 1954
5	*Gomphonema acuminatum* Ehr. v. *elongata* (Rabh.) W.Sm.	Biswas 1936
6	*Gomphonema acuminatum* Ehr. v. *directum* A.Cl.	Gandhi 1959b
7	*Gomphonema acuminatum* Ehr. v. *turris* (Ehr.) Cl.	Krishnamurthy 1954; Gandhi 1960a; Sarode and Kamat 1980; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992; Kumawat et al. 2008
8	*Gomphonema aequatoriale* Hust.	Gandhi 1960a; Gandhi 1964; Sarode and Kamat 1980; Sarode and Kamat 1983; Sarode and Kamat 1984; Kumawat et al. 2008
9	*Gomphonema angustatum* (Kütz.) Rabh.	Krishnamurthy 1954; Srinivasan 1965; Kumawat et al. 2008
10	*Gomphonema angustatum* (Kütz.) Rabh. v. *producta* Grun	Krishnamurthy 1954; Kumawat et al. 2008
11	*Gomphonema angustatum* (Kütz.) Rabh. v. *producta* Grun. f. indica Gandhi*	Gandhi 1960a; Sarode and Kamat 1984
12	*Gomphonema apicatum* Ehr.	Singh 1963
13	*Gomphonema augur* Ehr.	West and West 1907; Gandhi 1959a; Gandhi 1960a; Singh 1961; Gandhi 1962a; Gandhi 1966; Gandhi 1983a†; Sarode and Kamat 1984; Kumawat et al. 2008
14	*Gomphonema augur* Ehr. v. *gautieri* V.H	Gandhi 1983a†
15	*Gomphonema augur* Ehr. v. *genuinum* May.	Gandhi 1956; Singh 1961; Singh 1963; Prasad and Srivastava 1992; Kumawat et al. 2008
16	*Gomphonema balatonis* Pant.	Gandhi 1960a; Srinivasan 1965; Sarode and Kamat 1984; Kumawat et al. 2008
17	*Gomphonema balatonis* Pant. v. *lanceolata* Gandhi	Gandhi 1960a; Sarode and Kamat 1984;
18	*Gomphonema brasiliense* Grun.	deToni 1891–94; Srinivasan 1965
19	*Gomphonema bengalensis* Grun*	deToni 1891-94;
20	*Gomphonema bohemicum* Reichelt et Fricke	Gandhi 1983a†
21	*Gomphonema capitatum* Ehr.	Abdul-Majeed 1935
22	*Gomphonema clavatoides* Gandhi*	Gandhi 1960a; Gandhi 1964; Srinivasan 1965; Gandhi 1966; Sarode and Kamat 1984; Prasad and Srivastava 1992; Gandhi 1998; Kumawat et al. 2008
23	*Gomphonema clavatoides* Gandhi v. *valida* Gandhi*	Gandhi 1960a; Sarode and Kamat 1984
24	*Gomphonema clavatoides* v. *rostrata* Gandhi*	Gandhi 1998
25	*Gomphonema clavatum* Ehr.	Ehrenberg 1845
26	*Gomphonema clevei* f. *acuta* Gandhi*	Gandhi 1966
27	*Gomphonema clevei* Fricke	Gandhi 1959b; Srinivasan 1965; Gandhi 1966; Prasad and Srivastava 1992

28	*Gomphonema clevei* v. *bipunctata* Gandhi*	Gandhi 1959b; Gandhi 1966
29	*Gomphonema clevei* v. *javanica* Hust.	Gandhi 1966
30	*Gomphonema clevei* v. *undulata* Gandhi*	Gandhi 1966
31	*Gomphonema constrictum* Ehr.	Abdul-Majeed 1935; Biswas 1936; Srinivasan 1965; Gandhi 1983a†; Kumawat et al. 2008
32	*Gomphonema constrictum* Ehr. v *capitata* (Ehr.) Cl.	Gandhi 1960a; Gandhi 1983a†; Sarode and Kamat 1984; Kumawat et al. 2008
33	*Gomphonema constrictum* Ehr. v. *indica* Gandhi*	Gandhi 1960a; Sarode and Kamat 1984; Kumawat et al. 2008
34	*Gomphonema constrictum* Ehr. v. *capitatum* Cleve. f. *italica* Kuetz.	Kumawat et al. 2008
35	*Gomphonema constrictum* Ehr. v. *capitatum* Cleve. f. *turgida* Mayer	Kumawat et al. 2008
36	*Gomphonema dharwarensis* Gandhi*	Gandhi 1956; Srinivasan 1965
37	*Gomphonema dichotomum* Kütz.	Ehrenberg 1845; Grunow 1865;
38	*Gomphonema dubia* Meister	Meister 1932
39	*Gomphonema dubravicense* Pant.	Gandhi 1998
40	*Gomphonema geminatum* Ag. v. *hybrida* Grun.	Gandhi 1983a†
41	*Gomphonema ghosea* Abdul-Majeed*	Abdul-Majeed 1935
42	*Gomphonema gracile* Ehr.	Ehrenberg 1845; Carter 1926; Krishnamurthy 1954; Gandhi 1955; Gandhi 1957a; Gandhi 1959c; Gandhi 1960a; Gandhi 1962a; Singh 1962; Singh 1963; Gandhi 1966; Srinivasan 1965; Sarode and Kamat 1984; Gandhi 1998; Kumawat et al. 2008
43	*Gomphonema gracile* Ehr. f. *turris* (Ehr.) Hust.	Sarode and Kamat 1984
44	*Gomphonema gracile* Ehr. v. *auritum* A.Br.	Gandhi 1960a; Gandhi 1966; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992
45	*Gomphonema gracile* Ehr. v. *dichotomum* (W.Smith) Cleve	Thomas and Gonzalves 1965d
46	*Gomphonema gracile* Ehr. v. *frickei* Gandhi*	Gandhi 1960a; Sarode and Kamat 1984
47	*Gomphonema gracile* Ehr. v. *hybridum* A.Cl.	Sarode and Kamat 1984
48	*Gomphonema gracile* Ehr. v. *intricatiforme* May.	Sarode and Kamat 1983; Sarode and Kamat 1984
49	*Gomphonema gracile* Ehr. v. *lanceolata* (Kütz.) Cl.	Krishnamurthy 1954; Gandhi 1960a; Sarode and Kamat 1984; Kumawat et al. 2008
50	*Gomphonema gracile* Ehr. v. *major* Grun.	Thomas and Gonzalves 1965b; Sarode and Kamat 1984; Kumawat et al. 2008
51	*Gomphonema gracile* Ehr. v. *naviculoides* (W.Sm.) Grun.	Gandhi 1960a; Gandhi 1962b; Sarode and Kamat 1983; Sarode and Kamat 1984; Kumawat et al. 2008
52	*Gomphonema gracile* Ehr. v. *subcapitata* Gandhi*	Sarode and Kamat 1984; Gandhi 1960a; Kumawat et al. 2008
53	*Gomphonema grovei* M.S	Gandhi 1983a†; Gandhi 1998†
54	*Gomphonema grovei* M.S v. *conspicua* Gandhi et al.*	Gandhi 1983a†; Gandhi 1998†
55	*Gomphonema grovei* M.S v. *lanceolata* Gandhi et al.*	Gandhi 1983a†; Gandhi 1998†
56	*Gomphonema grovei* M.S v. *rhomboidea* Gandhi et al.*	Gandhi 1983a†; Gandhi 1998†
57	*Gomphonema hebridense* Ehr.	Gandhi 1970; Sarode and Kamat 1980; Sarode and Kamat 1983 ; Sarode and Kamat 1984; Prasad and Srivastava 1992; Kumawat et al. 2008

Table 1 continued.

	Species name	Reference
58	*Gomphonema intermedium* Hust.	Prasad and Srivastava 1992
59	*Gomphonema intricatum* Kütz.	West and West 1907; Abdul-Majeed 1935; Krishnamurthy 1954; Gandhi 1958a; Gandhi 1960a; Gandhi 1983a†; Gandhi 1985†; Sarode and Kamat 1984; Gandhi 1998†
60	*Gomphonema intricatum* Kütz. v. *dichotoma* (Kütz.) Grun.	Gandhi 1983a†; Gandhi 1985†; Gandhi 1998†
61	*Gomphonema intricatum* Kütz. v *vibrio* Cl. f. *subventricosa* Gandhi*	Gandhi 1962b
62	*Gomphonema intricatum* Kütz. v. *bohemicum* (Reich. et Fricke) A.Cl.	Gandhi 1958a; Sarode and Kamat 1984
63	*Gomphonema intricatum* Kütz. v. *fossile* Pant.	Sarode and Kamat 1980; Sarode and Kamat 1983; Sarode and Kamat 1984
64	*Gomphonema intricatum* Kütz. v. *pumila* Grun.	Singh 1962; Sarode and Kamat 1984
65	*Gomphonema intricatum* Kütz. v. *pusillum* May.	Sarode and Kamat 1983; Gandhi 1970; Prasad and Srivastava 1992
66	*Gomphonema intricatum* Kütz. v. *vibrio* (Ehr.) Cl.	Venkataraman 1939; Gandhi 1959b; Gandhi 1960a; Sarode and Kamat 1980; Sarode and Kamat 1984; Kumawat et al. 2008
67	*Gomphonema lacus-rankala* Gandhi*	Gandhi 1958a; Gandhi 1964; Srinivasan 1965; Sarode and Kamat 1984; Gandhi 1998
68	*Gomphonema lacus-rankala* Gandhi v. *gracilis* Gandhi*	Gandhi 1962b; Gandhi 1964; Gandhi 1967; Gandhi 1970; Sarode and Kamat 1980; Sarode and Kamat 1984; Gandhi 1998; Kumawat et al. 2008
69	*Gomphonema lacus-rankala* v. *chandolensis* Gandhi*	Gandhi 1964; Gandhi 1998; Kumawat et al. 2008
70	*Gomphonema lacus-rankala* Gandhi v. *robusta* Gandhi*	Gandhi 1958a; Sarode and Kamat 1980; Sarode and Kamat 1983; Sarode and Kamat 1984; Gandhi 1998; Kumawat et al. 2008
71	*Gomphonema lapponicum* A.Cleve	Kumawat et al. 2008
72	*Gomphonema lanceolatum* Ehr.	Grunow 1865; Carter 1926; Venkataraman 1939; Gandhi 1958a; Gandhi 1959c; Gandhi 1960a; Gandhi 1960b; Gandhi 1962a; Gandhi 1962b; Gandhi 1964; Gandhi 1966; Gandhi 1967; Gandhi 1983a†; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992; Kumawat et al. 2008
73	*Gomphonema lanceolatum* Ehr. v. *insingis* (Greg.) Cl.	Venkataraman 1939; Gandhi 1955; Gandhi 1960a; Gandhi 1966; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992
74	*Gomphonema lanceolatum* Ehr. f. *turris* (Ehr.) Hust.	Gandhi 1959b
75	*Gomphonema lanceolatum* Ehr. v. *affine* (Kütz.) A.Cl.	Gandhi 1957b; Gandhi 1960b; Sarode and Kamat 1984
76	*Gomphonema lingulatum* Hust.	Gandhi 1960a; Sarode and Kamat 1984
77	*Gomphonema longiceps* Ehr.	Krishnamurthy 1954
78	*Gomphonema longiceps* Ehr. v. *subclavata* Grun.	Krishnamurthy 1954; Sarode and Kamat 1983
79	*Gomphonema longiceps* Ehr. v. *subclavata* Grun. f. *gracilis* Venkataraman*	Venkataraman 1956
80	*Gomphonema macropunctatum* Krishnamurthy*	Krishnamurthy 1954; Srinivasan 1965
81	*Gomphonema magnifica* Gandhi*	Gandhi 1960a; Srinivasan 1965; Sarode and Kamat 1984; Kumawat et al. 2008

82	*Gomphonema magnifica* Gandhi v. *rhomboida* Gandhi*	Gandhi 1960a; Sarode and Kamat 1984
83	*Gomphonema major* A.Cl.F. *unipuncta* A.Cl.	Thomas and Gonzalves 1965c
84	*Gomphonema martini* Fricke	Sarode and Kamat 1984; Gandhi 1960a
85	*Gomphonema moniliforme* Gandhi*	Gandhi 1960a; Srinivasan K.S. 1965; Sarode and Kamat 1984
86	*Gomphonema montanum* Schum	Gandhi 1960a; Gandhi 1964; Sarode and Kamat 1984
87	*Gomphonema montanum* Schum v. *acuminatum* May.	Gandhi 1956; Gandhi 1960a; Gandhi 1960b; Gandhi 1964; Gandhi 1967; Sarode and Kamat 1980; Sarode and Kamat 1983; Sarode and Kamat 1984; Gandhi 1998; Kumawat et al. 2008
88	*Gomphonema montanum* Schum v. *acuminatum* May. f. *indicum* Sarode et Kamat*	Sarode and Kamat 1984; Kumawat et al. 2008
89	*Gomphonema montanum* Schum v. *acuminatum* May. f. *maharashtrensis* Sarode et Kamat*	Sarode and Kamat 1980; Sarode and Kamat 1984
90	*Gomphonema nagpurense* Sarode et Kamat*	Sarode and Kamat 1984
91	*Gomphonema olivaceoides* Hust.	Sarode and Kamat 1984
92	*Gomphonema olivaceum* (Lung.) Kütz.	Biswas 1936; Krishnamurthy 1954; Gandhi 1958a; Gandhi 1960a; Singh 1962; Singh 1963 Sarode and Kamat 1980; Gandhi 1985†; Sarode and Kamat 1984; Prasad and Srivastava 1992
93	*Gomphonema olivaceum* (Lyng.) Kütz. v. *calcarea*	Krishnamurthy 1954;
94	*Gomphonema olivaceum* (Lyng.) Kütz. v. *balticum* Cl.	Krishnamurthy 1954; Gandhi 1956
95	*Gomphonema olivaceum* (Lyng.) Kütz. v. *genuinum* Mayer. f. *minutula* Mayer	Kumawat et al. 2008
96	*Gomphonema oregonicum* Ehr.	Grunow 1865
97	*Gomphonema parvulum* (Kütz.) Grun.	Grunow 1865; Skvortzow 1935; Venkataraman 1939; Gandhi 1955; Gandhi 1957a; Gandhi 1958b; Gandhi 1959a; Gandhi 1959c; Gandhi 1960a; Gandhi 1960b; Singh 1961; Gandhi 1962a; Gandhi 1966; Gandhi 1967; Sarode and Kamat 1980; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992; Gandhi 1998; Kumawat et al. 2008
98	*Gomphonema parvulum* (Kütz.) Grun. v. *lagenula* (Grun.) Hust.	Gandhi 1960a; Gandhi 1962b; Gandhi 1966; Sarode and Kamat 1983; Sarode and Kamat 1984; Kumawat et al. 2008
99	*Gomphonema parvulum* (Kütz.) Grun. v. *micropus* (Kütz.) Cl.	Gandhi 1960a; Gandhi 1960b; Gandhi 1962b; Gandhi 1966; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992
100	*Gomphonema parvulum* (Kütz.) Grun. v. *subellipticum* Cl.	Gandhi 1956; Gandhi 1957a; Gandhi 1958b; Gandhi 1960a; Gandhi 1960b; Gandhi 1966; Sarode and Kamat 1983; Sarode and Kamat 1984; Kumawat et al. 2008
101	*Gomphonema parvulum* (Kütz.) Grun. v. *subcapitata* V.H.	Venkataraman 1957
102	*Gomphonema parvulum* (Kütz.) v. *exlissma* Grun.	Gandhi 1959c; Gandhi 1962b; Gandhi 1964; Gandhi 1967; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992; Gandhi 1998; Kumawat et al. 2008;
103	*Gomphonema parvulum* (Kütz.) V.H. v. *genuinium* May.	Gandhi 1956

Table 1 continued.

	Species name	Reference
104	*Gomphonema punctatum* Krasske	Kumawat et al. 2008
105	*Gomphonema saravanthense* Gandhi*	Gandhi 1970
106	*Gomphonema sphaerophorum* Ehr.	Krishnamurthy 1954; Gandhi 1957a; Gandhi 1958b; Gandhi 1959c; Gandhi 1960a; Gandhi 1964; Srinivasan 1965; Gandhi 1966; Sarode and Kamat 1980; Sarode and Kamat 1983; Sarode and Kamat 1984; Prasad and Srivastava 1992; Kumawat et al. 2008
107	*Gomphonema sphaerophorum* Ehr. v. *kolhapurense* Sarode et Kamat*	Sarode and Kamat 1984; Kumawat et al. 2008
108	*Gomphonema sphaerophorum* Ehr. v. *subcapitata* Venkatraman*	Venkataraman 1939; Thomas and Gonzalves 1965a
109	*Gomphonema sphaerophorum* f. *jogensis* Gandhi*	Gandhi 1966
110	*Gomphonema spiculoides* Gandhi*	Srinivasan 1965; Gandhi 1960a; Sarode and Kamat 1984
111	*Gomphonema spiculoides* Gandhi v. *major* Gandhi*	Gandhi 1960a; Sarode and Kamat 1984
112	*Gomphonema subapicatum* Fiitsch et Rich v. *okamurae* (Skv) Gandhi	Gandhi 1960a; Sarode and Kamat 1984
113	*Gomphonema subapicatum* Fritsch et Rich	Abdul-Majeed 1935; Gandhi 1956; Gandhi 1958a; Gandhi 1960a; Gandhi 1960b; Gandhi 1962b; Gandhi 1964; Gandhi 1966; Gandhi 1967; Sarode and Kamat 1984; Gandhi 1998
114	*Gomphonema subcapitatum* v. *curta* Fritsch et Rich	Abdul-Majeed 1935
115	*Gomphonema subclavatum* Grun.	Carter 1926; Abdul-Majeed 1935
116	*Gomphonema submalayense* Gandhi*	Gandhi 1970
117	*Gomphonema substicature* Fritsch v. *stipitata*	Abdul-Majeed 1935
118	*Gomphonema subtile* Ehr.	Gandhi 1958b; Gandhi 1962a; Gandhi 1966; Sarode and Kamat 1984
119	*Gomphonema subtile* Ehr. v. *malayensis* Hust.	Gandhi 1960a; Gandhi 1966; Gandhi 1970; Sarode and Kamat 1984; Prasad and Srivastava 1992
120	*Gomphonema subventricosum* Hust.	Gandhi 1962a; Gandhi 1966; Sarode and Kamat 1984; Prasad and Srivastava 1992
121	*Gomphonema sumatrense* Fricke	Gandhi 1960a; Sarode and Kamat 1984
122	*Gomphonema tenellum* W.Sm.	Dickie G 1882; West and West 1907; Gandhi 1998
123	*Gomphonema tenuis* Gandhi*	Gandhi 1960a; Srinivasan 1965; Sarode and Kamat 1984
124	*Gomphonema tergestinum* (Grun.) Frickie	Krishnamurthy 1954
125	*Gomphonema tropicale* Brun	Gandhi 1959b
126	*Gomphonema turris* Ehr.	Ehrenberg 1845; Grunow 1865
127	*Gomphonema undulatum* Hust.	Gandhi 1960a; Sarode and Kamat 1984
128	*Gomphonema varanasis* Singh*	Singh 1961
129	*Gomphonema vastum* Hust *v elongata Skv.*	Gandhi 1958b
130	*Gomphonema vidarbhense* Sarode et Kamat*	Sarode and Kamat 1984

Naphrax mounting medium and observed with Olympus BX-51 light microscopes equipped with DIC and 1.4NA objectives. Digital images were taken with an Olympus DP-71 digital camera. Scanning electron microscopy was done with cleaned specimens air dried onto cover glasses, attached to aluminum stubs, sputter-coated with 10 nm of Au-Pd, and examined in high vacuum mode with a JSM-6480LV (LVSEM) at 15 kV, with a spot size of 15, and a working distance of 8 mm. SEM work was performed at the University of Colorado's Nanomaterials Characterization Facility. In India, SEM work was accomplished with cleaned material air-dried onto cover glasses and sputter coated with ca. 10 nm of Au-Pd. Coated material was viewed in a FEI Quanta 200 ESEM at Indian Institute of Science Nanoscience Initiative Facility. Terminology on the diatom valves follows Ross et al. (1979). For features found in the gomphonemoid diatoms, we follow the terminology and character descriptions of Kociolek & Stoermer (1993). Water chemistry analysis were carried out as per the Standard methods for water and waste water analysis by American Public Health Association (APHA, 2005)

Results

Gomphonema gandhii Karthick & Kociolek, **sp. nov.** Figs 2–19

Descriptio: Valvae lineares ad lineares-lanceolatae clavatae apicibus rotundatis ad anguste-rotundatis ad fere acuminatae capitolo-polo. Area apicalis porellorum distincta ad baso-polo. Frustula aspectu cincturae cuneata. Striae continuae circa capitulum-polum. Longitudo 19–51 µm. Latitudo 3–7 µm. Area axialis lata linearis-lanceolata. Area centralis indistincta. Raphe lateralis undulata. Extrema proximales externi raphis dilatatae. Externum orificium stigmatis rotundatis. Striae punctatae leviter radiatae ad parallelae, 9–11/10 µm. Septa et pseudosepta prasentia ad polos.

Description: Valves linear- to linear-lanceolate-clavate, with apices rounded to narrowly-rounded to nearly acuminate at the headpole. Apical pore field distinct at the footpole. Frustules cuneate, striae are continuous around the headpole. Length 19–51 µm, breadth 3–7 µm. Axial area broad, linear-lanceolate. No distinct central area. Raphe lateral, undulate. External proximal raphe ends dilated. Stigmal opening is round. Striae are punctate, slightly radiate to parallel, 9–11/10 µm. Septa and pseudosepta are present at the poles.

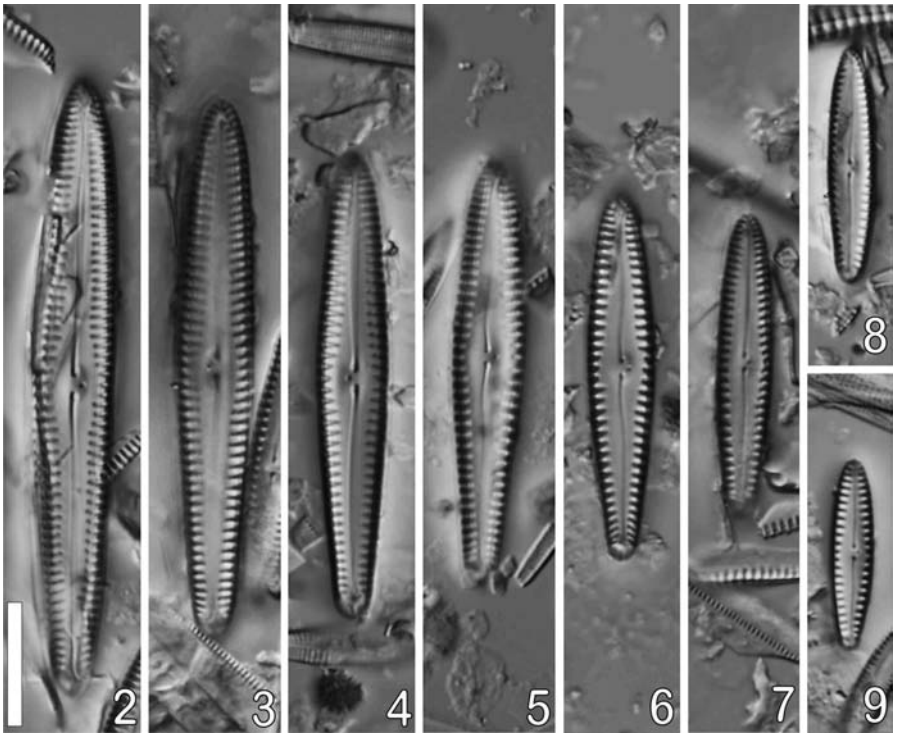
Holotype: CESH-5-1869, Centre for Ecological Science Herbarium Diatom Collection, Indian Institute of Science, Bangalore, INDIA.

Isotypes: BM 101392. The Natural History Museum, Department of Botany, London, UK and Diatom Collection, University of Colorado, Boulder, USA

Type Locality: A Stream at Kammani (14°42' 47.52"N–74°35' 44.988"E); Altitude 109 m asl (meters above sea level), a tributary Bedthi River. Uttara Kannada District, Karnataka, India. (leg. Karthick, B. and D.M.Vishnu, January 2006)

Etymology: Named in honor of H.P.Gandhi, for his outstanding contributions to diatom research in India.

In the SEM, the exterior of the valve is dominated by areolae with flaps that form c-shaped openings (Figs 10–13). The undulate raphe has dilated proximal ends, while the external ends are deflected onto the mantle in the same direction (opposite the side bearing the stigma) (Figs 10, 13). The external stigmal opening is small and round (Figs 10, 12). The apical pore field is separated from the striae, and composed of rounded porelli (Figs 10, 13, 15). Internally, a small central nodule, relatively large helictoglossae, pseudosepta and the raphe slit are visible (Figs 16, 17, 18, and 19). The central nodule has highly recurved raphe ends that terminate as tight loops. A flap extends from each side of the central nodule, obscuring part of the curvature

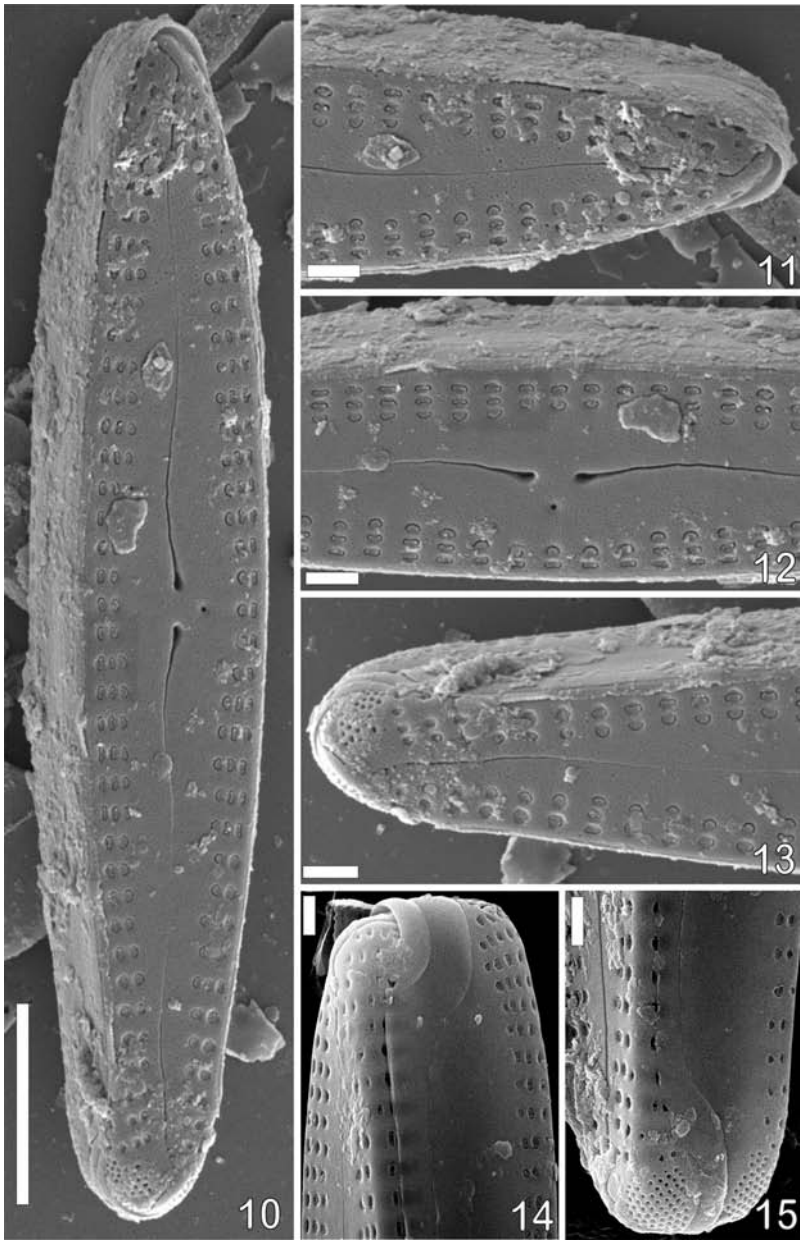


Figs 2–9. LM of *Gomphonema gandhii,* from the type population; valve views showing the size diminution series. Scale bar represents 10 µm.

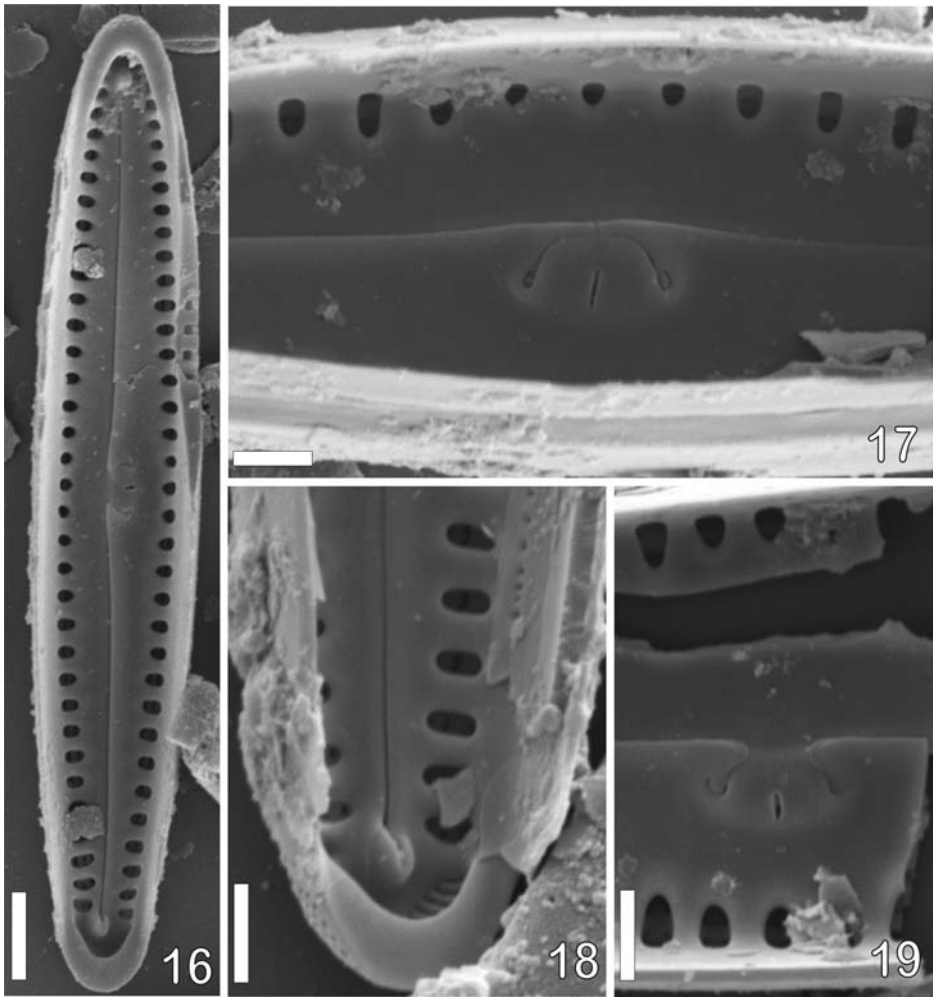
of the raphe (Figs 16, 17, 19). A slit-like stigmal opening is present on the small central nodule (Figs 16, 17, 19). On either side of the valve interior, marginal laminae are present (Figs 16). Helictoglossae appear to be in line with each raphe branch (Figs 16, 18).

In girdle view, the apical pore field porelli are round, extending from the edge of the valve face and to the end of the mantle (Fig. 15). Bands are of the open type, and narrow; they follow the contour of the valve in girdle view. At the headpole the distal raphe end can be seen extending onto the mantle (Fig. 14). Areolae appear sunken into ellipsoidal depressions, in each of which is a flap (Figs 14, 15).

This species resembles both *G. pararhombicum* Reichardt, Jüttner & Cox and *G. incognitum* Reichard, Jüttner & Cox (Jüttner et al. 2004, p. 238). All three taxa have a similar valve outline and wide axial area. *Gomphonema gandhii* is more slender, has a narrower headpole and coarser striae than either of the species described from Nepal. The expanded concept of *G. incognitum* suggested by Reichardt (2005) is difficult to embrace, since specimens with very different valve shapes, sizes and striae densities have been considered conspecific. Coarser striae and more slender valves also distinguish *G. gandhi* from *G. siamense* Reichardt, and valve shape



Figs 10–15. SEM. External view of *Gomphonema gandhii.* Fig. 10. Exterior view of whole valve. Fig. 11. Exterior of valve, headpole, with the external distal raphe end curving onto the valve mantle. Fig. 12. Exterior of valve center showing the stigma, dilated proximal raphe end and striae. Fig. 13. Exterior of valve showing the deflected apical end of raphe and rounded porelli. Fig. 14. Girdle view of the head pole showing the distal raphe end extending on to the mantle. Fig. 15 Girdle view of the foot pole with round apical pore field porelli. Scale bar represents 5μm (Fig. 10); 1 μm (Figs 11, 12, 13, 14, 15).



Figs 16–19. SEM. Internal view of *Gomphonema gandhii*. Fig. 16. Interior view of the whole valve showing the central nodule, large helictoglossae, pseudosepta and raphe slit. Fig. 17. Interior view of the center showing the central nodule, curvature of raphe and slit like stigmal opening. Fig. 18. Internal view showing the helictoglossae, pseudosepta and raphe slit. Fig. 19. Internal view of center showing the curvature of the raphe and slit-like stigmal opening. Scale bar represents 2 μm (Fig. 16); 1 μm (Figs 17, 18, 19).

(lacking the cuneate headpole) and coarser striae separate the Indian species from *G. uniserhombicum* Reichardt (2005).

Ecology: *Gomphonema gandhii* is found throughout the central Western Ghats rivers. This species is present throughout the year, reaching maximum relative abundance (60%) in September. The population of this species increases in winter season (Oct–Jan). This species occurs in abundance in many hill streams of central Western

Table 2. Water Chemistry Characteristics (Mean ± Standard Deviation) for the type localities measured from January to December 2006.

Water Chemistry Characters (Units)	Kammani	Andhalli
pH	7.08±0.17	7.16±0.27
Water Temperature (°C)	26.66±2.20	24.96±1.90
Electrical Conductivity (μScm^{-1})	89.86±26.18	79.71±11.12
Total Dissolved Solids (mgl^{-1})	44.62±13.09	39.63±5.78
Air Temperature (°C)	30.54±2.94	26.25±2.97
Free Carbon di oxide (mgl^{-1})	8.53±3.02	9.83±3.55
Alkalinity (mgl^{-1})	33.27±16.29	47.00±42.67
Chlorides (mgl^{-1})	13.00±3.17	14.82±3.19
Hardness (mgl^{-1})	33.78±14.38	28.87±4.16
Calcium (mgl^{-1})	7.32±3.34	6.63±1.37
Magnesium (mgl^{-1})	6.46±2.75	5.43±1.04
Dissolved Oxygen (mgl^{-1})	7.88±1.40	6.83±2.54
Phosphates (mgl^{-1})	0.04±0.02	0.08±0.08
Nitrates (mgl^{-1})	0.29±0.37	1.12±1.87
Sulphates (mgl^{-1})	8.58±3.00	21.09±26.94
Sodium (mgl^{-1})	7.62±2.26	13.59±1.85
Potassium (mgl^{-1})	1.64±0.60	3.15±1.17

Ghats region. This species occurs in circumneutral streams (pH: 7.08 ± 0.17) with poor nutrients (Phosphate: 0.04 ± 0.02 mgl^{-1}; Nitrates: 0.29 ± 0.37 mgl^{-1}) and conductivity between 89.86 ± 26.18 μScm^{-1} (see Table 2). The land cover in the catchment is characterized with wet evergreen to semi-evergreen forest type, and with least agricultural activities.

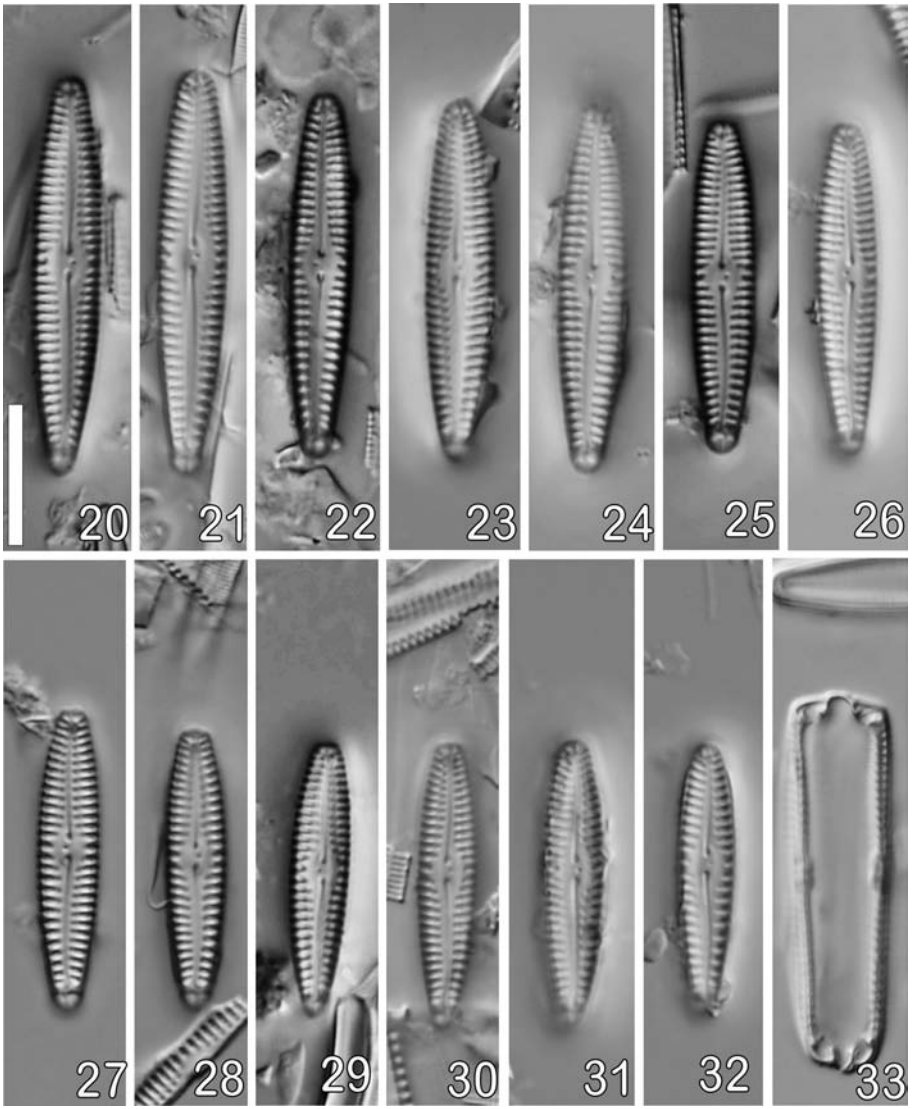
Gomphonema difformum Karthick & Kociolek, **sp. nov.** Figs 20–40

Descriptio: Valvae linearers-clavatae apicibus late rotundatibus ad quadratis ad capitolo-polo. Area apicalis porellorum distincta ad bsao-polo. Frustula cuneatum. Striae non-continuae circa capitulum-polum. Longitudo 19–32 µm. Latitudo 4–6 µm. Area axialis angusta dilatatescens dilute, faciens aream centralem linearem-ellipticalem. Raphe lateralis, dilute undulata. Extrema proximales externi raphis distincte dilatata. Striae aspectu costae, parallelae ad dilute radiatae 12–14/10 µm. Externum orificium stigmatis parvum rotundatis praesens in aream centralem. Area bilobata unornata ad capitolo-polo. Septa et pseudosepta prasentia ad polos.

Description: Valves linear-clavate, apices broadly rounded to quadrate at the headpole. Apical pore field distinct at the footpole. Frustules cuneate. Striae do not appear continuous around headpole. Length 19–32 µm, breadth 4–6 µm. Axial area narrow, expanded slightly to form a linear-elliptical central area. Raphe lateral, weakly undulate. External proximal raphe ends distinctly dilated. Striae appear costate, parallel to weakly radiate, 12–14/10 µm. A small round stigmal opening is present in the central area. A bilobed unornamented area is present at the headpole. Septa and pseudosepta are present at both poles.

Holotype: CESH-5-1870, Centre for Ecological Science Herbarium Diatom Collection, Indian Institute of Science, Bangalore, INDIA

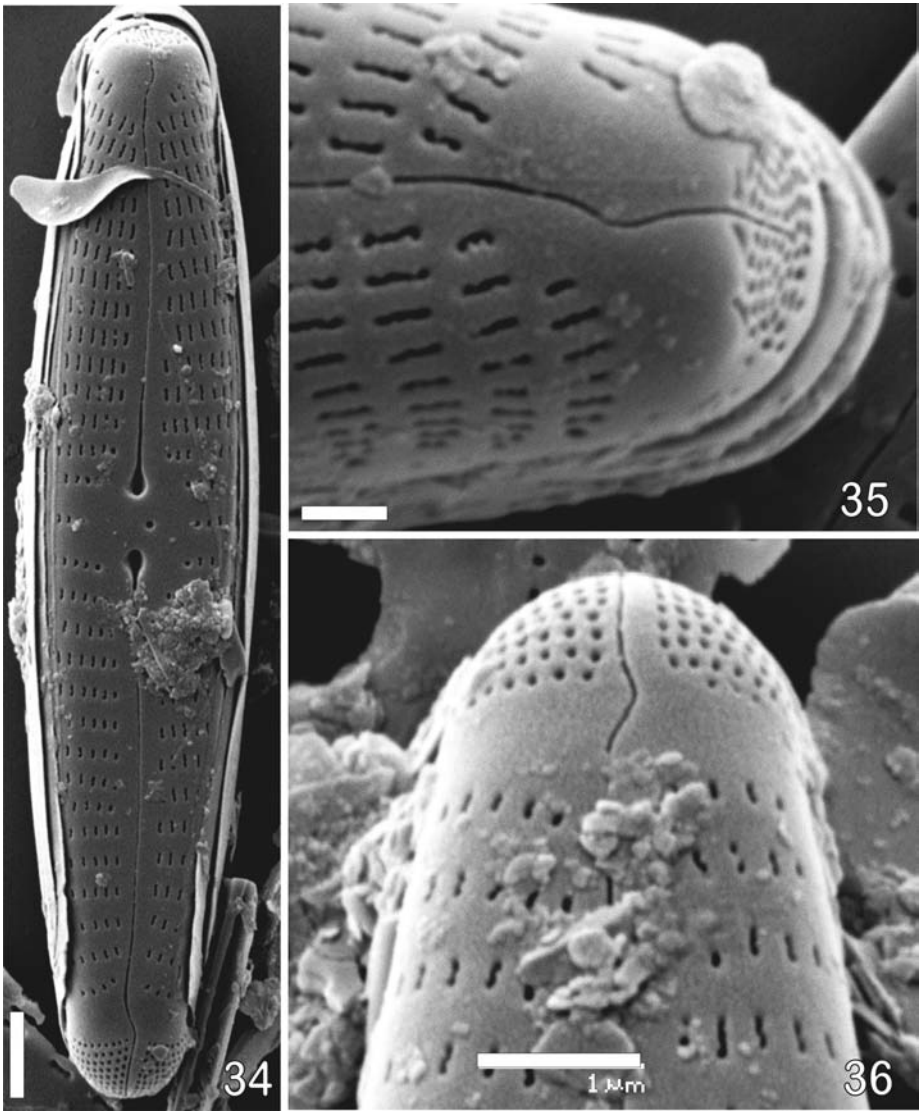
Isotypes: BM 101393, The Natural History Museum, Department of Botany, London, UK. And Diatom Collection, University of Colorado, Boulder, USA.



Figs 20 –32. LM of *Gomphonema difformum,* from the type population; valve view showing the size diminution series. Figure 33. Girdle view showing apical pore field like structures at both apices. Scale bar represents 10 µm.

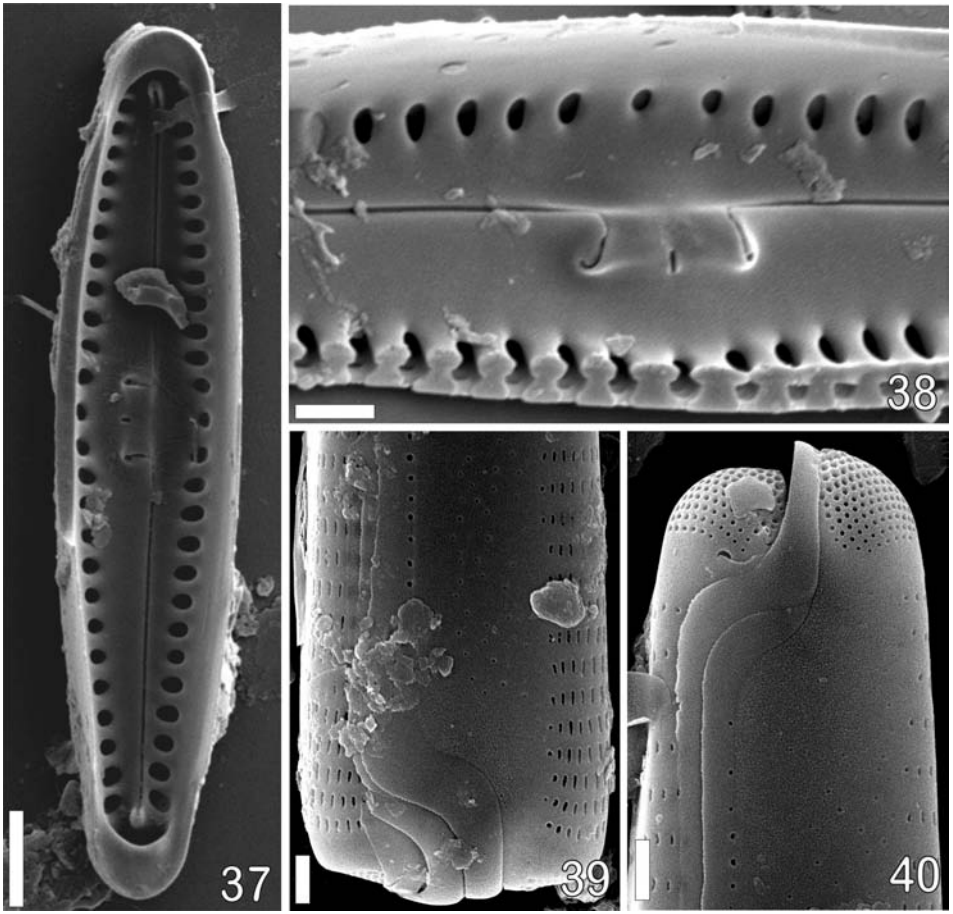
Type Locality: A Stream at Andhalli (14°40'12.1794"N–74°48'5.904"E; Altitude 483 mtrs above MSL), a tributary Bedthi River. Uttara Kannada District, Karnataka, India. (leg. Karthick, B. and D.M.Vishnu -12th, January, 2006)

Etymology: The species epithet indicates the very different structure of this diatom relative to other members of the genus.



Figs 34–36. SEM. External view of *Gomphonema difformum.* Fig. 34. Exterior view of whole valve showing slit-like areolae, round stigma opening and undulate raphe with dilated proximal ends. Fig 35. Exterior view of the valve showing blunt headpole. Fig 36. Exterior view of the valve showing raphe bends onto the mantle, porelli and hyaline area which separates porelli from areolae. Scale bar represents 2 µm (Fig. 34); 1 µm (Fig. 36); 0.5 µm (Fig. 35)

In the SEM, the valve exterior is dominated by slit-like areolae, a slightly undulate raphe with dilated proximal ends and a bilobed apical pore field (Figs 34–36). The central area has large, tear-dropped shaped proximal raphe ends and a small, round



Figs 37–40. SEM. Interior and girdle view of *Gomphonema difformum.* Fig. 37. Interior view of the whole valve showing pseudosepta at both ends and large helictoglossae. Fig. 38. Interior view showing the central nodule with broadly recurved proximal raphe ends, rounded stigmal opening and marginal lamina. Fig. 39. Girdle view showing randomly distributed porelli on the mantle Fig. 40. Girdle view showing the open type bands with septa. Scale bar represents 2 μm (Fig. 37); 1 μm (Figs 38, 39, 40).

stigmal opening (Fig. 34). The apical pore field is composed of round porelli that are both physically separated and morphological distinct from the areolae (Figs 34, 36). The headpole looks blunt, where the interface between the valve face and mantle is abrupt (Figs 34, 35). The raphe bends onto the mantle, and bisects a group of porelli-like pores that are both physically separate and morphologically differentiated from the areolae (Figs 34, 36). Porelli extend from the valve face onto the mantle (Figs 34, 36, 40). Internally, the proximal raphe ends are broadly recurved on a central nodule that appears composed of two internally-elevated sections. Between the sections is situated a rounded stigmal opening (Figs 37, 38). Along the mantle on each side is a marginal lamina (Fig. 38). Helictoglossae are relatively large, and the

one positioned at the headpole is usually offset from the raphe branch (Fig. 37). Pseudosepta are visible at each pole (Fig. 37).

In girdle view the mantle has round porelli randomly distributed across it. Bands are of the open type, with the closed ends also bearing septa (Figs 39, 40). The bands follow the valve outline in girdle view.

This taxon resembles *Gomphonema kaznakowi* Meresch. in that the headpole looks similar in structure to the footpole. In both *G. kaznakowi* and G. *difformum*, the headpole striae are physically separated from the striae. In *G. difformum*, the headpole has porelli-like openings, very similar to the porelli of the apical pore field at the footpole; this condition is not seen in *G. kaznakowi* (Kociolek 1996; Li et al. 2006).

ECOLOGY: *Gomphonema difformum* is known only from the type locality. This species is present throughout the year with relative abundance of 20% and less. This species occurred in a stream with neutral pH (7.16 ± 0.27), poor nutrients (Phosphate: 0.04 ± 0.02 mgl^{-1}; Nitrates: 0.29 ± 0.37 mgl^{-1}) and conductivity between 79.71 ± 11.12 μScm^{-1} (see Table 2). The land cover in the catchment is characterized with wet evergreen to semi-evergreen forest type with moderate agricultural activities.

Gomphonema diminutum Karthick & Kociolek, **sp. nov.** Figs 41–51

DESCRIPTIO: Valvae anguste lineares-clavatae apicibus rotundatibus. Longitudo 21–27 µm. Latitudo 3–4 µm. Area axialis angusta linearis. Area centralis indistinctis. Raphe lateralis undulata. Externum orificium stigmatis rotundatis. Area apicalis porellorum distincta bilobata. Septa et pseudosepta praesentia ad polos.

DESCRIPTION: Valves narrowly linear-clavate with apices rounded. Length 21–27 µm, breadth 3–4 µm. Axial area narrow, linear. Central area indistinct. Raphe lateral, undulate. External proximal raphe ends dilated. A round stigmal opening is present. Striae are parallel to radiate, 16–17/10 µm. Apical pore field evident, bilobed. Septa and pseudosepta are present at the poles.

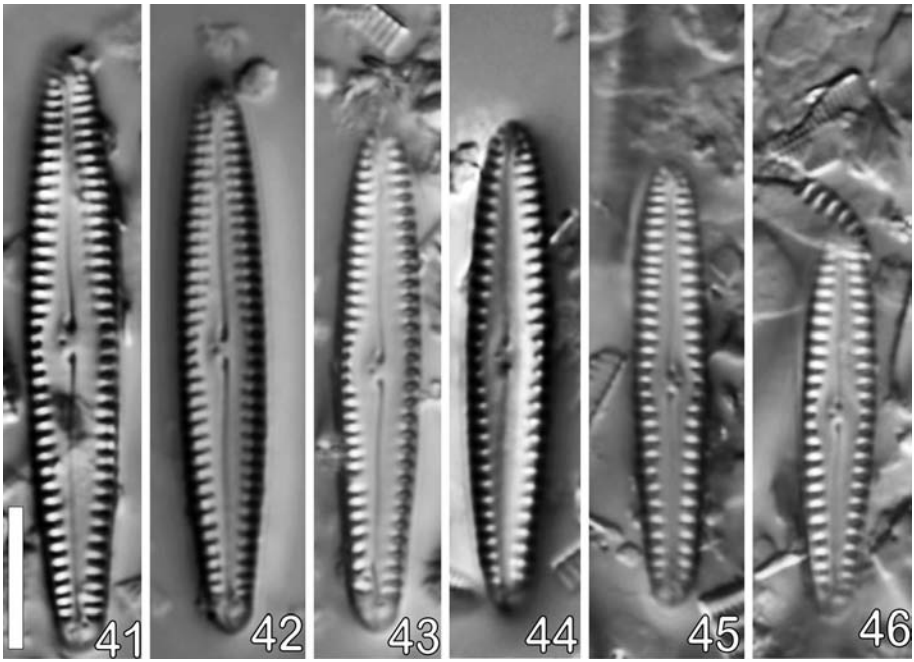
HOLOTYPE: CESH-5-1871, Centre for Ecological Science Herbarium Diatom Collection, Indian Institute of Science, Bangalore, INDIA

ISOTYPES: BM 101394, The Natural History Museum, Department of Botany, London, UK. Diatom Collection, University of Colorado, Bolder, USA

TYPE LOCALITY: A Stream at Kammani (14°42'47.52"N–74°35'44.988"E); Altitude 109 m asl, a tributary Bedthi River. Uttara Kannada District, Karnataka, India. (leg. Karthick, B. and D.M.Vishnu, January, 2006).

ETYMOLOGY: The species is named for its small size.

In the SEM, the valve exterior has areolae that are slit- or c-shaped on the valve face, but on the mantle striae are composed of two rows of rounded areolae (Figs 47, 48). The raphe appears slightly undulate with enlarged proximal raphe ends. A small, round external stigmal opening is present in the central area (Figs 47, 48). At the footpole, the apical pore field is physically offset from the areolae by a hyaline border. Porelli are round, sembling in size and shape the last stria near the hyaline area. At the headpole areolae are rounded and in double rows, like those on the mantle (Figs 47 and 49). Internally, the central nodule is bilobed, hosting the broadly recurved proximal raphe ends. In the middle of the central nodule is placed an



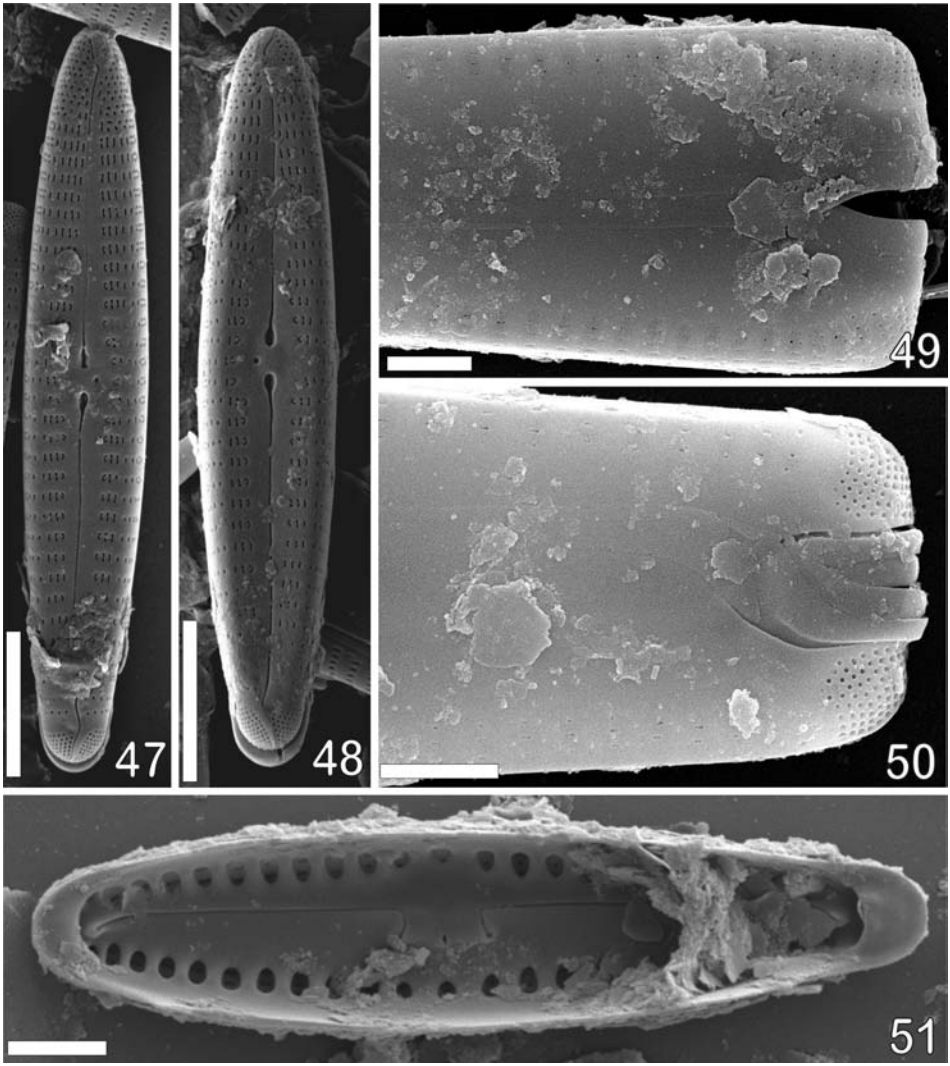
Figs 41–46. LM of *Gomphonema diminutum,* from the type population; valve view showing the size diminution series. Scale bar represents 10 µm.

ellipsoidal stigmal opening (Fig. 51). Marginal laminae are present on each side of the valve (Fig. 51). Helictoglossae at the headpole and footpole are offset from the raphe branches. Pseudosepta are present at the poles (Fig. 51).

In girdle view the mantle of the valve has striae with areolae that terminate as slits or in double rows of punctate striae. Striae have round areolae at the headpole (Fig. 49). At the footpole the round apical pore field porelli extend onto to the end of the mantle (Fig. 50). Girdle bands are of the open type, following the contour of the valve. Closed ends of the bands possess septa.

Gomphonema diminutum resembles *G. incognitum* Reichardt, Jüttner & Cox in Jüttner et al. (2004, p. 245) in size range and having a wide axial area. The species from India is linear in shape, is narrower and has finer striae than the species described from Nepal. Superficial resemblance in terms of having a broad axial area exists between *G. diminutum* and *G. schweickerdtii* Cholnoky (which was, in part, recently suggested to be conspecific with *G. clevei* Fricke, Reichardt 2005), but the Indian species is longer but narrower than the South African taxon (Cholnoky 1953).

Ecology: *Gomphonema diminutum* was found in many central Western Ghats Rivers. This species was present throughout the year with relative abundance ranging from 20–40%. This species occurred in a stream with circumneutral pH (7.08 ± 0.17), poor nutrients (Phosphate: 0.04 ± 0.02 mgl^{-1}; Nitrates: 0.29 ± 0.37 mgl^{-1}) and



Figs 47–51. SEM. Exterior, Interior, Girdle view of whole valve of *Gomphonema diminutum.* Figs 47–48. Exterior view of whole valve showing slit or c-shaped areolae, mantle striae with two rows of rounded areolae, hyaline border, a stigmal opening and proximal raphe ends. Fig. 49. Girdle view of the valve showing doubly punctate striae with rounded areolae at headpole. Fig. 50. Girdle view of the valve showing open type girdle bands and closed ends of bands with septa. Fig 51. Internal view of the valve showing central nodule with stigmal opening, marginal laminae, pseudosepta and helictoglossae at both the poles. Scale bar represents 5 µm (Figs 47, 48); 2 µm (Fig. 51); 1 µm (Figs 49, 50).

conductivity between 89.86 ± 26.18 μScm^{-1} (see Table 2). The land cover in the catchment is characterized with wet evergreen to semi-evergreen forest type with the least agricultural disturbance.

Discussion

Our work on the present group of species contributes to a growing opinion that endemism in freshwater diatoms, particularly those based in Southern Hemisphere locations, may be much more common than was previously thought (e.g., Mann & Droop 1996, Mann 1999, Kociolek & Spaulding 2000, Kociolek & Stoermer 2001, Kilroy et al. 2003, Vanormelingen et al. 2008). However, recent taxonomic work on selected diatom taxa from Himalayas (Jüttner et al. 2004) and the current study has led to the recognition of an increasing number of endemic taxa in the freshwater diatom flora of the Indian subcontinent, particularly biodiversity hotspots like Western Ghats and Eastern Himalayas. Based on unpublished work by Karthick (Ph.D. Dissertation on Ecology of Stream Diatom Community in Central Western Ghats, to be submitted to Mysore University), some of the *Gomphonema* species found in the Western Ghats are widespread on other continents, but a few others, particularly those in streams of Western Ghats, seem to have limited geographical distributions. India has a diverse flora, but there is still a lot to do to document and create a more substantial understanding of this large and complex country. The three new species presented here occur in several environments, and are the dominants or represent a large proportion of the diatoms present in the collections. While there have been many (over 100) *Gomphonema* taxa reported from India, it still does not approach the number recorded from the intensely studied continent of Europe (e.g. Krammer & Lange-Bertalot 1986, e.g. Reichardt 1999) or the little studied country of the USA (Kociolek 2005, lists 237 *Gomphonema* taxa reported in the literature).

Of the three new species, *G. difformum* is quite different from almost all other *Gomphonema* species. Of particular note is the presence of what appears to be apical pore fields at both the headpole and footpole. Our observations illustrate at the headpole, groups of pores on the mantle at either side of the external distal raphe end that are separate from and quite dissimilar to the areolae. Their oblong to rounded appearance is more similar to the porelli of the apical pore fields at the footpole than the slit-like areolae found in *G. difformum*. Structures similar to apical pore fields at the headpole are also seen in *G. kaznakowi*, described from high mountain sites from China (Mereschkowsky 1906). Kociolek (1992) showed with electron microscopy that hyaline areas at the headpole of this species were composed of densely arranged areolae, that were physically separate from valve face areoale, but not structurally differentiated from nor more compact (at least in terms of the porelli found at the footpole) than the valve areolae. *Gomphonema difformum* differs from *G. kaznakowi* by a number of features, most notably by possessing a stigma and having external proximal raphe ends that are quite dilated. *Gomphonema gandhii* has a unique feature, namely the presence of a hood or siliceous fold over the central nodule, the edge of which is suggestive of the internal proximal raphe ends. In this feature it looks very similar to *Gomphocymbella* species from the East African Rift Valley lakes (Kociolek & Stoermer 1993); the feature is found in no other freshwater gomphonemoid diatoms. *Gomphonema diminutum* seems to be closely allied with species described from the Himalayas, though more work is necessary to affirm their relationships. For example, though not described nor illustrated in the original work, it appears that the Himalayan species do have both septa and pseudosepta. These features have been overlooked by

many students of the genus *Gomphonema* (e.g. Patrick in Patrick & Reimer 1966, Reichardt 2005, 2007). These similarities with species from a variety of areas support the idea of biogeographic distributions that have a phylogenetic basis. Williams & Reid (2006) have addressed this issue amongst the Eunotioid diatoms. These three new species occur in oligotrophic, low conductivity, pH neutral water, whereas the commonly reported *Gomphonema* species in Southern India, such as *G. parvulum*, *G. gracile, G.affine, and G. pseudoaugur,* occur in eutrophic, alkaline and high conductivity, waters. The distribution ranges of all three species were restricted to Western Ghats streams; hence these three species appear to be endemic to Western Ghats. However studies on diatoms in peninsular India are meager and it is too early to comment on the distribution of these species.

A phylogenetic analysis based on morphological data is necessary to further confirm the relationships of these three taxa with African and Himalayan taxa. The data from fossil and contemporary faunas indicate that, throughout the late Cretaceous, India maintained biological exchanges with adjacent lands (Briggs 2003). This could be a reason for these species connection with the African and Himalayan species. The biotic components of Africa, Madagascar and Western Ghats have inspired centuries of speculation relating to the mechanisms by which these biotas came to reside in these regions, and regarding their commonalities. Most of the authors claim that the most probable causal factors are Gondwanan vicariance and/or Cenozoic dispersal (Yoder & Nowak 2006). It would be interesting to study further on diatom flora of Western Ghats in detail and compare them with Indian Ocean islands and African species to elucidate their biogeographic history.

While recent researches on diatom taxonomy from tropical regions are challenging the ubiquity hypothesis for diatoms, they also seem to confirm that diatom communities are controlled by the same processes affecting macro-organisms in a different scale (Vanormelingen et al. 2008). These studies therefore also highlight the need for conservation and the protection of unique and isolated areas, such as Western Ghats, against habitat alterations and introduction of exotic species. Thus, it is important for future studies of diatom biodiversity to include the mechanisms generating diatom species diversity and distributions. Previous reports of *Gomphonema* taxa from Western Ghats are from light microscope observations and therefore are subject to further verification. The current report improves our knowledge of status, and phylogentic relation of *Gomphonema* and the biodiversity of freshwater diatoms of Western Ghats. These current results underscore the pressing need to continue research into diatom taxonomy and ecology in least explored geographical zone on earth particularly southern hemisphere.

Acknowledgements

We thank SEM facility at University of Colorado's Nanomaterials Characterization Facility and Indian Institute of Science-Nanoscience Initiative. We are grateful to Indian Institute of Science, Ministry of Science and Technology and The Ministry of Environment and Forests, Govt. of India for the financial support and the Principal, Yuvaraja's College, Mysore, for encouragement. We thank Sameer, Vishnu, Shrikant, Sudhira, Gururaja, Alakananda and Supriya of CES, IISc, Bangalore for active interactions in the field and laboratory.

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Received 9 October 2009, accepted in revised form 8 January 2010.