



Research Article

Diatoms of the *Cymbella* sensu lato species of the two different eco-regions of the Indian Mountain Rivers.

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Abstract: This paper describes *Cymbella* sensu lato (*Cymbopleura*, *Delicata*, *Encyonema*, *Encyonopsis* and *Reimeria*) species from two different ecoregions of India. In the present study, twenty-six diatom taxa belonging to the genus *Cymbella* sensu lato were identified. In the flora nineteen species were recorded from the Vindhya region while eleven from the Himalaya. All of them were first records for the Vindhyan rivers. Seven taxa were new records for the Himalayan river.

Keywords: Central Highlands, diatoms, ecoregions, flora, India.

Introduction

The diatom classification in Round *et al.*, (1990) placed five genera in the family Cymbellaceae: *Placoneis* Mereschkowsky, *Cymbella* Agardh, *Brebissonia* Grunow, *Encyonema* Kützing, and *Gomphocymbella* Müller. Since then a number of new genera have been proposed for inclusion in Cymbellaceae based largely on differences in valve shape and symmetry, areolae and raphe structure, and other features observed under the scanning electron microscope (SEM). These new genera include *Afrocybella* Krammer (2003), *Cymbellopsis* Krammer (1997a), *Cymbopleura* Krammer (2003), *Delicata* Krammer (2003), *Navicymbula* Krammer (2003), and *Oricymba* Jüttner *et al.*, (2010). In addition, to accommodate *Encyonema*-like taxa that are symmetric or nearly symmetric with respect to the apical axis, Krammer (1997a) erected the genus *Encyonopsis* with *Navicula cesatii* Rabenhorst as the type species. Recently, a total of 15 genera and many species have been included into the *Cymbellaceae* (Guiry and Guiry 2016).

The Indian mountain streams and its adjacent countries support a diverse diatom flora (at both species and generic levels), including several new, and rarely found, *cymbelloid* taxa *Oricymba* (Jüttner *et al.*, 2010a), *Cymbopleura*, *Cymbella* (Jüttner *et al.*, 2010b), *Encyonema* and *Encyonopsis*, some of which have unusual morphological features for their respective genera. In the present paper, we present an account of the *Cymbella* sensu lato species from the Yamuna drainage in the Himalaya and Central Highlands, Vindhya rivers in particular, and some locations on the Bhagirathi, Alaknanda and Ganga rivers and their tributaries.

Study Area

The part of Gangetic drainage considered in the study originates in the West Himalaya as the Yamuna and Ganga. While most of their tributaries arise in the Himalaya some arise in the Vindhya. The Vindhya rivers Ken and Paisuni join the lower part of the Yamuna before its confluence with the Ganga and Tons joins the Ganga little downstream of this confluence. Except for this connection with the Ganga R., these two regions vary in climate by virtue of their geographic location and geomorphology.

The Vindhya rivers selected for the study were located between 23°30' to 26°N, 78°30' to 82°30'E while in the west Himalaya between 29°31' to 31°20'N latitude, 77°33' to 80°6'E longitude). The Vindhya rivers Ken, Paisuni and Tons flow north from low (north of Narmada, around Tropic of Cancer) to high latitude along southern fringe of the Indo-Gangetic Plains. The Ken and Tons were relatively larger drainage (300 to 350 km) compared to the Paisuni (100 km) having an average gradient of 0.91 m km⁻¹, 2.0 m km⁻¹ and 1.02 m km⁻¹, respectively. The land is primarily used for agriculture along the banks of the Ken and the Tons River. Patches of forest (*Shorea robusta*) occur in case of the Ken River. In case of the Paisuni river the headwaters is covered by forest and only lower stretch of the river is used for agriculture. Except for the mouth zone these rivers vary topographically (Table 1).

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Table 1. Geographical co-ordinates of the sampling stations in different rivers of the Central Highland and Himalayan region.

River system	Rivers/ Stations with acronym	Latitude (N)	Longitude (E)	Altitude (m asl)	Distance from source (Km.)	Substrate
Yamuna (lower stretch)	Ken River					
	Shahnagar K1	23°59'	80° 15' 45"	400	ca.10	R, P-MB, Cb, Pb, Si, Cl
	Panna K2	24°43'18"	80° 11' 25"	200	142.5	-do-
	Banda K3	25°29'24"	80° 19' 16"	140	267.5	R, Cb, Pb, Gr, Sd, Av
	Chilla K4	25° 46' 54	80° 32' 08"	100	340	Cl
	Paisuni River					
	Anusuya P1	25° 08' 14	80° 51' 01"	160	10	R, P-B, Cb, Pb, Sd
	Chitrakut P2	25° 13' 54	80° 54' 36"	140	26	R, P-B, Cb, Pb, Sd, Gr, Si, Cl
	Purwa P3	25° 16' 17	80° 52' 28"	100	42	
Ganga (middle stretch)	Tons River					
	Amdara T1	24° 00'	80° 26' 21"	400	20	Gr, Si, Cl
	Maihar T2	24° 16' 35	80° 48' 53"	400	56	P-B, Cb, Pb, Gr, Av
	Satna T3	24° 34' 07	80° 54' 36"	323	98	Av
	Chakghat T4	25° 03' 28	81° 42' 21"	100	232.5	P-B, Cb, Pb, Gr, Av
Yamuna (upper stretch)	Supin (Tons) S	31° 45' 2"	78°10'29"	1500	60	MB, Cb
	Yamuna Y	30°55'35"	78° 23' 8"	1800	70	Large & small B
Bhagirathi (middle stretch)	Dharasu D	30° 37'17"	78°19'17"	800	120	Cb, Pb, Gr
	Bhagirathi B	30° 24'48"	78°27' 25"	620	150	B, Cb, Pb, Si
Ganga (foothill)	Nagni N					
	Khiret N1	30° 23'25"	78°19'30"	2200	16	P-MB
	Nagni N2	30° 19'15"	78°21'10"	1400	79	B, Cb
	Jajal N3	30° 18'15"	78°20'40"	1200	98	Cb, Pb, Gr
	Shivpuri N4	30° 8'15"	78° 23'30"	375	142	B, Cb, Pb, Gr, Si
Alaknanda (middle stretch)	Alaknanda A	30° 13'10"	78°48'32"	550	150	B, Cb, Pb, Gr, Si

R = rock, P-MB = prismatic and maturing boulder, B = boulders, Cb= cobble, Pb= pebble, Gr = gravel, Sd = sand Si = silt = Cl= clay/muddly, Av = aquatic vegetation.

The Himalaya streams Dharasu and Nagni Gad and rivers Supin-Tons, Yamuna, Bhagirathi and Alaknanda flow in southerly direction. The latter two are the parent Mountain Rivers forming the Ganga R. The Dharasu and Nagni Gad are right bank tributaries of the Bhagirathi (ca. 40 km upstream of Tehri) and Ganga (downstream of Devprayag). The Supin, a parent tributary of the Tons which along with the Giri R. forms the western limit of the Yamuna watershed and thus the Gangetic drainage. There was relatively more forest cover (*Cedrus deodara*, *Quercus* spp.) in the Yamuna system and Nagni Gad, than the Bhagirathi and Alaknanda (Pine on hill tops) where most of the slopes below 1100 -1500 m asl have scrub. The gradient ranges from 15 to 2.0 m km⁻¹.

Materials and Methods

Sampling: Diatom collections were obtained from 20 stations; 11 stations on 3 rivers in the Vindhya region and 9 stations on 3 rivers and 2 streams in the Himalaya seasonally in 2007. The samples were replicated at each station. Diatom samples were collected by scraping the cobble surface with a brush. The scrapings were transferred to storage vials and preserved in 4% formalin for further processing. The formalin preserved samples were first cleaned with double distilled water to remove traces of formaldehyde. Samples were given Hydrochloric acid- peroxide treatment, washed

repeatedly and mounted in Naphrax. Two slides were prepared for each sample. Each slide was examined under bright field in a BX-40 Trinocular Olympus microscope with x100 oil immersion objective to identify the species. Images were obtained by NIKON Digital Imaging System and processed with ADOBE PHOTOSHOP software to prepare photographic plates of the flora at x1500.

Identifications were made according to standard literature Krammer (1982a, b, 1997a, b, 2002, 2003) Taxonomy of our research along with the data list published for the last century was adopted under a modern classification system (Fourtainer and Kociolek 2011, Guiry and Guiry 2016). The dimensions and distribution of the species were separately indicated for each species. Species and intraspecific taxa are arranged alphabetically in the text and plates. were also consulted. The permanent mounts have been adequately stored at the Aquatic Biodiversity Unit, Department of Zoology, H. N. B. Garhwal University, Srinagar, Uttarakhand, India.

The diatoms were identified according to Krammer (1982a, b, 1997a, b, 2002, 2003) Krammer & Lange-Bertalot (1986). The dimensions and distribution of the species were separately indicated for each species. Species and infraspecific taxa are arranged in the text and plates.

Results

1. *Cymbopleura angustata* Krammer 2003 (Figs. 102: 1-7; 105: 9-17b; 109: 12-16). Length (L) 23-26, Width (W) 5-6, Striae (S) 18-20, Rhomboid-lanceolate, ends produced and narrowly capitate, axial area narrow, linear, central area small, raphe slightly lateral, striae radiate throughout (Plate 1, Fig. 1).
2. *C. angustata* var. *spitsbergensis* Krammer 2003 (Figs. 106: 11-20). L 22µm, W 6µm, S 17-18/10 µm, very small lanceolate forms, body symmetrical lanceolate, ends subcapitate to capitate (Plate 1, Fig. 2).
3. *C. citrus* (Cattrer and Bailey-Watts) Krammer 2003 (Figs. 97: 5-12). L 16-26, W 7.4-9.6, S 12-13, broadly sub elliptic-lanceolate, dorsal and ventral margins strongly arched, ends slightly apiculate. Maximum L/B ratio 2.9. Axial area narrow, linear, central area asymmetric, raphe filiform to slightly lateral, striae slightly radiate throughout, puncta 33-36/10 µm (Plate 1, Fig. 3).
4. *C. cf. bercynica* (A. Schmidt) Krammer 2003 (Figs. 96: 17, 19-21; 97: 1-4). L 19µm, W 7µm, S 16-18/10 µm Valve slightly dorsiventral, broadly sub-elliptical to elliptical-lanceolate, dorsal margin strongly, axial area narrow, ventral margin slightly arched, striae radiate throughout, striae in the middle portion (Plate 1, Fig. 4).
5. *C. diminuta* (Grunow) Krammer 2003 (Figs. 127: 1-10). L 15-27, W 5-6, S 15-16, Lanceolate-elliptical, dorsal margin convex, ventral nearly straight, ends tapering to rounded, axial area narrow, slightly ventrally displaced, central area indistinct. Raphe filiform, curved. Striae very slightly radiate in the middle portion. Puncta 28-30/10 (Plate 1, Fig. 5).
6. *C. kuelsii* Krammer 2003 (Figs. 113: 1-7b; 127: 11, 12, 19, 20-27). L 23-37, W 6-8.5, S 10-13, Lanceolate, dorsal and ventral margins similarly arched, ends rounded. Axial areas narrow, especially towards the ends, almost in median line of the valve, central area unilateral. Raphe filiform to slightly lateral. Striae barely radiate, indistinctly punctate, puncta 23-28/10 µm (Plate 1, Fig. 6)
7. *C. kuelsii* var. *nonfasciata* Krammer 2003, (Figs. 127: 20-27). L 20-25, W 6-7.5, S 11-16, Lanceolate, arched dorsally, ends sharply rounded, striae parallel (Plate 1, Fig. 7).
8. *C. laponica* (Grunow) Krammer 2003 (Figs. 137: 12-17). L 48-54, W 7-8, S 21-22, Rhomboid-lanceolate, gradually tapering from the middle to the acute, slightly apiculate protracted ends, short ends, sharp, set off, axial area narrow linear, central area rather large, striae radiate throughout, puncta delicate (Plate 1, Fig. 8).
9. *C. anglica* Krammer 2003 (Figs. 76: 1-13; 77: 1-13; 781-8; 79;1-14; 8012; 821-12; 839-11). L 26-45, W 9-12, S 12-14, Elliptical-lanceolate, valves moderately dorsiventral, ventral margin slightly arched, slightly convex in the middle portion. Ends produced rostrate sub-capitate, axial area narrow, raphe lateral, striae radiate throughout, on the dorsal side of the central area irregularly arranged, puncta 27-33/10 µm (Plate 1, Fig. 9).
10. *C. rupicola* (Grunow) Krammer 2003, (Figs. 66: 1-17; 67: 1-18). L 20-40, W 7-10, S 12-16, Rhomboid-lanceolate, dorsal and ventral margins continuously arched or ventral margin barely arched, ends are narrowly rounded, only subtly set off from the valve body, axial area narrow, linear, widening towards central area, central area only a slight central widening. Raphe slightly lateral, curved, narrowing towards the both ends and slightly reverse-lateral towards the proximal ends. Striae radiate throughout (Plate 1, Figs. 10).
11. *C. cf. subaequalis* var. *subaequalis* (Grunow) Krammer 2003 (Figs. 199: 1-15). Length 28-32µm, width 9-11µm, striae 9-12/10 µm (Plate 1, Fig. 11).
12. *Encyonopsis subminuta* Krammer & Reichardt Krammer 1997b (Fig. 144: 1-2). L 12-18, W 4-5, S 11-13, Elliptic, dorsal and ventral margins slightly arched, tapering to small, ends narrowly capitate, axial area narrow, central area lacking or not well expressed, raphe filiform, striae radiate throughout (Plate 1, Figs. 12-13).
13. *C. vrana* Lange-Bertalot and Krammer 2003 (Figs. 93: 9-18). L 20-34, W 8-9.4, S 12-13, Lanceolate, dorsal margin more arched than the ventral one, ends apiculate, protracted, axial area moderately wide, linear, narrowing slightly towards the ends, almost in the median line of the valve. Central area very small, irregular, asymmetric space. Raphe barely lateral, narrowing towards the proximal and distal ends. Striae slightly radiate throughout, irregularly arranged around the central nodule (Plate 1, Fig. 14).
14. *Delicata sparsistriata* var. cf. *parva* Krammer 2003 (Figs. 132: 21-33). L 19-25, W 4.5-5.3, S 12-14, Lanceolate, valves slightly dorsiventral, ends slightly or not produced and narrowly rounded, axial area narrow, barely ventrally displaced, linear, raphae filiform, striae slightly radiate, puncta 25-30/10 µm (Plate 1, Figs. 16).
15. *Encyonema jemtlandicum* var. *venezolanum* Krammer, Metzeltin et al., 2005 (p. 129, Figs. 1-8, 16). L 30-39, W 8.5-10, S 10-13, Semielliptical, dorsal valve strongly convex and ventral side almost straight, ends not set off, raphe straight and eccentric, isolated stigma on the middle of the dorsal striae, striae almost parallel (Plate 1, Figs. 17-18).
16. *E. minutum* (Hilse ex Rabenhorst) 1862 (Figs. 119: 1-13; 164). L 12-20, W 4-6, S 12-14, Semielliptical, smaller forms, ends not set off, or only slightly so, partially curved a little towards the ventral side, one stigma on the dorsal striae (Plate 1, Figs. 19-20).

17. *E. perminutum* Krammer Metzeltin et al., 2005 (Figs. 6-15). L 22-24, W 6-7, S 13-14, Semielliptical, smaller forms, dorsal valve strongly convex and ventral side almost straight, one stigma on the dorsal side, raphe straight, striae almost parallel (Plate 1, Fig. 21).
18. *E. silesiacum* [Bleisch in Rabenhorst] 1864 (Figs. 117: 1-24). L 20-30, W 8-12, S 12-16, Semielliptical to semilanceolate, valve crescent shaped, dorsal valve strongly convex and ventral side almost straight, raphe strongly displaced to the ventral side, two stigmas on the dorsal striae (Plate 1, Fig. 22).
19. *E. vulgare* Krammer var. *vulgare* Metzeltin et al., 2005 (Figs. 10-12; p. 128, Figs. 5-11). L 67-72, W 12-13, S 9, Semielliptical, dorsal valve convex and ventral side straight to somewhat convex in middle, striae straight to radiate (Plate 1, Fig. 23).
20. *Encyonema* spp. Length 16-21µm, width 7-8µm, striae 10-11/10 µm (Plate 1, Figs. 24-25).
21. *Encyonopsis krammeri* Reichardt (Krammer 1997, p. 99, figs 144: 12-15). Length 17-22 µm, width 5-6 µm, striae 18-20/10 µm Valves weakly dorsiventral, both dorsal and ventral margin convex. Apices protracted, capitate, narrow rounded, slightly ventrally deflected. Axial area linear, narrow. Central area absent. Raphe weakly lateral, proximal and distal portions filiform. Polar (distal) raphe endings first dorsally then ventrally deflected. Striae weakly radial in the central region becoming strongly radial towards the apices. (Plate 1, Fig. 15).
22. *Encyonopsis leei* Krammer 2003 (Figs. 162: 4-11; 15-19). L 19-25, W 7-7.5, S 8-9, Elliptical, valves nearly symmetrical, dorsal and ventral margins slightly convex, ends broadly rounded. Axial area narrow, linear, central area small, formed by shortening or lacking of some central dorsal striae. Raphe filiform, curved, terminal fissures ventrally bent. Striae in the middle portion parallel slightly radiate at the ends, puncta 21-29/10 µm (Plate 1, Figs. 26-27).
23. *E. leei* var. *leei* Krammer 2003 (Figs. 162: 15-19). L 22-25, W 7-8, S 8-9 Elliptical, striae more coarsely punctate, 22-23 puncta/10 µm (Plate 1, Fig. 28).
24. *E. leei* var. *sinensis* Metzeltin and Krammer, Krammer 2003 (Figs. 162: 4-11). L 23-29, W 7-8, S 8 Elliptical, striae finely punctate, 26-27 puncta/10 µm (Plate 1, Fig. 29).
25. *Reimeria sinuata* (Gregory) Kociolek & Stoermer, Metzeltin et al., 2005 (Figs. 148: 10-17). L 10-16, W 3.5-5, S 9-11, Lanceolate, valve asymmetrically linear, with broadly rounded apices, ventral margin slightly concave with gibbous midvalve, dorsal margin convex, linear, central area small formed by lack of striae, ventral isolated punctum, striae nearly parallel (Plate 1, Figs. 30-31).
26. *R. uniseriata* Sala, Guerrero and Ferrario, Metzeltin et al., 2005 (Figs. 1-13). L 14-16, W 3.5-4.5, S 8-10, Lanceolate, valve asymmetrically linear, broadly rounded apices, ventral margin slightly undulated with slightly gibbous midvalve, dorsal margin convex, linear, central area small, formed by shortening or lacking of some central striae, ventral isolated punctum, striae parallel to radiate (Plate 1, Fig. 32).

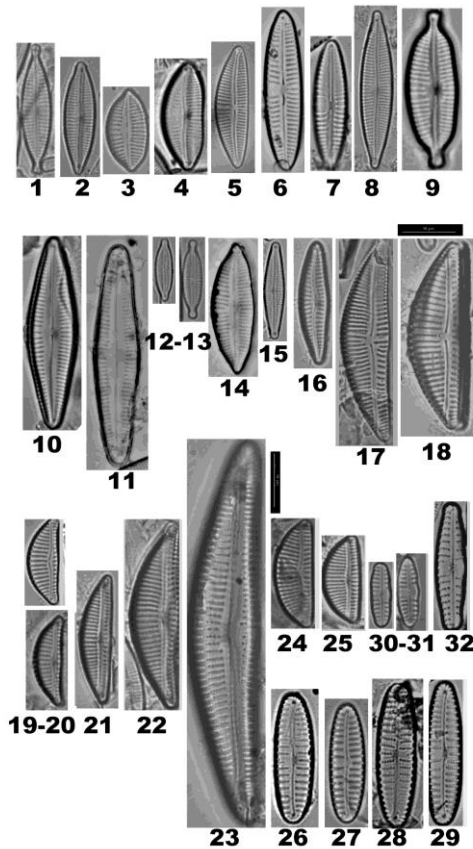


Plate 1

Discussion

Twenty six diatom taxa belonging to the genus *Cymbella* sensu lato (*Cymbopleura*, *Delicata*, *Encyonema*, *Encyonopsis* and *Reimeria*) were recorded, nineteen from the Vindhya region and eleven from the Himalaya. Four taxa (*Delicata sparsistriata* v. *parva*, *Encyonema jemtlandicum* v. *venezolanum*, *E. minutum*, *E. silesiacum*) were common to both the ecoregions. Seven taxa (*Cymbopleura diminuta*, *C. cf. berynicum*, *Delicata sparsistriata* var. *parva*, *Encyonema jemtlandicum* var. *venezolanum*, *Encyonopsis leei*, *E. leei* var. *leei*, *Reimeria uniseriata*) were new records from the Himalayan region. Twenty four *Cymbella* sensu lato taxa are known from forty six sites in the Himalaya (Nautiyal et al., 2004 a & b). Now, the Himalayan region has thirty one taxa (7 present + 24 earlier) from 55 sites belonging to *Cymbella* sensu lato. The Vindhya region seems to be richer in

Cymbella sensu lato as 19 taxa were obtained from 11 sites.

There is limited investigation of freshwater diatoms in South East Asia. Among species of the genus *Cymbella*, 49 were reported from northeastern China (Fan et al., 1993, Bao et al., 1992), 44 from India (Jena et al., 2006, Nautiyal et al., 2004 a & b), and 9 from Japan (Hirano 1972). In the Himalayan region, 4 new species of *Cymbella* from alpine lakes and springs have been reported from Everest National Park of Nepal (Jüttner et al., 2010, 2000). There were also studies on cymbelloid diatoms near Mount Everest in China (Li et al., 2007b), showing that 44 species belong to *Cymbella*, of them 16 new records, some of them unique to this region. One new species of *Cymbella* has been found from northwest Tibet (Li et al., 2003a), and one from the Far East (Lee et al., 1993), respectively. One *Cymbella* species was found that is unique to this area (Li et al., 2007a), and some taxa belonging to *Cymbella* are found that have different morphological features compared with previously published descriptions (Li et al., 2003c).

Considering the distribution of the species in this study, *Cymbopleura angusta*, *E. minutum*, *E. silesiacum*, *Reimeria sinuata*, *Reimeria uniseriata* were the most common diatom species in mountain freshwater ecosystems and it is tolerant to high levels of eutrophication (Kelly & Whitton 1995, Gosselain et al., 2005). It has been reported from many different parts of the world, for instance Australia (Foged 1978), Europe (Krammer & Lange-Bertalot 1986), Japan (Kawashima & Mayama 2001), Siberia (Lange-Bertalot & Genkal 1998), South America (Metzeltin et al., 2005) and the United States (Patrick & Reimer 1975).

The diversity of diatoms in the Indian biogeographic region is relatively low compared to the world record and there are several reasons why the taxa have not been recorded in India. Some species are probably confused to the morphologically similar taxa. So, the samples would be investigated attentively.

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