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ECO-TAXONOMICAL STUDIES ON DIATOMS FROM THE CHAMBAL RIVER (CENTRAL INDIA)

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Abstract

The present study is the first record of diatoms from the Chambal River. A checklist of diatom taxa has been prepared for the Chambal River which includes 102 diatom taxa from 27 sampling sites along the river. Most of the diatom taxa belong to classes Bacillariophyceae (32 genera 89 species) followed by Fragilariophyceae (4 genera 6 species) and Coscinodiscophyceae (4 genera 5 species). Dominant diatom species belong to genera like *Cyclostephanos* (1), *Cyclotella* (1), *Melosira* (1), *Achnanthidium* (4), *Amphora* (1), *Brachysira* (1), *Caloneis* (2), *Cocconeis* (2), *Cymbella* (2), *Gomphonema* (4), *Navicula* (2), *Neidium* (1), *Nitzschia* (2), *Rhopalodia* (1), *Sellaphora* (2), *Hantzschia* (1) and *Synedra* (2). Eco-taxonomical characters of 30 abundant diatom taxa have been described.

Key words: Diatoms, Chambal River, Biomonitors, Coscinodiscophyceae, Bacillariophyceae, Fragilariophyceae

Introduction

Diatoms are unicellular, eukaryotic, microscopic algae of class Bacillariophyceae. They are highly successful and distinctive group of ubiquitous organisms found in almost all fresh water and marine ecosystems where they occur as free floating or attached forms. They have been found to harbor moist soils also (Antonelli *et al*., 2017). The most distinguishing characteristic of diatoms is the possession of siliceous cell walls, known as the 'frustule'. Though, diatoms account for only about 1% of the Earth's photosynthetic biomass, yet they are responsible for about 45% of our planet's annual net primary productivity (Field *et al*., 1998). They are extremely important for the biochemical cycling of silica and have been reported as significant contributors to global fixed Carbon (Willey *et al*., 2008). Diatoms communities are known to respond directly and sensitively to many physical, chemical, and biological changes in aquatic ecosystems, such as temperature (Squires *et al*., 1979; Descy and Mouvet, 1984), organic pollution (Watanabe *et al*., 1986; Rott *et al*., 2003), herbivory (Steinman *et al*., 1987; McCormick and Stevenson, 1989), nutrient concentrations, supply rates and silica/phosphate ratios (Pan *et al*., 1996; Kelly, 1998; Potapova and Charles, 2007). The sensitivity to environmental variables coupled with their ubiquity and persistent nature of siliceous cell walls have allowed diatoms to be established as robust ecological indicators of aquatic ecosystems and been extensively used to monitor water bodies with respect to eutrophication, organic pollution and human interference (Kelly and Whitton, 1995; Descy and Coste, 1991; Karr, 2006; Fore and Grafe, 2002). As the silica cell walls do not decompose, diatoms have been recognized as ideal tools for a wide range of applications as both fossils and living organisms. Diatoms in marine and lake sediments can be used to interpret conditions in the past and provide a detail of changes in the quality of the overlying water over a huge span of time (Mackay *et al.,* 2010; Jordan and Stickley, 2010; Leventer *et al*., 2010). This attribute alone has significant and far-reaching relevance for the determination of reference conditions, not only climatic but also due to the intrusion of anthropogenic activities.

Diatoms, along with other biomonitors, are particularly useful for ecological assessment of lotic ecosystems that show high spatial and temporal variability and are perhaps the most vulnerable habitats throughout the world that have been subjected to increasing anthropogenic stresses, including changes in food and habitat availability, exposure

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to contaminants and increases in nutrient inputs (Adams and Greeley, 2000). To evaluate the actual state of these ecosystems and to monitor their rate of changes is a challenging task and conventional physic-chemical analytical approaches are insufficient. Biological monitors such as diatoms, reflect the overall ecological integrity by unifying various stressors, thus providing a broad measure of their synergistic impacts. They integrate and reflect the effects of chemical and physical disturbances that occur over extended periods of time. These communities provide a holistic and an integrated measure of the integrity or health of the rivers and streams as a whole (Chutter, 1998).

Taxonomic identification is an essential prerequisite in all fields of application of diatoms and hence has been extensively focused upon throughout the world (Hustedt, 1930, 1938, 1942; Hendy, 1964; Patrick and Reimer, 1966; Khromov *et al*., 2002; Lange-Bertalot *et al*., 2002; Lee *et al*., 1997; Li *et al*., 1999, 2002, 2003a, b; Rai, 2006; Syed *et al*., 2006).

Diatom research in India has a long history and can be traced to the pioneering research work of Ehrenberg (1845). Some prominent works on diatom taxonomy include that of Skvortzow (1935); Gonzalves and Gandhi (1952, 1953, 1954); Krishnamurthy (1954); Gandhi (1952, 1955, 1956a, b, 1957a, b, c, 1958b, c,1959a, b, c, d, 1960a, b, c, 1961, 1962b, c 1966, 1970, 1998); Venkataraman (1957); Sarode and Kamat (1984); Gandhi *et al*. (1983a, b, c, 1986); Trivedi (1982); Jakher *et al*. (1990); Dadheech *et al*. (2000); Singh *et al*. (2006, 2010); Kumar *et al*. (2008, 2009), Tarar and Bodhke (1998); Bhagat (2002); Mishra and Mishra (2002); Mishra (2006); Patil and Kumawat (2007) and Anand (1998). Studies on the ecology and taxonomy of freshwater diatoms have been dismally neglected in India and many regions are yet to be studied for baseline information of diatom diversity (Karthick *et al*., 2013). However, phytoplankton ecology has received frequent attention (Sarma and Khan, 1991; Karthick *et al*., 2010). With reference to diatom research from lotic ecosystems, majority of work has been carried out in the streams and rivers of Himalayas regions (Ormerod *et al*., 1994; Suren, 1994; Rothfritz *et al*., 1997; Cantonati *et al*., 2001; Nautiyal *et al*., 2004a, 2015). Taxonomic studies on diatoms have been carried out in the rivers of Central Highlands (Verma and Nautiyal, 2010; Mishra and Nautiyal, 2011; Verma and Nautiyal, 2016) and Peninsular India (Karthick *et al*., 2011, 2013). In spite of being a pristine and protected river with high biological diversity diatom flora of the Chambal River has never been explored. However, recently biomonitoring potential of diatoms for this river has been probed into (Srivastava *et al*., 2017 *In press*).

The Chambal River is located in northern India and flows through three Indian states: Madhya Pradesh, Rajasthan and Uttar Pradesh. It originates from the summit of Janapav hill of the Vindhyan range at an altitude of 854 m above the msl at 22027’ N and 75037’ E in Mhow, district Indore, Madhya Pradesh. The river has a course of 965 km up to its confluence with the Yamuna River in the Etawah district of Uttar Pradesh. The Chambal River is one of the last remnant rivers in the greater Ganges River system, which has retained significant conservation values (Hussain and Badola, 2001). Chambal River is significantly rich in biodiversity and harbors many species that are critically endangered, endangered and vulnerable as listed by IUCN Red List of Threatened Species (Nair and Chaitanya, 2013) such as the gharial (*Gavialis gangeticus*) and Gangetic dolphin (*Platanista gangetica*). A 600 km stretch of the Chambal River between Kota barrage and Chambal -Yamuna confluence has been protected as the tri-state National Chambal Sanctuary (NCS) by the Government of India.

Diatoms from Chambal River have never been explored, though other rivers of the central highland region have received attention (Nautiyal and Nautiyal, 2014; Verma and Nautiyal, 2016; Nautiyal *et al*., 2017; Verma *et al*., 2016). The present research work was undertaken with the objective to prepare a checklist of diatoms along with record of abundant forms from this ecologically important river. Apart from the preparation of diatom herbaria, the present work would help in the exploitation of the biomonitoring potential of diatoms in future.

Methodology

Twenty seven sites were sampled for diatom assemblages during a period of May 2016 and Dec 2016. Of the 27 sites, 15 sites were located in the upper river basin which is under urban, agricultural and industrial impacts. Rest of the sites (12 sites) comes under the lower stretch of the National Chambal Sanctuary region of the Chambal River. The epilithic forms were collected from hard surfaces (Eloranta and Andersson, 1998). In the absence of epilithic diatoms at some sampling sites, epiphytic diatoms were also collected. The benthic diatoms were randomly collected by scraping about 5-10 cobbles or pebbles from each sampling sites and diatoms were scraped off using a tooth brush. Samples were preserved in 125 ml plastic (polylab) bottles and fixed with 4% formalin.

In the laboratory, about 5-10 ml sample of the diatom suspension were cleaned with hot HCl and $KMnO_4$ to remove organic coatings (Karthick *et al*., 2010) and the diatom samples then rinsed in distilled water until free of acids. The permanent slides were prepared using Naphrax (Brunel Microscopes Ltd). Using a pipette, a drop of diatom sample was put on the coverslip and mixed well, so the diatoms were spread across the coverslip. Then the coverslip were allowed to dry in a dust free environment at room temperature. Once the diatom coated coverslip has been dried, one or two drop of mountant were placed and heat the mountant on the coverslip gently for 30 seconds to one minute (Karthick *et al*., 2013). The coverslip was then adjusted on the slide and heat the slide on the hot plate until the mounting media was boiled for sufficient length. Then the slide was cooled thoroughly and the mounting media were hard and brittle (Karthick *et al*., 2013). Slides were scanned under a Light Microscope (Leica DM750) at a 100 × magnification using immersion oil in accordance with CEN standards (2001). A total of 400-800 diatom valves were counted on each slide, fewer valves were counted on some slides when diatoms were scarce. The diatoms were identified to species or subspecies level.

For ensuring taxonomic accuracy SEM was performed with a Carl Zeiss EVO 18 at AIAE, Amity University, Noida, India. The diatom samples were air dried onto a small coverslip and mounted on an aluminium microscope stub with carbon tape, and couted with gold palladium and finally examined in SEM at an accelerating voltage of 10-15 KV (Taylor *et al*., 2007).

Identification of diatoms was done in accordance of standard literature such as Hustedt (1931-1959); Krammer and Lange-Bertalot (1986, 1988, 1991a, b, 2000, 2004); Lange-Bertalot and Metzeltin (1996); Gandhi (1998); Metzeltin and Lange-Bertalot (1998, 2002, 2007); Krammer (1997, 2000, 2002, 2003); Siver *et al*. (2005), Siver and Hamilton (2011); Watanabe *et al*. (2005) and Karthick *et al*. (2013).

Observations

A total of 102 taxa were recorded from the present study. Taxonomic descriptions along with Scanning Electron Micrograph (SEM) of some of the dominant taxa are under:

Class: *Coscinodiscophyceae*

1. *Cyclostephanos dubius* (Fricke) Round in Theriot *et al*., 1987 (plate 1, fig 4)

   Diameter: 8.6-18.5 µm; Rows of areolae in 10 µm: 12-15

   Valves are centric, with distinct costae. The valves are strongly concentrically undulate and show complementarity, with the central area of the valve face being either concave or convex. Characteristic chambers, called alveolae, are present near the valve margin. In large specimens, the central areolae are often organized into radial striae. In small specimens, the central areolae appear to be scattered randomly. A single rimoportula is located on the mantle, on an extension of a costa. Several central fultoportulae are positioned on the valve face, forming an irregular ring. Fultoportulae are also present on the mantle, on an extension of every second to third costa. Costae number 9-12 in 10 µm.

   Ecology: Alpha-mesosaprobic taxa, known to occur mostly in eutrophic environment (van Dam *et al*., 1994).

2. *Cyclotella meneghiniana* Kützing, 1844 (Plate 1, Fig 2 and 3)

   Diameter: 10-34.5 µm; Rows of areolae in 10 µm: 6-8

   Valves are disc-shaped, with a narrow mantle. The valve face may be flat or transversely undulate. The central area is distinct and isolated from the marginal chambered striae. The central area contains 1-4 fultoportulae, which are distinct in LM. In the SEM, marginal fultoportulae are positioned on each costa. One to two rimoportulae are present near the valve margin, in line with a costa. Marginal spines may be present, positioned in line with each costa.

   Ecology: This taxon has a cosmopolitan distribution and occurs in nutrient rich waters (Karthick *et al*., 2013).

3. *Melosira varians* Agardh, 1827 (plate 1, fig 1)

   Diameter: 6-30 µm; Mantle Height: 5-15 µm

   Cells are cylindrical, forming chains. Frustules are 6-30 µm in diameter with a mantle height of 5-15 µm. The valve face is slightly convex, covered with small spines. The mantle is covered by small granules. Numerous rimoportulae are scattered over valve face and mantle and one row of rimoportulae occurs on the mantle edge.

   Ecology: Common in freshwater habitats, especially eutrophic waters (Karthick *et al*., 2013).

Class: *Bacillariophyceae*

1. *Achnanthidium chitrakootense* Wojtal *et al*., 2010 (plate 1, fig 8)

   Length Range: 13-42 µm; Width Range: 3.4-4.2 µm; Striae in 10 µm: 26-30

   Frustules with slightly bent apices in girdle view. Raphid valves externally concave, and rapheless valves are slightly convex. Large valves linear with

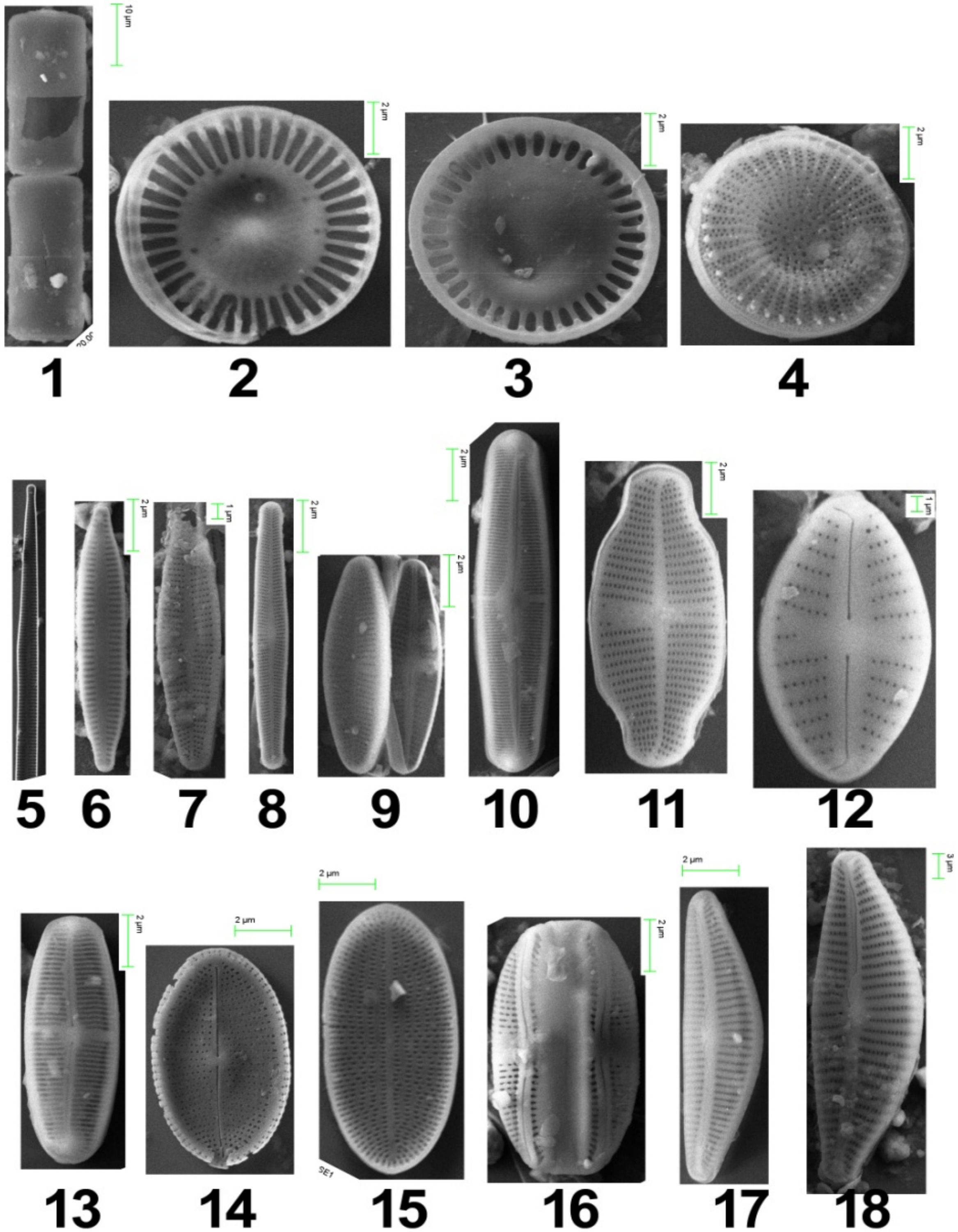

Plate-I

Figure: Scanning Electron Micrograph of 1. *Melosira varians,* Agardh*;* 2 & 3. *Cyclotella meneghianiana,* Kützing*;* 4. *Cyclostephanos dubius,* (Fricke) Round*;* 5. *Synedra ulna,* Ehrenberg*;* 6. *Synedra tabulata,* (C.Agardh) Kützing*;* 7 & 9. *Achnanthidium minutissimum,* (Kützing) Czarnecki*;* 8. *Achnanthidium chitrakootense,* Wojtal *et al.;* 10. *Caloneis beccariana,* (Grunow) Cleve*;* 11. *Achnanthidium exiguum,* (Grunow) Czarnecki*;* 12. *Achnanthidium subatomus,* (Hustedt) Lange-Bertalot*;* 13. *Caloneis bacillum,* (Grunow) Cleve*;* 14. *Cocconeis placentula v lineata,* (Ehrenberg) Van Heurck*;* 15. *Cocconeis pediculus,* Ehrenberg*;* 16. *Amphora pediculus,* (Kützing) Grunow*;* 17. *Cymbella vulgata,* Krammer*;* 18. *Cymbella affinis,* Kützing.

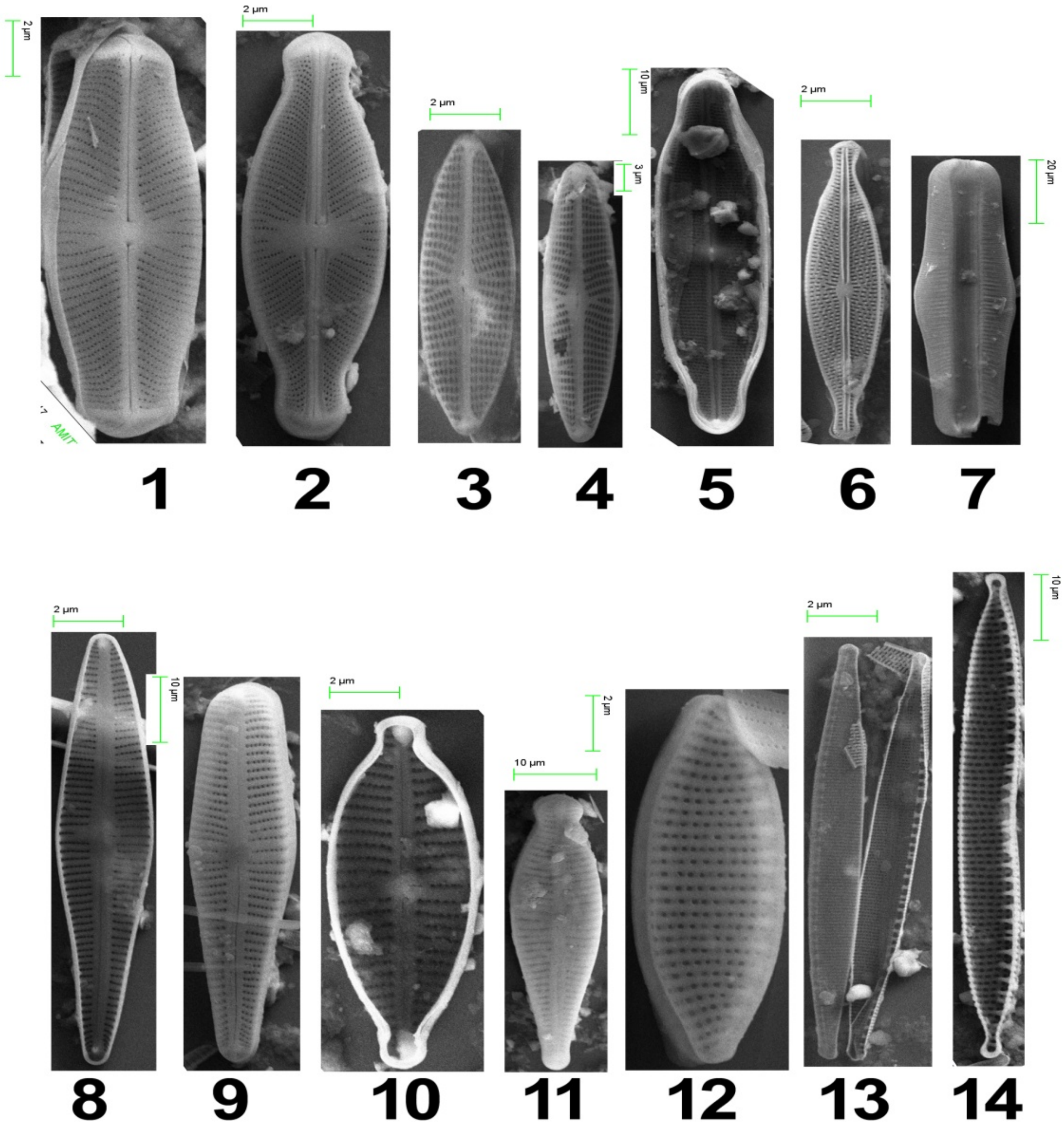

Plate-II

Figure: Scanning Electron Micrograph of 1. *Sellaphora pupula*, (Kützing) Mereschkowsky; 2. *Sellaphora densistriata*, Metzeltin and Lange-Bertalot; 3. *Navicula caterva*, Hohn and Hellerman; 4. *Navicula symmetrica*, Patrick; 5. *Neidium ampliatum*, (Ehrenberg) Krammer; 6. *Brachysira vitrea*, (Grunow) Ross; 7. *Rhopalodia gibberula*, (Ehrenberg) O. Müller; 8. *Gomphonema gracile*, Ehrenberg; 9. *Gomphonema angustatum*, (Kützing) Rabenhorst; 10. *Gomphonema exillisimum*, (Grunow) Lange-Bertalot and Metzeltin; 11. *Gomphonema sphaerophorum*, Ehrenberg; 12. *Nitzschia amphibia*, Grunow; 13. *Nitzschia frustulum*, (Kützing) Grunow; 14. *Hantzschiaamphioxys*,(Ehrenberg)Grunow.

moderate inflation in middle portion of valve, and somewhat subcapitate apices. Smaller valves of linear-elliptical outline with broadly rounded (blunt) apices. Raphid valves with very narrow axial area, without distinct central area. Raphe filiform, straight from external view with relatively closely located proximal raphe pores.

Ecology: Circumneutral to slightly alkaline waters of moderate conductivity (Wojtal *et al*., 2010).

2. *Achnanthidium exiguum* (Grunow) Czarnecki, 1994 (plate 1, fig 11)

Length Range: 5-17 µm; Width Range: 4.5-6.2 µm; Striae in 10 µm: 24-34 in center of raphe valve, 20-25 in center of rapheless valve, up to 45 at apices.

Valves are linear-elliptical to elliptical-lanceolate with narrowly capitate, subcapitate, rostrate, or subrostrate apices. Larger valves are sometimes slightly constricted in the middle. Both raphe and rapheless valves have a narrow slightly sigmoid axial area. The raphe valve has a distinct fascia that is often slightly wider on one side. The rapheless valve has a small, transapically rectangular, often asymmetric, central area. The raphe is straight, but deflected to opposite sides near the apices, with terminal raphe fissures strongly curved to opposite sides. The external proximal raphe ends are simple, located in slight "pin-hole" depressions, giving the appearance that they are expanded. Internally, the central raphe ends curve toward opposite sides. The striae are radiate on both valves, but almost parallel at the apices. A few very small areolae may be present on the mantle of both valves. Areolae are round or transapically elongated externally, apically elongated internally within the striae.

Ecology: A cosmopolitan species, able to grow under very low light and grow in alkaline and moderate water condition (Karthick *et al*., 2013).

3. *Achnanthidium minutissimum* (Kützing) Czarnecki, 1994 (plate 1, fig 9)

Length Range: 6-21 µm; Width Range: 1.5-3.3 µm; Striae in 10 µm: 25-35.

Cells are solitary or in very short chains, often attached to substrate by a stalk. Frustules are monoraphid with a concave raphe valve and convex rapheless valve. Valves are linear-lanceolate with slightly drawn-out or slightly capitate ends, 1.5-3.3 µm wide, 5.6-20.8 µm long. Central external raphe ends are simple, terminal raphe fissures are short, almost straight, or absent. Internally, the central raphe ends are turned in opposite directions. Striae consist of one row of areolae. The striae are often interrupted in the central part of raphe valve to form a symmetrical or asymmetrical fascia. One row of elongated areolae is present on the valve mantle. External areolae openings of areolae vary in shape from circular to transapically elongated slits. Internal openings of the areolae are elliptical, occluded by hymens perforated by small pores.

Ecology: A cosmopolitan species found in well oxygenated, mostly occur in clean, fresh waters (Karthick *et al*., 2013).

4. *Achnanthidium subatomus* (Hustedt) Lange-Bertalot, 1999 (plate 1, fig 12)

Length Range: 6-35 µm; Width Range: 3-6 µm; Striae in 10 µm: 15-40.

Elliptic to linear-elliptic valves with rounded or broadly rounded ends. Flexed in girdle view. Linear axial area on both valves, opening into a narrow central area on the raphe valve.

Ecology: It is an oligosaprobic taxa which reflects good water quality (van Dam *et al*., 1994).

5. *Amphora pediculus* (Kützing) Grunow in Schmidt, 1875 (plate 1, fig 16)

Length Range: 6-16 µm; Width Range: 2.5-4 µm; Striae in 10 µm:18-24.

Valves moderately dorsiventral, semi-elliptical becoming semi-circular in small taxa. Dorsal margin arched, ventral margin straight to slightly concave. Valve ends rounded, sometimes with a slight ventral deflection. Axial area very narrow with the raphe ledge poorly developed. Raphe straight with proximal raphe ends straight and distal raphe ends dorsally deflected. Dorsal and ventral fascia distinct and extending to valve margins. Dorsal striae parallel in central area, becoming weakly radiate at the apices. Dorsal striae distinctly punctate with 2-3 rows of areolae near the central area. Ventral striae composed of a single row of areolae, radiate near the central area, becoming convergent at the apices.

Ecology: A taxon found in waters with moderate level of pollution and tolerating high nutrient concentration (van Dam *et al*., 1994).

6. *Brachysira vitrea* (Grunow) Ross, 1986 (plate 2, fig 6)

Length Range: 12-25 µm; Width Range: 4.3-5.9 µm; Striae in 10 µm: 32-36.

Valves are broadly elliptic-lanceolate with capitate apices. The axial area is narrow. The central area is small and elliptic. The raphe is filiform and straight. Proximal raphe ends are weakly expanded. Distal raphe ends are indistinct in LM. Striae are radiate and uniseriate. Areolae in the striae are transapically elliptic to bacilliform. Areolae are irregularly spaced, creating a pattern of undulating longitudinal lines.

Ecology: A species occurring in oligotrophic water indicate good water quality status (van Dam *et al*., 1994).

7. *Caloneis bacillum* (Grunow) Cleve, 1894 (plate 1, fig 13)

Length Range: 15-48 µm; Width Range: 4-9 µm; Striae in 10 µm: 25-29.

Valves are linear to linear-lanceolate with rounded apices. The valve margins are straight to slightly convex in smaller specimens. The axial area is linear and expanded at the central valve to form a broad transverse fascia. The fascia is typically asymmetric from one side of the axial area to the other. The raphe is straight and filiform, with dilated proximal external ends. The striae are parallel to radiate. Longitudinal lines are visible in larger specimens.

Ecology: A beta mesosaprobic taxa found in moderate trophic environment (van Dam *et al*., 1994).

8. *Caloneis beccariana* (Grunow) Cleve, 1894 (plate 1, fig 10)

Length Range: 25-39 µm; Width Range: 5.5-7.5µm; Striae in 10 µm: 23-28.

Valves lanceolate with a slight bilateral swelling in the central region. The weakly protracted apices are bluntly rounded. The central area usually reaches both the margins of the valves.

Ecology: A diatom species found in neutral to alkaline waters (Karthick *et al*., 2013).

9. *Cocconeis pediculus* Ehrenberg, 1838 (plate 1, fig 15)

Length Range: 17-42 µm; Width Range: 14-23 µm; Striae in 10 µm:16-22 in the raphe valve center, 16-21 in the rapheless valve center.

Valve strongly convex, broadly elliptical or somewhat rhombic-elliptical. Raphe valve (RV) with narrow, linear axial area terminating in a small, semicircular hyaline area near the valve ends. Central area small, circular to somewhat irregular in outline. Raphe filiform, proximal endings close, extending into the central area; distal endings straight, terminating at the small, semicircular hyaline area near the valve end. Striae curved and radiate with distantly placed conspicuous areolae; in LM, the areolae are externally slit-like and are arranged in longitudinally, undulating rows.

Ecology: A beta-mesosaprobic taxa occurs in eutrophic waters (van Dam *et al*., 1994).

10. *Cocconeis placentula var. lineata* (Ehrenberg) Van Heurck, 1885 (plate 1, fig 14)

Length Range: 10-40 µm; Width Range: 7-30 µm; Striae in 10 µm: 16-20 on raphe valve, 15-25 on rapheless valve.

Valves are elliptic to linear-elliptic and relatively flat. The raphe valve has a narrow axial area and a small circular or oval central area. The raphe is straight and filiform. The distal raphe ends are straight and expanded externally. The proximal raphe ends are straight externally and slightly expanded. Internally, the proximal raphe ends are deflected to opposite sides. Striae are radiate and interrupted by a hyaline ring positioned close to the valve margin. The valvocopula attached to raphe valve has conspicuous fimbriae. The rapheless valve has a linear to linear-lanceolate axial area and radiates striae. The external openings of areolae are narrow, long transapical slits. The internal openings are comparatively shortened and are oval, or nearly round.

Ecology: A diatom species occurs in eutrophic flowing and standing waters (Karthick *et al*., 2013).

11. *Cymbella affinis* Kützing, 1844 (plate 1, fig 18)

Length Range: 19-36 µm; Width Range: 6.9-9.0 µm; Striae in 10 µm:9-12 in the center valve, 13-14 at the ends.

Valves are strongly dorsi-ventral, with subrostrate to rostrate apices. The dorsal margin is strongly arched, whereas the ventral margin is slightly convex or flat, often excised. The axial area is narrow, linear. The central area is very small or not distinct. One stigma is present at the end of the middle striae. The proximal raphe ends have central pores that curve to the ventral side. The raphe is lateral, becoming filiform near the distal end. Striae are slightly radiate.

Ecology: This taxon occurs in eutrophic waters and can tolerate moderate saprobity (van Dam *et al*., 1994).

12. *Cymbella vulgata* Krammer, 2002 (plate 1, fig 17)

Length Range: 25-41 µm; Width Range: 6.9-8.9 µm; Striae in 10 µm:10-12 at the valve center, up to 14 near the apices.

Valves are lanceolate and dorsi ventral with narrowly rounded, unprotracted apices. The dorsal margin is moderately arched; the ventral margin is slightly convex to nearly flat in the smallest specimens. The axial area arched and located ventral to the valve mid line. A single isolated stigma (occasionally 2) is located at the end of the median stria on the ventral side.

Ecology: This taxon has been recorded in low conductivity lakes and rivers of subtropical and tropical regions (Karthick *et al*., 2013).

13. *Gomphonema angustatum* (Kützing) Rabenhorst, 1864 (plate 2, fig 9)

Length range: 20-40µm; Width range: 6-12 µm; Striae range in 10 µm: 9-12.

Valves asymmetrical to transapical axis (heteropolar), symmetrical to apical axis. Cells slightly wedge-shaped in girdle view with pseudosepta visible. Apices bluntly to sharply rounded. Raphe weakly lateral, proximal endings barely enlarged. A single stigma is present on one side of the central area. Striae coarse and clearly punctate, sometimes unevenly spaced. Central area with one absent stria on opposite side to stigma.

Ecology: A species commonly found in meso-eutrophic waters (van Dam *et al*., 1994).

14. *Gomphonema exillisimum* (Grunow) Lange-Bertalot and Metzeltin, 1996 (plate 2, fig 10)

Length range: 14-34µm; Width range: 3-10 µm; Striae range in 10 µm: 7-15.

Valves lanceolate to clavate, with apices slightly protracted. The axial area is narrow, straight, expanded slightly to form an irregular, rectangular central area. Raphe weakly lateral, undulate with proximal ends dilated slightly. A single stigma is positioned at the end of a median stria. Striae indistinctly punctuate, radiate strongly at the footpole, becoming nearly parallel at the headpole.

Ecology: A oligosaprobic taxon found in circumneutral, oligotrophic waters (van Dam *et al*., 1994).

15. *Gomphonema gracile* Ehrenberg, 1838 (plate 2, fig 8)

Length: 40-80µm; Width: 5-11µm; Stria range in 10µm: 9-17.

Valves slightly asymmetrical to transapical axis (heteropolar), symmetrical to apical axis. Valves appear lanceolate in outline. Cells wedge-shaped in girdle view with pseudosepta visible. Apices narrowly rounded to narrowly sub-rostrate. Raphe often slightly sinuous. A single stigma is present on one side of the central area. Striae are coarse and punctate, often with one shorter stria in the central area.

Ecology: A Oligosaprobic species which is not tolerant to more than moderate levels of pollution (van Dam *et al*., 1994).

16. *Gomphonema sphaerophorum* Ehrenberg, 1845 (plate 2, fig 11)

Length Range: 27-55 µm; Width Range: 7.5-12.5 µm; Striae in 10 µm: 10-16.

Valves are clavate with a distinctly capitate headpole and a narrow footpole. Axial area is narrow, becoming linear-lanceolate in smaller specimens. Central area is transversally elliptic and incomplete. A stigma is present opposite a single shortened stria. The raphe is undulate and lateral. Striae are nearly parallel mid-valve, becoming radiate at the apices. Areolae are distinctly punctuate.

Ecology: Species occurring in oligotrophic to mesotrophic waters (Karthick *et al*., 2013).

17. *Navicula caterva* Hohn and Hellerman, 1963 (plate 2, fig 3)

Length Range: 10.4-16.6 µm; Width Range: 4.2-5.2 µm; Striae in 10 µm:16-18.

Valve lanceolate, ends slightly subrostrate. Striae broad, indistinctly punctuate, radiate at center. Axial area linear, raphe thin and straight. The central area small, transapically rectangular. Occasionally the center pair of striae is more shortened than illustrated and is enclosed by the adjacent striae.

Ecology: A beta mesosaprobic taxon occur mostly in polluted waters (van Dam *et al*., 1994).

18. *Navicula symmetrica* Patrick, 1944 (plate 2, fig 4)

Length Range: 24-35 µm; Width Range: 5-7.5 µm; Striae in 10 µm: 12-17.

Valves are linear-elliptical to linear-lanceolate with narrow, rounded apices. The axial area is narrow and linear and the central area is asymmetrically rounded. The raphe is filiform with enlarged proximal raphe ends that weakly unilaterally deflected. The distal raphe fissures are distinctly deflected from the valve face onto the mantle, with the deflection to the secondary side. The lineolate striae are strongly radiate at the center and radiate throughout the valve. The space between each stria is equal or wider to the width of the stria. Voigt faults are often evident on the secondary side of the valve. A thickened central nodule is present on the primary side, positioned between the deflected proximal fissures.

Ecology: This taxa is found in eutrophic water and tolerant of strong polluted conditions (Karthick *et al*., 2013).

19. *Neidium ampliatum* (Ehrenberg) Krammer, 1985 (plate 2, fig 5)

Length Range: 39-42µm; Width Range: 8-10µm; Striae in 10 µm: 26-30.

Cells solitary. Valves often linear in their central region, with bluntly rounded, sometimes subrostrate or rostrate apices, girdle view rectangular, narrower than the valve width. Raphe slit central, in a narrow axial area, the central fissures usually deflected in opposite directions, the polar fissures forked. Striae uniseriate, comprised of fine rounded or elongate pores, more or less transverse, interrupted by longitudinal lines (canals) near the valve margins.

Girdle bands plain, without pores.

Ecology: Mostly occur in oligotrophic to oligomesotrophic environment (van Dam *et al*., 1994).

20. *Nitzschia frustulum* (Kützing) Grunow in Cleve and Grunow, 1880 (plate 2, fig 13)

Length Range: 10-30 µm; Width Range: 2.5-4.5 µm; Striae in 10 µm: 19-30.

Cells solitary. Frustules isopolar, bilaterally symmetrical. Cells lie in valve or girdle view and isolated valves always in valve view. Valves bilaterally symmetrical, linear to linear-lanceolate, with subrostrate poles (becoming apparently rounded in small lanceolate valves). Striae clearly visible in LM and stria pores often also resolvable. Raphe system fibulate (the raphe itself is impossible to detect in LM), marginal. Central pair of fibulae usually more widely separated than the others; central raphe endings present and detectable with care by a tiny pimple-like thickening of the margin.

Ecology: It is a beta mesosaprobic taxa and rich in nutrients, supporting a dense plant population (van Dam *et al*., 1994)

21. *Nitzschia amphibia* Grunow, 1862 (plate 2, fig 12)

Length Range: 14-35 µm; Width Range: 3.0-4.5 µm; Striae in 10 µm: 14-18.

Valves are linear to lanceolate. The valves taper to bluntly rounded apices. The central nodule is evident. Striae are characteristically prominent and distinctly punctate, but not necessarily regularly spaced.

Ecology: Cosmopolitan taxa found in moderate to high pollution waters (van Dam *et al*., 1994).

22. *Rhopalodia gibberula* (Ehrenberg) O. Müller, 1895 (plate 2, fig 7)

Length Range: 27-43 µm; Width Range: 5-9.5 µm; Striae in 10 µm: 12-23 (ventral).

Valves are lanceolate, with strongly convex dorsal margins that are often slightly notched in the middle. The ventral margin is slightly concave to straight. In girdle view, frustules are widely lanceolate to elliptic. The apices can be slightly bent ventrally or may be protracted and rounded. The raphe is positioned on the dorsal margin. Costae are parallel at the valve center to slightly radiate toward the apices.

Ecology: Mostly occur in well oxygenated and alkaline environments (Karthick *et al*., 2013).

23. *Sellaphora densistriata* Metzeltin and Lange-Bertalot, 2002 (plate 2, fig 2)

Length Range: 20-60 µm; Width Range: 7-15 µm; Striae in 10 µm: 12-25

24. *Sellaphora pupula* (Kützing) Mereschkowsky, 1902 (plate 2, fig 1)

Length Range: 10-60 µm; Width Range: 5-12 µm; Striae in 10 µm: 16-28.

Cells solitary. Frustules isopolar. Mantles and girdle shallow fairly deep, so that cells can be seen often in valve view or girdle view. Isolated valves usually lie in valve view. Valves bipolar, bilaterally symmetrical, very variable in shape (linear, lanceolate to elliptical), with rounded, rostrate or subcapitate poles. Striae visible, radial at the centre, becoming parallel towards the poles. Stria pores usually invisible, but detectable in a few variants. Axial area very narrow. Central area variable: transversely rectangular, bow-tie shaped or forming a transverse fascia, often somewhat irregular, and often bordered by alternating long and short striae. Central raphe endings (as seen in LM) slightly expanded and often deflected a little towards the opposite side from the terminal fissures.

Ecology: Alpha mesosaprobic taxa which can tolerate moderate to heavy pollution (van Dam *et al*., 1994).

25. *Hantzschia amphioxys* (Ehrenberg) Grunow, 1880 (plate 2, fig 14)

Length Range: 20-210 µm; Width Range: 5-15 µm; Striae in 10 µm: 11-28.

Frustules isopolar but dorsiventral. Valves bilaterally asymmetrical (dorsiventral), with a slightly concave ventral margin and a convex dorsal margin. Poles rostrate or capitate, rarely (small cells only) simply rounded. Transverse striae visible, regularly spaced, sometimes visibly uniseriate. The raphe system runs along the ventral edge of the valve face and is subtended by large square or rectangular fibulae. In a frustule, the raphe systems of both valves lie on the same side ('hantzschioid symmetry') Two chloroplasts per cell, one towards each pole. Each chloroplast consists of two plates, one appressed to either side of the girdle, connected by a narrow but robust bridge containing a pyrenoid (this is seen end-on in girdle view, in profile in valve view). The central gap between the chloroplasts is where the nucleus lies.

Ecology: Alpha mesosaprobic taxa found in circumneutral to neutral environment (van Dam *et al*., 1994).

Class: *Fragilariophyceae*

1. *Synedra tabulata* (C.Agardh) Kützing, 1844 (plate 1, fig 6)

Length Range: 34-100 µm; Width Range: 4.5-6.0 µm; Striae in 10 µm: 12-15.

Valves are linear-lanceolate to lanceolate, with some specimens slightly or even distinctly asymmetric to the transapical axis, although this is not characteristic of the species. The apices are set off slightly and rounded but not capitate. The axial area is very broad and the width can be variable within populations. No central area is evident. The length:breadth ratio is also variable, even in this more restricted sense of the species (as compared to the interpretation of Krammer and Lange-Bertalot 1991). Striae are costate, areolae are not visible in the LM. Both apices appear to have small pore fields.

Ecology: Alpha mesosaprobic taxa found in circumneutral to neutral environment (van Dam *et al*., 1994).

2. *Synedra ulna* Ehrenberg, 1836 (plate 1, fig 5)

Length Range: 27-250 µm; Width Range: 1.5-9.0 µm; Mantle depth: 7-24 µm.

Linear or sometimes linear-lanceolate valves narrowing to blunt sub-rostrate or rostrate apices. Central area is distinct, roughly square in outline and usually reaching the valve margin. Ghost striae are often visible within the central area. In a few populations the central area is smaller, circular or elliptical in outline and not reaching the valve margin.

Ecology: Alpha mesosaprobic taxa found in polluted water (van Dam *et al*., 1994).

Discussion

A total of 102 diatom taxa belonging to 40 genera have been identified and reported for the first time from the Chambal River. The diatom flora was dominated by Bacillariophyceae (32 genera 89 species) followed by Fragilariophyceae (4 genera 6 species) and Coscinodiscophyceae (4 genera 5 species). The diatom community was mainly dominated by biraphids (*Navicula*, *Nitzschia*, *Achnanthidium, Gomphonema, Cymbella* and *Amphora*), followed by araphids (*Synedra*, *Fragilaria* and *Ulnaria*) and centric (*Cyclotella*, *Cyclostephanos* and *Melosira*). Biraphids have been also known to dominate diatom communities of Himalayan Rivers (Nautiyal and Nautiyal, 1999b; Nautiyal *et al*., 2004a) and Kumaun region (Juttner *et al*., 1996; Verma and Nautiyal, 2009). The Peninsular or other parts of India including the mountainous zones like the Western Ghats are equally rich in biraphid flora (Krishnamurthy, 1954). The most species rich genera were *Navicula*, *Nitzschia*, *Achnanthidium* and *Cymbella*. Similar results have been found in Vindhya region (Nautiyal and Verma, 2009).

In the present study, the number of taxa was higher in the lower stretch of the Chambal River as compared to the upper river basin sites. The lower stretch sites come under the National Chambal Sanctuary was more diverse probably due to the prevailing pristine condition and a lesser degree of anthropogenic stressors.

Diatom flora has been scantily studied in India. Most studies are from southern parts of the Peninsular India, its islands Andaman and Nicobar and some from Himalaya region (Dickie, 1882; Carter, 1926; Ghosh and Gaur, 1991; Rout and Gaur, 1994; Ormerod *et al*., 1994, 1996; Jüttner *et al*., 1996; Rothfritz *et al*., 1997; Jüttner *et al*., 1998; Gandhi, 1998; Nautiyal and Nautiyal, 1999 a, b; Jüttner and Cox, 2001; Khan, 2002; Nautiyal *et al*., 2004 a, b). In Himalayan regions, 200 diatom taxa were recorded from the Mandakini basin (Nautiyal *et al*., 2004b), 194 taxa were reported in Alaknanda-Ganga (Nautiyal and Nautiyal, 1999a), 293 in the Vindhya region (Nautiyal and Verma, 2009). As compared to high altitude rivers richness of Central Highlands Rivers was found to be higher (Nautiyal and Verma, 2009).

The upper stretch of river which have moderately polluted to heavily polluted sites (Srivastava *et al*., 2017, *In press*) was dominated by *N. amphibia*, *N. cryptotenella* and *C. meneghiniana*. Similarly, pristine sites with less anthropogenic disturbance were dominated by *B.vitrea*, which is an oligosaprobic species (van Dam *et al*., 1994) and *A. minutissimum*, an â-mesosaprobic species (van Dam *et al*., 1994). Abundance of diatom taxa varied less with seasons. In both the seasons, *A. minutissimum* and *B.vitrea* were dominant in moderately and sanctuary sites. However, in heavily polluted region, *N. amphibia* was dominant during winter and *C. meneghiniana* was dominant during summer.

Diatom communities have never been explored for the Chambal River. 102 diatom taxa have been reported for the first time in Chambal and a checklist has been formulated (Appendix I). The present study will help us to document the magnitude of biodiversity, understand the population and community dynamics of diatoms. However, still some of the taxa encountered in this study remain unidentified and require further taxonomic work. Chambal River is one of the few pristine rivers in India with high biological diversity. As such continuous and long time monitoring is required for the river. The use of diatoms becomes indispensible as diatoms have been known to be providing early warning signals of environmental changes and provide an integrated and holistic status of river health. The taxonomic studies on diatoms will help in the exploitation of the monitoring potential of diatoms.

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APPENDIX - I

Diatom community of River Chambal.

S.No	Species Name	S.No	Species Name
	Coscinodiscophyceae	46	*Gomphonema pseudoaugur* Lange- Bertalot
1	*Aulacoseira granulata* Ehrenberg	47	*Gomphocymbelopsis ancyli* (Grunow) Hustedt
2	*Cyclostephanos dubis* (Fricke) Round	48	*Gomphonema sphaerophorum* Ehrenberg
3	*Cyclotella meneghiniana* Kützing	49	*Geissleria decussis* Lange- Bertalot & Metzeltin
4	*Cyclotella stelligera* Grunow	50	*Gyrosigma scalproides* Rabenhorst
5	*Melosira varians* Agardh	51	*Hantzschia amphioxys* (Ehr) Grunow
	Bacillariophyceae	52	*Mastogloi smithii* Thwaites
1	*Achnanthidium biasolettiana* Grunow	53	*Navicula amphiceropsis* Lange- Bertalot & Rumrich
2	*Achnanthidium exiguum* Grunow	54	*Navicula caterva* Hohn & Hellerman
3	*Achnanthidium lineare* Grunow	55	*Navicula cataracta-rheni* Lange- Bertalot
4	*Achnanthidium petersenii* Hustedt	56	*Navicula cryptotenella* Lange- Bertalot
5	*Achnanthidium minutissimum* Kützing	57	*Navicula exilis* Kützing
6	*Achnanthidium min. v. gracillima* Lange- Bertalot	58	*Navicula parabryophila* Lange- Bertalot
7	*Achnanthidium min. v. jackii* Rabenhorst	59	*Navicula radiosa* Kützing
8	*Achnanthidium min. v .scotica*	60	*Navicula rostrata*
9	*Amphora aequalis* Krammer	61	*Navicula rostellata* (Kützing) Cleve
10	*Amphora coffeaeformis* Kützing	62	*Navicula symmetrica* Patrick
11	*Amphora copulata* Schoeman & Archibald	63	*Navicula stroemii* Hustedt
12	*Amphora twentiana* Krammer	64	*Navicula viridula (*Kützing) Ehrenberg
13	*Amphora veneta* Kützing	65	*Neidium ampliatum* (Ehrenberg) Krammer
14	*Aneumastus tuscula* Mann & Stickle (Hust.)	66	*Nitzschia amphibia* Grunow
15	*Bacillaria paradox* Gmelin	67	*Nitzschia acuta* Hantzsch
16	*Brachysira vitrea* Grunow	68	*Nitzschia acicularis* Kützing
17	*Caloneis bacillum* (Grunow)Cleve	69	*Nitzschia calida* Grunow
18	*Caloneis beccariana* Grunow	70	*Nitzschia capitellata* Hustedt
19	*Caloneis silicula* Ehrenberg	71	*Nitzschia frustulum* (Kützing)Grunow
20	*Cocconeis pediculus* Ehrenberg	72	*Nitzschia intermedia* Hantzsch
21	*Cocconeis placentula v. Lineata* Ehrenberg	73	*Nitzschia Hantzschiana* Rabenhorst
22	*Cocconeis scutellum* Ehrenberg	74	*Nitzschia obtusa* W. Smith
23	*Craticula ambigua* (Ehrenberg) Mann	75	*Nitzschia palea* (Kützing) W. Smith
24	*Craticula haloponanica* Lange- Bertalot	76	*Nitzschia punctata* (W. Smith) Grunow
25	*Cymbella aspera* Ehrenberg	77	*Nitzschia sinuta var. tabellaria*
26	*Cymbella kolbei* Hustedt	78	*Pinnularia stomatophora* (Grunow) Cleve
27	*Cymbella laevis* Kützing	79	*Placoneis elegans* Lange- Bertalot
28	*Cymbella metzeltinii* Krammer	80	*Placoneis witkowskii* Metzeltin Lange- Bertalot
29	*Cymbella tumida* Grunow	81	*Planothidium lanceolata var. rostrata*
30	*Cymbella vulgata* Krammer	82	*Planothidium rostrata* Lange- Bertalot
31	*Cymbopleura*	83	*Pleurosigma angulatum* W. Smith
32	*Cymbopleura citrus* Krammer	84	*Rhopalodia gibberula* Ehrenberg
33	*Cymbopleura diminuta* (Grunow) Krammer	85	*Sellaphora bacillum* Ehrenberg
34	*Cymbopleura microcephala*	86	*Sellaphora densistriata* Lange- Bertalot & Metzel
35	*Cymatopleura solea* W. Smith	87	*Surirella angustata* Kützing
36	*Cymbopleura rupicola*	88	*Surirella ovalis* Brebisson
37	*Diadesmis confervacea* Kützing		**Fragilariophyceae**
38	*Delicata sparsistriata v. parva* Krammer	1	*Fragilaria crotonensis* Kitton
39	*Denticula kuetzingii* Grunow	2	*Staurosira pinnata* (Ehrenberg) Williams & Round
40	*Diploneis pseudovalis* Hustedt	3	*Synedra rumpens* Kützing
41	*E. Jemtlandicum v venezolanum* Krammer	4	*Synedra ulna* Ehrenberg
42	*Epithemia adnata* Kützing	5	*Synedra tabulata* Kützing
43	*Eunotia pseudopectinalis* Hustedt	6	*Ulnaria ulna* Compere
44	*Gomphonema exilissimum* Lange- Bertalot		
45	*Gomphonema gracile* Ehrenberg		