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Morphological descriptors of different species of diatom *Cyclotella* (Kutzing) Brebisson in the surface sediments of Indian Sundarbans

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Abstract

The species diversity of the genus *Cyclotella* (Kutzing) Brebisson in the surface sediments of the Indian Sundarbans is presented with morphological and morphometric data and their analysis. Surface sediment samples were collected from three sampling sites adjoining different estuarine rivers of Indian Sundarbans with distinct ecological variations and land use patterns. Six different species of *Cyclotella* identified are *Cyclotella baltica* (Grunow) H. Hakansson, *C. striata* (Kutzing) Grunow, *C. litoralis* Lange & Syvertsen, *C. stylorum* Brightwell, *C. atomus* Husted and *C. meneghiniana* Kutzing. The most common species encountered in the system is *C. stylorum.* The morphological and morphometric descriptors of each species analysed using LM and SEM have been tabulated. The study also highlights the site-specific dynamics with regard to abundance of the different species of *Cyclotella* encountered.

Keywords: *Cyclotella*, morphology, morphometry, relative species abundance, Sundarbans, surface sediments

Introduction

Sundarbans, the single largest tract of mangrove ecosystem in the world attracts a lot of attention owing to the tremendous biodiversity that it sustains in its habitats. The noteworthy life-forms include not only the charismatic tigers and the mangroves but also the smaller forms of flora and fauna. Of immense interest among these are the diatoms (Kingdom-Chromista, Phylum-Bacillariophyta), which occupy almost all available habitats in this mangrove land and can be found in the aquatic systems (rivers, creek, canals, ponds, etc.) as phytoplankton, in surface sediments, within sediment cores, on exposed and submerged surfaces of mangroves, other macrophytic algae, fish, other aquatic animals and inanimate objects like concrete jetties, boats, ships, buildings, etc.

The earlier noteworthy publications in India on diatoms (Krishnamurthy, 1954; Sarode and Kamat, 1979, 1980, 1983, 1984; Gandhi, 1955, 1956, 1960, 1961, 1966; Gopinathan, 1984) and those in recent times (Karthick, *et al*., 2011; Karthick and Kociolek, 2012; Karthick, Hamilton and Kociolek, 2013; Karthick *et al*., 2015; Alakananda *et al*., 2015; Roy and Keshari, 2016; Keshari, Ghosh and Roy, 2016; Karthick, Taylor and Hamilton, 2017; Lokhande *et al*., 2017; Kale, Levkov and Karthick, 2017) mostly deal with marine, brackish and fresh water diatoms within benthos and phytoplankton assemblages. Moreover, most of these works focus on pennate diatoms. It is only in the works of Desikachary and Ranjitha Devi (1986), Desikachary and Prema (1987), Desikachary *et al*., (1987, 1987a), Desikachary (1988, 1989) and Karthick and Kociolek (2011) that we find detailed illustrations and photomicrography of many recent marine and fossil centric forms from India. There has been interest in centric diatoms of saline lakes and estuaries worldwide, particularly in the genus *Cyclotella* (Kutzing) Brébisson (Lange and Syvertsen 1989, Prasad *et al*., 1990, Wendker 1991, Hakansson *et al*., 1993, Hakansson and Kling 1994,
Hakansson 1996, 2002; Oliva *et al*., 2008). Although mostly reported as a freshwater species with very few works detailing marine/ brackishwater species (Lange and Syvertsen, 1989), the genus has also been reported to occur over a wide range of environmental conditions (Oliva *et al*., 2008). Hasle and Syvertsen (1997), reported *C. caspia, C.litoralis, C. striata, C. stylorum,* and *C. meneghiniana* (reported as *C. cryptica*) as marine representatives of *Cyclotella*. Subsequently, Oliva *et al*., (2008) mentioned eight species (*C. caspia*, *C. choctawhatcheeana*, *C. cryptica*, *C. quillensis*, *C. litoralis, C*. *meneghiniana*, *C. striata* and *C. stylorum*) as inhabitants of saline waters.

Worldwide reports on multiple species of *Cyclotella* deal with its diversification trends majorly based on morphological characters (Lowe, 1975; McFarland and Collins 1978; Serieyssol, 1981; Servant-Vildary, 1986; Loginova, 1990; Kociolek and Khursevich 2013). Hakansson (2002) described nine species of *Cyclotella* based on different morphological characters. Hasle and Syvertsen (1997) have given a comparative account of four

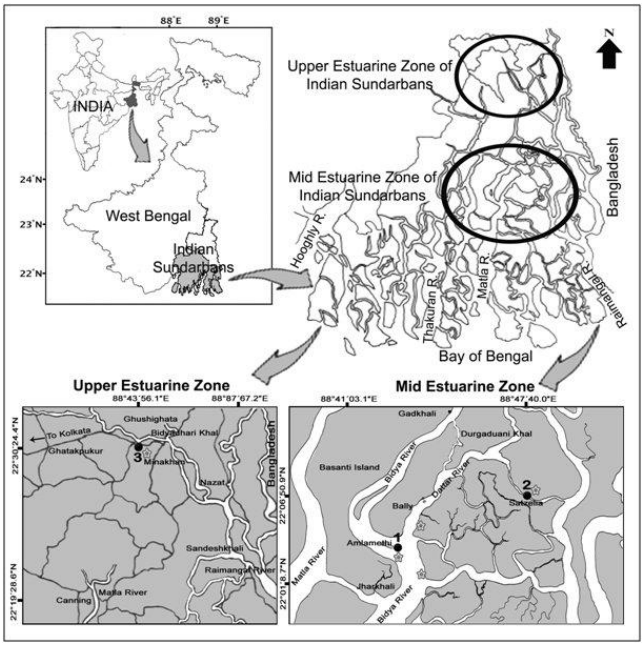
species of *Cyclotella* based on morphological variations. New species of *Cyclotella* – *C. desikacharyi* and *C. choctawatcheeana* were reported from Florida Bay and Choctawatchee Bay in Florida by Prasad, Nienow and Livingston (1990) and Prasad and Nienow (2006) respectively. Park, Lee and Lee (2013) described five species of *Cyclotella* – *C. atomus* var. *marina, C. baltica, C. litoralis, C. meduanae,* and *C. meneghiniana* from coastal waters of Korea. Tofilovska *et al*., (2016) recorded two new fossil *Cyclotella* species from Lake Ohrid, Macedonia. *Cyclotella* is in fact a considerably difficult genus to handle owing to the extent of morphological variation that it exhibits among species (Hakansson and Kling, 1994; Meyer and Hakansson, 1996). Genkal and Popovskaya (2008) reported morphological variability of a single species of *Cyclotella* - *Cyclotella ocellata* occurring in the Lake Khubsugul in Mongolia and attributed the morphological variability of qualitative (valve relief, presence of several morphotypes, structure and arrangement of rimoportulae, central and marginal fultoportulae, and alveoli) and quantitative features (diameter of vegetative and initial valves, number of central fultoportulae and rimoportulae) to the possibility of the lake being simultaneously inhabited by several subpopulations of *C. ocellata* with cells of various sizes and therefore the formation of auxospores occurring in several size ranges. Hakansson (2002) in his comprehensive studies on original materials from museum collections noted that the genus *Cyclotella* includes species which have a central area that is smooth, none to several fultoportulae on valve face, a simple marginal striation that is alveolate and the rimoportulae, typically with an external round or slit-like opening on the mantle that interrupts the ring of fultoportulae on the mantle. Although a few species complexes exhibit external opening of the rimoportula on the valve face usually near the junction of the valve face - mantle. Hakansson (2002) selected *C. distinguenda* as the type genus, and transferred a few species with an areolate central area consisting of areolae and valve face fultoportulae (in some species only fultoportulae in others only areolae), and/ or with a complex alveolate striated marginal area, and/ or with rimoportulae on the valve face at the end of a shortened interstriae to the new genus *Puncticulata* Håkansson gen. nov. Houk and Klee (2004) proposed the transfer of "stelligeroid" taxa of the genus *Cyclotella* (Kützing) Brébisson into a new genus *Discostella* gen. nov., these forms have marginal fultoportulae and the rimoportula(e) positioned between costae and so do not fit the current description of the genus *Cyclotella* (Kützing) Brébisson nom. cons. Scheffler, Houk and Klee (2004) discussed the morphology and morphological variability of *Cyclotella dellcatula* Hustedt from Hustedt's materials.

Studies on diatoms in sediments are few in India and almost none have been done on surface sediments in Sundarbans except for Mandal *et al*., (2015). The present work is a first report of different morphological forms of *Cyclotella* spp. in surface sediments of Indian Sundarbans.

Materials and methods

Sampling sites:

Sampling of surface sediments was conducted from three different zones in Indian Sundarbans, each belonging to different land strata characteristic and varied land use patterns (Map – 1). The collections were made between March, 2013 and March, 2015.



Map 1. Sampling sites in the upper and mid estuarine zones of Indian Sundarbans

Sampling site 1: Sampling site 1 is located in a newly silted up landmass situated on the bank of the river Dattar at Amlamethi island in the mid estuarine zone of Indian Sundarbans. The GPS coordinates of this site are 22° 2′ 40.5″ N and 88° 43′52.4″ E. No human settlement or activity is recorded in the vicinity of the site.

Sampling site 2: Sampling site 2 is located on the bank of Bidya river at Satzelia in the mid estuarine zone of Indian Sundarbans. The GPS coordinates being 22° 6′ 50.9″ N and 88° 47′ 40.0″ E. This area is scarcely populated with slight anthropogenic disturbance.

Sampling site 3: Sampling site 3 is located on the bank of Bidyadhari river at Minakhan within the upper estuarine zone of Indian Sundarbans. The GPS coordinates of this site are 22° 30′ 24.4″ N and 88° 43′ 56.1″ E. This area is densely populated, thus implying pronounced anthropogenic disturbance.

Sampling:
The sediment samples investigated were collected using 15 cm long and 3 cm diameter glass tubes with open mouths on both sides. The glass tubes were inserted straight through the surface sediments to let the sediment fill up the entire glass tube. Samples were collected from 3 sampling points at every sampling site. After collection the samples were air dried in the laboratory. The dried samples from each site were mixed well. These samples were treated chemically as described in Mandal *et al*., (2015) to remove calcium carbonate particles and organic materials present.

Analysis:
Microscopic analysis: From the treated samples, 50 µl aliquots were analysed on each slide with the samples mounted in Naphrax^{TM} for light microscopic study. The specimens were then observed under a Labomed LX-300 light microscope at 100x magnification using oil immersion. During LM observation a minimum of 500 frustules were counted (FC) from each site and relative species abundance (RSA) of each *Cyclotella* species was calculated.

$$RSA = FC\ of\ a\ single\ Cyclotella\ species/Total\ FC\ of\ all\ Cyclotella\ species$$

Scanning electron microscopy was done with cleaned and treated specimens, air dried on 1cm X 1cm glass stubs, and examined with a Carl Zeiss, model – EVO LS 10 at 10 kV. The SEM analysis was performed at the University of Kalyani's DST-PURSE sponsored Central Instrumentation Facility. Descriptor terminology followed was according to Cox (1996), Lowe (1975), Park, Lee and Lee (2013) among others and identification was carried out using number of manuals, particularly Greville (1866), VanLandingham (1978), Desikachary and Prema (1987), Hasle and Syvertsen (1997), Park, Lee and Lee (2013), Guiry and Guiry (2016).

Statistical analysis: The frustule count data from each sampling site was statistically analysed for deriving diversity indices and cluster analysis of morphological parameters for phylogenetic studies using PAST3 software.

Results
Analysis of surface sediments (0-15cm) from different sampling sites of Indian Sundarbans established the presence of six different species of *Cyclotella* – *C. baltica*, *C. striata*, *C. litoralis*, *C. stylorum*, *C. atomus* and *C. meneghiniana* (Plates 1 - 4).

Most of the *Cyclotella* species (*C. baltica, C. litoralis, C. striata* and *C. stylorum*) were found to be present in all the three studied sites, but *C. atomus* and *C. meneghiniana* show restricted presence, with presence of *C. atomus* noted only from Minakhan (site - 3) and *C. meneghiniana* noted only from Amlamethi (site - 1).

The frustule count data (FC) of *Cyclotella* within a total count of ±500 diatom frustules from each site and an estimate of relative species abundance (RSA) of each *Cyclotella* species in relation to total number of *Cyclotella* frustules at each site (Table - 1) reveals highest frustule count of different species of *Cyclotella* at site - 1 (Amlamethi) with highest frustule count noted in case of *C. litoralis* at site – 1 and *C. stylorum* as the most commonly encountered species with highest total frustule count. Highest RSA was recorded for *C. litoralis* at site – 1 followed by *C. baltica* at site – 2. Incidentally *C. litoralis* was reported for the first time from Jharkhali in Indian Sundarbans also in the surface sediments of the site by Mandal et al. (2015), its presence in the adjoining aquatic system is yet to be confirmed.

Table -1. Frustule count and Relative Species Abundance of *Cyclotella* frustules per 500 diatom frustules at the 3 sampling sites

	Cyclotella baltica		*Cyclotella striata*		*Cyclotella litoralis*		*Cyclotella stylorum*		*Cyclotella atomus*		*Cyclotella meneghiniana*		Total FC of *Cyclo-tella*
	FC	RSA	FC	RSA	FC	RSA	FC	RSA	FC	RSA	FC	RSA	
Site - 1	16	0.09	26	0.15	76	0.44	48	0.28	0	0	7	0.04	173
Site - 2	61	0.41	42	0.28	14	0.09	33	0.22	0	0	0	0	140
Site - 3	13	0.10	32	0.25	22	0.17	36	0.28	16	0.12	0	0	129

A further analysis of the diversity indices (Table - 2) yielded highest species diversity of *Cyclotella* at site - 3 both in terms of Shannon's Diversity Index and Brillouin's Diversity Index (Figure - 1). The later was performed since randomness of the sample could not be guaranteed. Nevertheless similar trends in diversity data obtained in terms of both the indices ensures the non random attribute of our sample.

Table -2. Diversity Indices of *Cyclotella* spp. at the 3 Sampling Sites

	Site - 1	**Site - 2**	**Site - 3**
Species Richness	5	4	5
Individuals	173	150	119
Dominance	0.30	0.30	0.22
Evenness	0.77	0.89	0.93

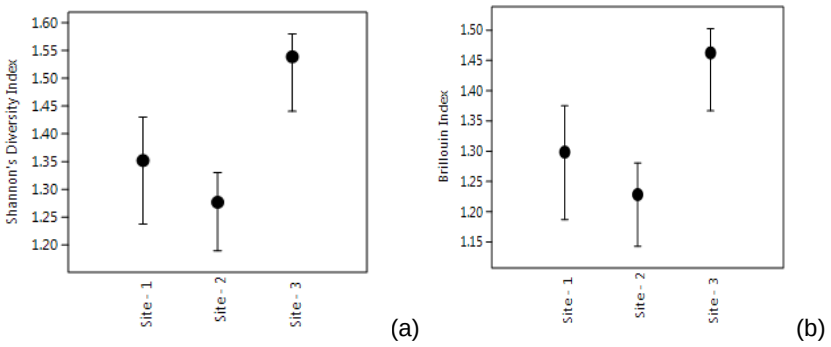


Figure - 1. Comparison of Diversity Indices at the 3 sampling sites. (a) Shannon's Diversity Index; (b) Brillouin' Diversity Index

Taxonomic enumeration
Cyclotella baltica (Grunow) H. Hakansson
Basionym: *Cyclotella striata* var. *baltica* Grunow
Slide: Ghusi/3-15/0-15/088/PLKU/BB
Fig.: Plate 1a; Plate 2 ai, aii
Description: Valves 11 - 67 µm in diameter. Tangentially undulate and slightly colliculate ornamentation present in the central area. Diameter of the central area ranges from 12 - 35µm. Striae density ranges from 8 to 12/ 10µm. Length of the striae ranges from 4 to 15 µm. Valve face fultoportula number 2 to 7. A single rimoportula present internally besides the ring of marginal fultoportula, marginal fultoportuale located at every interstriae.

Distribution: Cyclotella baltica was reported from Baltic Sea by Grunow (1882), Tanaka (2007) studied this species from Mikawa Bay (from Hokkaido to Kyushu in Lake Abshiri) and marked it as a brackish to marine water

species. Park, Lee and Lee (2013), described this species from Korean coastal waters. We have collected this species from the surface sediments of all the three sampling sites in our study area. This is the first record of *C. baltica* from this area.

Cyclotella striata (Kutzing) Grunow
Basionym: *Coscinodiscus striatus* Kutzing
Slide: Mina/3-15/0-15/073/PLKU/BB
Fig.: Plate 1b; Plate 2 bi, bii
Description: Valves range from 12 to 56 µm in diameter. Tangential undulation and slightly colliculate ornamentation present in the central area. Diameter of the central area ranges from 8 to 48 µm. Striae density ranges from 8 to 14/ 10µm. Length of the striae ranges from 4 to 6 µm. Valve face fultoportula present in the central area (variable number) each with 3 satellite pores. Valves with marginal chambers, each covering 2-3 alveolus openings.

Distribution: Jasprica and Hafner (2005) described *C. striata* from Croatia. Prasad and Nienow (2006) studied it from Germany. Park *et al*., (2012) reported this species from Northeast Asia, Japan. *C. striata* was found at all the three sampling sites of our study area in Indian Sundarban. It is a common species in the phytoplankton assemblages of Indian Sundarbans (Choudhury and Pal, 2010; Manna *et al.*, 2010, Mitra, 2013, Mukherjee *et al.*, 2014). It was reported for the first time in the sub-surface sediment at a depth of 30-40 cm at Jharkhali in Indian Sundarbans (Mandal *et al*., 2015).

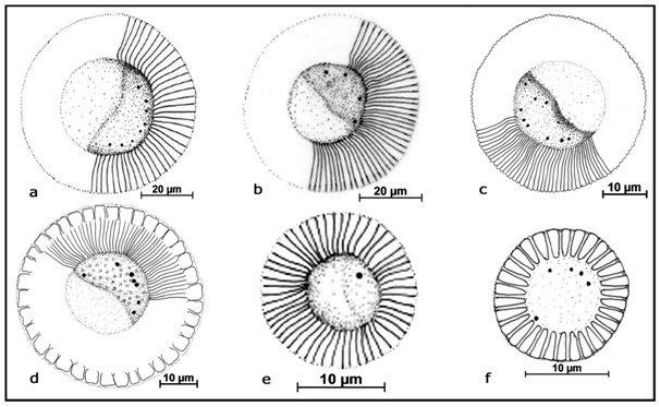


Plate – 1 (figs. a - f). Camera lucida sketches of *Cyclotella* spp. from surface sediments of Indian Sundarbans. a. *C. baltica*; b. *C. striata*; c. *C. litoralis*; d. *C. stylorum*; e. *C. atomus*; f. *C. meneghiniana*

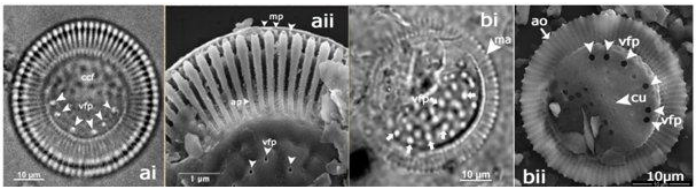


Plate – 2. figs. ai. LM of *C. baltica* showing valve face fultoportulae (vfp) restricted to one side of the undulated central field in an arc like formation and the colliculate nature of the central field undulation (ccf). fig. aii. SEM of *C. baltica* showing distinction between tangentially undulate central field and mantle region with prominent fultoportulae in valve face (vfp), marginal fultoportulae on every interstriae (mp) and prominent perforations in alveolae (ap). fig. bi. LM of *C. striata* with tangentially undulate central field and a narrow mantle compared to central field with 2-3 interstriae opening into marginal chambers each covering 2-3 alveolus openings (ma) and scattered valve face fultoportulae (vfp). fig. bii. SEM of *C. striata* showing colliculate central field that is tangentially undulate (cu), scattered valve face fultoportulae (fp) at the edge of the central field and marginal zone with interstriae, 2–3 of which create an alveolus opening (ao).

Cyclotella litoralis Lange & Syvertsen

Holotype: *Cyclotella tecta* Hakansson & Ross
Slide: Amla/3-13/0-15/026/PLKU/BB
Fig.: Plate 1c; Plate 3 ai, aii
Description: Valves range from 29 to 61 µm in diameter. Central area tangentially undulate with colliculate ornamentation. Diameter of the central area ranges from 9 to 36 µm. Striae density ranges from 10 to 14/ 10 µm. Length of the striae ranges from 4 to 9 µm. Fultoportula numbering 8 – 12 present in the central area, distributed

in one or more arcs near the margin of the central field. Valves without any marginal chambers. Marginal fultoportula in a ring each present at every interstriae, and alveoli with prominent perforated layer running from central part of the valve to the margin.
Distribution: Lange and Syvertsen (1989) described this species of *Cyclotella* from the south western Atlantic. Tanaka (2007) reported this from Japan (Isahaya Bay, Nagasaki Prefecture). Park, Lee and Lee (2013) and Park *et al*., (2012) described this species from Japan and Korea respectively. *Cyclotella litoralis* was frequently encountered in all the three sampling sites of our study area. It was reported for the first time from surface sediment at a depth of 0-10 cm at Jharkhali in Indian Sundarbans by Mandal *et al*., (2015).

Cyclotella stylorum Brightwell
Holotype: *Cyclotella tecta* Hakansson & Ross
Slide: Mina/3-15/0-15/074/PLKU/BB
Fig.: Plate 1d; Plate 3 bi, bii
Description: Valves 17 – 83 µm in diameter. Tangential undulation and colliculate ornamentation present in the central area. Central area ranges from 7 to 43 µm in diameter. Striae density ranges from 8 to 15/ 10µm. Length of the striae ranges from 3 to 17 µm. Fultoportula present in the central area numbers 6 to 14 arranged in a semi-hemispherical formation. A single marginal rimoportulae along with a ring marginal fultoportulae. Valves with prominent marginal chambers covering 3 to 4 alveolus openings.
Distribution: Prasad and Nienow (2006) reported this species from Florida bay, USA. This species of *Cyclotella* is the most frequently observed species at all the three sampling sites of our study area. The species has previously found mention in the phytoplankton assemblages in tidal creeks of Sundarbans in India and Bangladesh (Bhattacharjee *et al*., 2013; Rahaman *et al*., 2013).

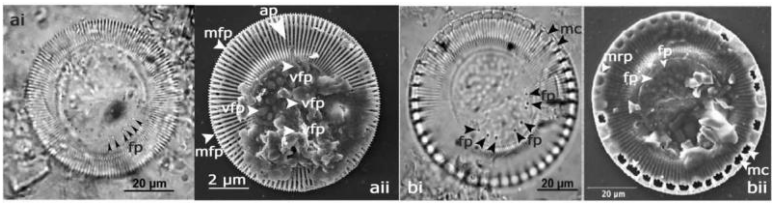


Plate – 3. fig. ai. LM of *C. litoralis* showing tangentially undulated central field with numerous fultoportulae (vfp) in valve face and no marginal chambers (ma). fig. aii. SEM of *C. litoralis* showing prominent undulate and colliculate nature of central field of valve along with numerous valve face fultopotulae distributed arbitrarily all over the central region, ring of marginal fultoportulae between every consecutive inter striae (mfp) and alveoli with prominent perforation running from central part of the valve to the margin (ap). fig. bi. LM of *C. stylorum* with tangentially undulate central field and prominent fultoportulae in the central field and prominent marginal chambers (mc) and 7 prominent valve face fultoportulae (fp). fig. bii. SEM of *C. stylorum* showing colliculate central field that is tangentially undulate, number of valve face fultoportulae (fp), a single marginal rimoportulae (mrp) and marginal zone with interstriae, 2–3 of which create a marginal chamber (mc).

Cyclotella atomus Hustedt
Holotype: *Cyclotella tecta* Hakansson and Ross
Slide: Mina/3-15/0-15/074/PLKU/BB
Fig.: Plate 1e; Plate 4 ai, aii
Description: Valves 12 to 19 µm in diameter. Central area flat to slightly tangentially undulate with smooth central area. Central area ranges from 9 to 14 µm in diameter. Striae density ranges from 4 to 10/ 10µm. Length of striae ranges from 1.5 to 2 µm. A single fultoportula present in the central region associated with 3 satellite pores. Marginal chambers absent. Ring of marginal fultoportulae present along with a single marginal rimoportulae between two consecutive marginal fultoportulae.
Distribution: Hustedt (1937) described this genus from Sindanglaja Reservoir in West Java, Indonesia. Schoeman and Archibald (1976) described the species from South Africa. Hakansson and Clarke (1997) discussed its morphology and taxonomy. Kiss *et al*., (2012) described this species among other centric diatoms from large rivers and tributaries of Hungary. *C. atomus* was found only at site - 3 (Minakhan) during this study and is the first report of this species from the Indian Sundarbans.

Cyclotella meneghiniana Kutzing
Holotype: *Cyclotella tecta* Hakansson and Ross
Slide: Ghusi/3-15/0-15/087/PLKU/BB
Fig.: Plate 1f; Plate 4 bi, bii
Description: Valves 15 to 27 µm in diameter. Slightly tangentially undulate with smooth central region. Central area ranges from 7 to 15 µm in diameter. Striae density ranges from 7 to 9/ 10µm. Length of striae ranges from 4 to 6 µm. Fultoportula present in the central region numbering from 3 to 7 arranged in an arc like formation near

the margin of the central field and associated with 2-3 satellite pores. One marginal rimoportula present along with a ring of marginal fultoportulae. Valves without any marginal chambers.

Distribution: Hakansson (2002) and Tanaka (2007) have reported this species from different habitats of brackish and marine waters. Lee and Lee (1988) have described this species from Korea. *C. meneghiniana* was found in the surface sediment at site - 1 (Amlamethi) only during the present study, although it is widely reported in the phytoplankton assemblages of Indian Sundarbans (Choudhury and Pal, 2010; Mitra *et al.*, 2014).

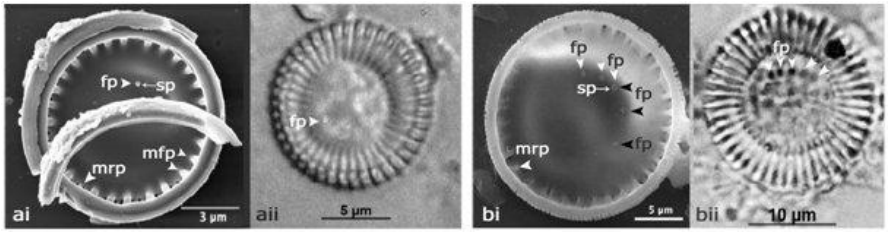


Plate - 4. figs. ai. SEM of inner side of valve *C. atomus* showing central field with a single prominent fultoportulae (fp) associated with 3 satellite pores (sp) and ring of marginal fultoportulae (mfp) with a single marginal rimoportulae (mrp). aii. LM of *C. atomus* showing single fultoportulae and simple alveolus structures running from edge of the central field to margins. fig. bi. SEM of *C. meneghiniana* with tangentially undulate central field and 5 fultoportulae in the central region arranged in an arc each with 2-3 satellite pores and a single marginal rimoportula (mrp) located within a ring of marginal fultoportuale. bii. LM of *C. meneghiniana* showing colliculate central field that is tangentially undulate and fultoportulae (numbering 6) near the edge of the central field.

The presence of a heterovalvar character with high morphological variability in different species of *Cyclotella* renders its identification extremely problematic (Houk *et al*. 2010; Tofilovska *et al.* 2016). A comparative analysis of the morphological characters of the six different *Cyclotella* species from the surface sediments of Indian Sundarbans was performed to determine relationships between the species identified (Table – 3) and validate their taxonomic identities determined during the study.

Table – 3. Comparison of *Cyclotella* spp. from Indian Sundarbans *wrt* morphological descriptors

#	*C. baltica*	*C. striata*	*C. litoralis*	*C. stylorum*	*C. atomus*	*C. meneghiniana*
1	11 - 67	12 - 56	29 - 61	17 - 83	12 - 19	15 - 27
2	Tangentially undulate	Tangentially undulate	Tangentially undulate	Tangentially undulate	Flat to slightly tangentially undulate	Slightly tangentially undulate
3	Slightly colliculate	Slightly colliculate	Prominently Colliculate	Colliculate	Smooth	Smooth
4	12 - 35	8 - 48	9 - 36	7 - 43	9 - 14	7 - 15
5	4 – 15	4 - 6	4 - 9	3 - 17	1.5 - 2	4 - 6
6	8 - 12	8 - 14	10 - 14	8 - 15	4 - 10	7 - 9
7	2 - 7	variable	8 - 12	6 - 14	1	3 - 7
8	Restricted to one side of undulation of central field	Scattered in the central field	In a ring near the margin of the central field	In a semi-circular ring near the margin of the central field	central field	central field
9	Not observed	Fultoportula associated with 3 satellite pores	Not observed	Not observed	Fultoportula associated with 3 satellite pores	Fultoportula associated with 2-3 satellite pores
10	Between the ring of marginal fultoportula	Could not be observed	Could not be observed	Between the ring of marginal fultoportula	Between the ring of marginal fultoportula	Between the ring of marginal fultoportula
11	Ring of marginal fultoportulae	Could not be observed	Ring of marginal fultoportulae	Ring of marginal fultoportulae	Ring of marginal fultoportulae	Ring of marginal fultoportulae

Morphological Characters – 1: diameter range (µm); 2: degree of undulation; 3: central field ornamentation; 4: central field diameter range (µm); 5: range of striae length (µm); 6: range of striae in 10 µm; 7: number of valve face fultoportulae; 8: location of valve face fultoportulae; 9: associated satellite pores; 10: location of rimoportulae; 11: marginal fultoportulae

Discussion

The six species of *Cyclotella* being described from the Indian Sundarbans possess the following generic characters that validates their inclusion in the genus *Cyclotella* (Kutzing) Brebisson –

1. Organisms occur as solitary cells
2. Valves tangentially undulated at various degrees
3. Central field prominently distinguishable from the marginal region
4. One to many fultoportulae in the central field
5. Presence of marginal ring of fultoportulae (not observed in *C. striata*)
6. Presence of a single marginal rimoportulae (not observed in *C. striata* and *C. litoralis*)

Mostly reported as a species that inhabits aquatic habitats, the *Cyclotella* species described in the present study were found occurring within the surface sediments of Indian Sundarbans. This may be attributed to the fact that this particular ecosystem, particularly sites 1 and 2 in the lower estuarine zone are located within a macrotidal regime. The surface sediments near the estuarine river banks are regularly inundated by tidal water and the diatom species usually get trapped within the surface sediments. But, interestingly species like *C. baltica*, *C. litoralis*, *C. atomus* have never found mention within the extensively studied phytoplankton assemblages of this ecosystem and are being reported for the first time from this area. Moreover, the presence of highest frustule count of different species of *Cyclotella* at site - 1 (Amlamethi) implies that *Cyclotella* shows preference for habitats which have minimum impact of anthropogenic disturbance, and on a similar note *C. litoralis* and *C. stylorum* with highest frustule count at site – 1 reflects upon this particular species' preference for clean and undisturbed habitats. On the other hand *C. baltica* and *C. striata* with high frustule count at site – 2 show their tolerance towards anthropogenic disturbances in the habitats that they occupy. *C. atomus* with its restricted presence at site – 3 is reflective of the species' preference for high anthropogenically disturbed ecosystems.

Conclusion

The study establishes the presence of six different *Cyclotella* species within the surface sediment habitat in the Indian Sundarbans. Among the species *C. atomus* and *C. meneghiniana* are closer in terms of their morphological characters and are also very different from the species *C. baltica, C. striata, C. litoralis* and *C. stylorum*. These two species are also very limited in terms of their site specificity and were found to occur at only one site each during the study. The rest of the four species occurred with high abundance at all the sites. A detailed analysis of *Cyclotella* species occurring within phytoplankton assemblages on a similar line of study is further needed to establish a comprehensive account of *Cyclotella* species in Indian Sundarbans.

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