CORPUS PUBLISHERS

Corpus International Journal of Oceanography and Aquatic Research (CIJOAR)

Volume 3 Issue 1, 2025

Article Information

Received date : January 17, 2025

Published date: January 31, 2025

*Corresponding author

Abhishek Mukherjee, Department of Marine Science, Calcutta University 35 Ballygunge Circular Road Kolkata-700 019, West Bengal, India

Keywords: *Coscinodiscus*; *Chaetoceros*; Hooghly Estuary; Sundarbans; Bay of Bengal

DOI: 10.54026/CIJOAR/1004

Research Article

Light Microscopic Morphometry of Species under two Cosmopolitan Centric Diatom *Coscinodiscus* and *Chaetoceros* from Hooghly-Matla Estuarine Waters around Indian Sundarbans

Abhishek Mukherjee[1]*and Tarun Kumar De[1]

[1]*Department of Marine Science, Calcutta University; 35 Ballygunge Circular Road; Kolkata-700 019, West Bengal, India.*

Abstract

The paper describes the light microscope mediated morphometry of widespread centric diatom genera *Coscinodiscus* and *Chaetoceros* based on surveys conducted for more than 15 years (2009-2024) in the brackish water realm of the Hooghly River involving sampling sites within the domain of Hooghly-Matla estuarine ecoregion encompassing both mangroves dominated as well as mangrove-devoid coastal areas associated with the Indian Sundarbans. The two genera were selected for the study owing to them being particularly large under their respective taxonomic families. Samples were collected year-round which was segregated into premonsoon, monsoon and post monsoon seasons to differentiate between the physicochemical influence on the distribution of certain species. It revealed the species that were present year-round as well as the seasonal ones. Some of the species observed during the study were not hitherto described from Hooghly estuarine region. The species at least twice recorded within a year were considered for the study to exclude the accidental introductions. A total of 19 species belonging to *Coscinodiscus* and 23 species under *Chaetoceros* were documented repetitively throughout the duration of the study. These species are described and illustrated in this article based on observations made under light microscopic objectives.

Introduction

The ubiquitous distribution of euryhaline centric and araphid diatoms is usually made sense of as their rather broad spectrum ecological malleability. According to [1-15] the identification and geographical distribution of a plankton species is inexorably linked to the actual concept of species applied in the taxonomic sense and the set of parameters employed in delineation of the species concerned. As speciation is the ultimate product of the process of evolution which itself is based on its presumptive notion of continuity, not all the characteristic features are well reflected within an ongoing differentiation resulting in species variability [16-24] and taxonomic flexibility both in terms of the concepts used and species grouped under various hierarchies formulated keeping in view of their genetic heterogeneity [25-81,82-86].The genus *Coscinodiscus* C. G. Ehrenberg 1839 belongs to one of the most dominant families of centric diatoms, Coscinodiscaceae Kützing 1844 (presently comprising nine genera) and is regarded as one of the largest marine planktonic diatom genera, with about 500 taxonomically valid taxa, according to [90-93]. Although a great number of most frequently recorded *Coscinodiscus* species have been transferred to [94] emend. [48], [1-39] to new genera as illustrated by the fact that of the approximately twenty *Coscinodiscus* species recorded in the Arctic literature between 1853 and 1911, only 4 are regarded as belonging to the genus [30]. The species under the genus is more or less cosmopolitan in distribution [47]. The bacillariophyceaen family Chaetocerotaceae Ralfs 1861 consists of five genera, viz. (87,88,8,9,36-39) single species of which has been assigned to the genus Attheya T. West 1860 as well as under *Chaetoceros*), (58-61,87) *Chaetoceros* is arguably the largest and most species rich genus of marine planktonic diatoms (with about 400 valid species) and mostly dominates the estuary mouths and coastal waters around the world (3). The taxonomic status within Chaetocerotaceae at present is somewhat unclear. The genus is more or less cosmopolitan in distribution (15,16) Works of euryhaline centric diatoms observed, especially the concerned genera, in estuarine waters surrounding the Indian Sundarbans at morphotaxonomic level have been rather scarce, and most of studies on morphotaxonomic, experimental as well as ecological aspects of phytoplankton in general, along with those emphasizing on diatoms (7,61-78) observed in the concerned ecoregion have been performed by a handful of the authors. The presently described study focuses on the brackish water estuarine region at the confluence of the River Hooghly and the Bay of Bengal in the vicinity of Indian Sundarbans. It had revealed eleven species under the genera *Coscinodiscus* and *Chaetoceros* respectively.

Materials and Methods

Study Area

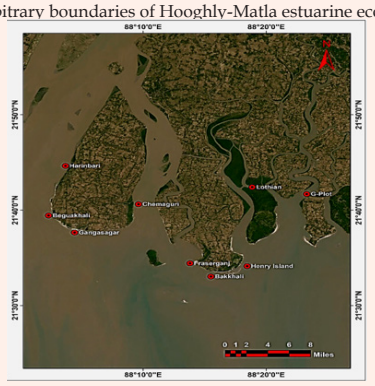
The estuarine and mangrove dominated ecoregions associated with the Hooghly-Matla river complex on which the presently reported work had taken place is characterized by its complex biogeochemical interactions and myriad works on equally

varied aspects viz. physico-chemical, geochemical, microbial (prokaryotic/eukaryotic) interspecific, and prokaryote-eukaryote interaction, influence of the environment on the organisms, the latter's role as indicators to changes etc. which had been observed both in situ and in vitro [25-28] to interpret the recorded data in the context of the ecosystem.

Sampling Sites

The study area is situated by the Indian Sundarban at 21°32' - 21°60' N and 88°05' - 89° E. which comprises a part of the estuarine system of the river Hooghly (Ganges) NE coast of Bay of Bengal. It is the largest delta on the planet (world heritage site, /www.unesco.org/en/list452), and is known for its biodiversity of mangrove flora and fauna, both on land and in water. The main artery of this ecosystem, the River Ganges along with its several distributaries, forms a confluence with the Bay of Bengal on its North West coast. Lower part of this estuarine system is crisscrossed by numerous creeks and wide distributaries and several marshy islands are formed. Nine sampling stations (Figure 1) had been selected viz. Harinbari (21.7440°N, 88.0616°E), Beguakhali (21.6573°N, 88.0387°E), Gangasagar (21.6276°N, 88.0739°E), Chemaguri (21.6770°N, 88.1604°E), Frasergunj (21.5738°N, 88.2302°E), Bakkhali (21.5507°N, 88.2585°E), Henry Island (21.5689°N, 88.3075°E), Lothian Island (21.7069°N, 88.3144°E), and G plot (21.6948°N, 88.4221°E) across the Hooghly-Matla estuarine region.

Figure 1: The map shows the sites of Phytoplankton collection from surface layers within the arbitrary boundaries of Hooghly-Matla estuarine ecoregion.



Sample Collection

The sampling frequency was mostly governed by the onset of meteorologically discernible seasons for which the authors had broadly categorized the 12 months into premonsoon (March-June), monsoon (July-October), and post monsoon (November-February) periods, although not all the months specified registered the intended set of conditions to be properly assigned to particular season, and in such cases contingent changes were adopted. The actual duration of the study has been well over a decade (2009-2024) and the taxa mentioned here are the ones which had been documented each year, at least once. The skimming of the surface waters for phytoplankton sampling was performed using a hand towed plankton net (bolting silk) with a knot to knot rhombic mesh size of ~45 µm. The net was dipped up to a depth of one and a half feet from the surface and both the high and low tide phytoplankton assemblages were studied. The gear used in this purpose was mainly country boats. The phytoplankton concentrates were transferred to 25 ml TARSON bottles and fixed with a composite mixture of 2% (v/v) Formalin and 2.5% (v/v) Acidic Lugol's iodine, as it had demonstrated to be more conducive for long storage [67] to increase the visibility of diatom species under the light microscope. Sole application of Lugol's iodine is detrimental to the preservation of setae and flagella, thereby compromising the accurate taxonomic identification of the taxa.

Sample Analysis

Light Microscopic (LM) Observations: Preserved samples were shaken well before examination. Phytoplankton specimens were prepared mainly as temporary (some were made permanent) slides. The collected samples were examined under the light microscopes (Olympus^R Compound and Magnus^R Inverted) to determine the general community composition of phytoplankton and to identify the different species at the genus and species levels. Different LM magnifications (100× - 1500×) were used according to the size of the phytoplankton. In addition, a bright field was used for interferential contrasts.

Phase contrast microscopy: Some of the samples were also viewed using a phase contrast microscopy (Nikon^R Eclipse-E200) for discerning the closely matched species more accurately.

Phytoplankton Species Identification: Phytoplankton taxa were identified using a variety of validly published bibliographic references [1,91,92,55-57,12,13]

Results and Discussion

Systematic Position and Morphometric Description of The Genus *Coscinodiscus* Ehrenberg

The Genus *Coscinodiscus* is taxonomically nestled under – Class: Bacillariophyceae, Subclass: Coscinodiscophycidae, Superorder: Coscinodiscanae, Order: Coscinodiscales, Family: Coscinodiscaceae. Members of the *Coscinodiscus* genus typically have disc or box-shaped cells, circular valves without big knobs or processes, with hexagonal areolae organized in different patterns, or minuscule, round puncta. These apertures seem to be rounded "central spots" in the areolae when viewed from the exterior of the valve. Although the areolae are often in a closed mesh system, certain species have more or less circular areolae that do not contact one another, according to [12]. Either smooth or sculptured, the frustule center frequently has bigger areolae arranged in a rosette. There are species that might be arosette. Marginal spinulae can be present or absent, but are often tiny and imperceptible when present. When present, apiculi (singular: apiculus) are spaced more than 90 degrees apart on the margin. There are frequently intercalary bands. Girdle zone made up of one or more intercalary bands that resemble collars or one girdle band to each valve. Chromatophores often have a large number of tiny plates. Under higher magnification and appropriate staining, the nucleus is typically at the center of one valve or suspended in the middle of the cell by protoplasmic strands [45-48] The ensuing account deals with the observed species under *Coscinodiscus* (Figure 2), collected from the sites of sampling.

Coscinodiscus argus [33]

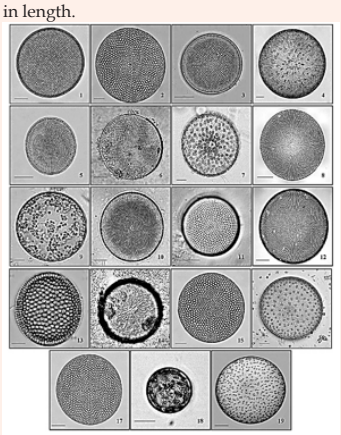
Flat valve face, sometimes concave in girdle view, rounded margins, high and steep mantle, LM reveals central transparent region, central and peripheral areolae differ in shape, but similar in size, increase in size from center towards mid-periphery, decreasing at margin, Decussating arcs not prominent, but present. Hyaline lines (ribs) not perceived with LM, neither are the marginal processes. This is the key difference with *C. radiatus*. Foramina and cribra just discernible with LM, in the present specimens the diameter ranged between 185 - 270 µm, normally can be up to 320 µm, with 4 - 6 striae per 10 µm [92].

Coscinodiscus asteromphalus [36]

(Synonyms - *Coscinodiscus radiatus* var. *asteromphalus* (Ehrenberg) Ehrenberg, *Coscinodiscus asteromphalus* var. *conspicua Grunow*).

Cells discoid, slightly convex in girdle view, valve center depressed, gently sloping mantle, Central rosette with larger areolae, usually prominent under low light at high magnification, Areolar arcs form distinct decussates, Cribra indistinct, barely visible at times, Finer areolae form interstitial meshes, partially complete striae,~4 striae in 10 µm of the present materials, labiate processes present but low in number, numerous planar chloroplasts clearly discernible in larger cells, barely visible ring of processes near the margin [47]. Diameter mostly within 300 µm, 180 - 280 µm in high salinity waters [50,51], 300 - 330 µm in the present specimens, taken from different localities across Hooghly-Matla estuary.

Figure 2: LM Images of valve view of various *Coscinodiscus* species encountered – 1. *C. argus*, 2. *C. asteromphalus*, 3. *C. concinnus*, 4. *C. centralis*, 5. *C. curvatulus*, 6. *C. eccentricus*, 7. *C. granii*, 8. *C. gigas*, 9. C. *hyalinus*, 10. *C. jonesianus*, 11. *C. lacustris*, 12. *C. lineatus*, 13. *C. marginatus*, 14. *C. nitidus f. nitidus*, 15. *C. oculus-iridis*, 16. *C. perforatus*, 17. *C. radiatus*, 18. *C. tumidus var. tumidus*, 19. *C. wailesii;* the scale measures 20 µm in length.



Coscinodiscus concinnus [5]

Girdle view shows distinctly convex valves, cells show numerous small chloroplasts, with fimbriated outline, under high power LM objectives. The marginal processes are discernible in the water mounts [47]. Valve view shows a large rosette with star-shaped clearance in the middle, Areola rows grouped together in broad bundles, prominent hyaline areas from marginal labiate processes toward the center [13]. The interstitial mesh hardly distinct, pentagonal areola at origin of incomplete stria, cribra barely observable, marginal processes, well more than 120° apart, with raised parts and smaller processes barely visible [50]. Mature cells were quite large in the presently described collection with diameter averaging over 300 µm, highest being over 350 µm, about 4 striae in smaller cells, with 2-3 in large cells per 10 µm.

Coscinodiscus centralis [33]

(Synonyms - *Coscinodiscus asteromphalus* var. *centralis Grunow*, *Coscinodiscus oculus-iridis* var. *tenuistriata* Grunow)

Cells discoid, valves slightly convex, numerous small plate-like chloroplasts in girdle view, valves with distinct rosette (large areolae) often with small central hyaline zone (as opposed to *C. concinnus*), rows of areola grouped into narrow bundles bordered by hyaline lines associated with the labiate processes at the valve margin [13], decussating arcs confined to central part of the valve, Interstitial meshes are present, identical with the pentagonal areola at the origin of incomplete stria, cribra distinct. Marginal processes clearly discernible, water mount reveals slightly curved smaller ones, two horned larger processes [92], the cribra and processes readily resolved with LM. About 4 - 5 striae were present within 10 µm in the materials from the Hooghly estuary, with cell diameters between 200 - 260 µm, seldom exceeding 300 µm.

Coscinodiscus curvatulus [87]

(Synonym - *Coscinodiscus curvatulus* var. *genuina Grunow*)

Valve face flat and circular, cells small in general, diameter of the specimens investigated had ranged from 40 µm to 55 µm, central region highly areolated in valve view, larger areolae at and near the centre which gradually reduce in size towards valve margin, 10 areolae in 10 µm at the center, increasing to about 13-15 in the middle section, to almost 25 within the same space near the margin, areolae in parallel, not prominently curved lines (not dead straight either) within fascicules, as opposed to *Actinocyclus curvatulus* with which it is mostly confused, longest lines of the fascicles originating from the center reach the margin, other being comparatively shorter in length, equidistant rimoportulae are observed near the margin, distance between these were more than 10 µm but, didn't exceed 15 µm, a similar measurement was observed in *A. curvatulus* as well [55] visible pseudo nodules are present on the valve face in clear frustules under higher magnification with LM.

Coscinodiscus eccentricus [34]

(Currently accepted as *Thalassiosira eccentrica* (Ehrenberg) Cleve 1904, Synonym - *Coscinodiscus eccentricus* var. *fasciculata* Hustedt)

Flat valve face with low, rounded mantle, connecting threads number usually double the cell number [48], however, present specimens did not always follow, pervalvar axis 1/6th or longer than the diameter. Areolae in curved fasciculated tangential rows (hence eccentric), a central areola surrounded by a ring of seven areolae, a strutted process visible in clear frustules, strutted processes on the valve are scattered, two marginal rings of strutted processes present, one with pointed spines, mostly 7 areolae in a length of 10 µm at the center, increasing in number through mid-valve towards margin, chromatophores small, numerous, cell diameter between 60 - 65 µm [92], at times more than 90 µm in present specimens.

Coscinodiscus granii [37]

Girdle view shows asymmetrical cells, one side higher than the other, valvocopulae (though hard to view with LM) are wedge shaped, valve convexity pronounced near the widest part of valvocopulae, discoid chloroplast with smooth outline, valve view yields a central large areolated rosette, centrally placed radial areolation, incomplete striae, decussating arcs. Cribra is not always observable in LM, marginal processes on valve mantle as indentations, clear, transparent lines converge from it toward the center. Cell diameter varies from 100 - 120 µm, girdle 40-200 µm at wider end, 8 - 11 areolae observed within 10 µm [1,92]. In the present study however, the recorded diameter had ranged mostly between 65 - 116 µm, and never more than 135 µm.

Coscinodiscus gigas [34]

This diatom's mantle slopes sharply or stays straight, while its cell walls are flat or almost flat. Numerous minuscule, spherical chloroplasts are found in the cells. The cells have thick walls and a discoid shape when viewed from the side (girdle view). When seen from the top (valve view), the cells exhibit uneven radial rows of coarse areolae (small apertures) instead of a central rosette. Essentially, this species' frustules, or siliceous diatom cell walls, have a coin-like shape [84]. The presently described specimens were very large, upwards of 400 µm, up to 490 µm in diameter, easily observable under low power objectives of LM. Areolae were semicircular to circular in outline, about 2 - 3 per 10 µm under 600× magnification.

Coscinodiscus hyalinus [43]

(Currently accepted as *Thalassiosira hyalina* [39]). The mantle is low and rounded, the valve faces flat or slightly convex, and the pervalvar axis is around 1/3rd of the

cell diameter. According to [45], the connecting thread is thick. The mantle is always areolated, and the valve face has rows of ribs or areolae organized radially. There are two to fifteen centrally strutted processes, one marginal process with noticeable exterior tubes is present, in this case, a labiate process replaces a marginal strutted process [49]. The presence of a single ring of marginal process and the low number of areola are the species' most noticeable identification characteristics [48]. Cell diameter was between 22 - 56 µm in present specimens, 10-13 fine areolae, and 7 - 8 marginal process in 10 µm, under very high (1000×) magnification.

Coscinodiscus jonesianus [51]

Single, cylindrical cells with valves that resemble watch glasses, The valve has a circular shape, is convex, flat or slightly recessed in the middle, slopes gently toward the edge, and has diameters between 106 and 226 µm. Areolar pattern fasciculate, producing spiral decussate arcs towards the valve center, central rosette of many larger, radially elongated areolae. Incomplete and full striae alternate. Near the center, areolae are roundish, 5 to 6 in 10 µm, and neither dense nor nearly so, 6 - 7 within 10 µm. In two rings are rimoportulae. Three to fourteen striae divide the more or less randomly distributed marginal ring of microrimoportulae, which includes two macrorimoportulae that develop at an angle of roughly 105° to 120° [84]. had observed that about halfway between the center and the outside of the valve is an uneven ring of tiny rimoportulae.

Coscinodiscus lacustris [43]

(Currently treated as a synonym of *Perpetua lacustris* [94],some authors also accept it as *Thalassiosira lacustris* [42,45].

Generally smaller in size compared to many other species of *Coscinodiscus* observed throughout the tenure of the study. Cells solitary, diameter ranges between 10 – 60 µm, current specimens mostly being within 40-50 µm, valves with a modest slope on the mantle and a rounded, tangentially undulating valve face, rectangular, polygonal to irregularly shaped areolae are arranged in radial rows of coarse striae that might have a somewhat haphazard appearance, 11 - 15 per 10 µm. There are marginal fultoportulae in a ring. A significant rimoportula is found on the valve face, near to the margin. According to [90]. *C. lacustris* has one complete ring of marginal fultoportulae and an inner ring of irregularly spaced occluded processes, but even under high LM magnification, faintly discernible marginal fultoportulae were detected on specimens collected from the Hooghly estuarine region, in clear frustules on water mounts.

Coscinodiscus lineatus [33]

(Currently accepted as *Thalassiosira leptopus* [42,45]

The valve face is flat, with a low and uniformly slanted mantle. Areolae on the valve face are organized in straight tangential rows (lineatus structure), but those on the mantle are smaller and more randomly structured, a central areola is bigger than the others. Small strutting processes are present in two to three marginal rings and are not resolved very clearly with LM, one ring of the coarser processes is present further away from the edge, comprising of one big labiate process and equally spaced course, short occluded processes [1]. Cell diameter was observed to be within 180 µm, with occasional larger cells crossing 200 µm, 5 - 7 areolar ribs and about 8 marginal processes per 10 µm.

Coscinodiscus marginatus [35]

(Synonyms - *Coscinodiscus limbatus* Ehrenberg, *Coscinodiscus fimbriatus-limbatus* Ehrenberg) Valves are nearly flat or almost so, with a straight or steeply sloping mantle, discoid cells have thick walls, several tiny, spherical chloroplasts per cell in girdle view. The valves are covered in strong and massive areolation, areolae are polygonal, no central hyaline area and rosette are seen. The areolae are placed slightly irregularly, radially, reaching their greatest size at about half, and radially striate. The current specimen from the Hooghly Estuary, Bay of Bengal, contained around 5 striae per 10 µm. The valve diameter ranges from 44 to 80 µm [13,91,30], with the currently studied specimens measuring within 54 - 56 µm.

Coscinodiscus nitidus f. nitidus [41]

(Currently treated as a synonym of *Psammodiscus nitidus* [41] Synonyms – *Coscinodiscus nitidus f. nitidus* W. Gregory, *Coscinodiscus nitidus* W. Gregory (no longer unaccepted))

Cells medium to large, recorded diameter of the observed specimens between 165 - 200 µm, valve face is almost flat, circular in outline in valve view, more or less discoid, thick walled cell in girdle view, with a very subtly sloping, narrow yet prominent mantle, each cell was observed to contain numerous round chloroplast. This species lacks the central rosette, and the angular, or polymorphic areolae typical of the *Coscinodiscus* species. Areolae are coin-like, coarse, irregular across the valve, (about 7 - 8 areolae accommodated with 10 µm, more or less similar observations were made Al-Yamani and [90] in their studies), small openings or rimoportulae scattered in radial rows, observable under higher magnifications of LM. It has similarity to the genus *Rhaphoneis t*o some extent [81].

Coscinodiscus oculus-iridis [34]

(Basionym - *Coscinodiscus radiatus* var. *oculus-iridis* [34])

Large, single, discoid cells, Valves are virtually flat or faintly convex. There are long and short radiating lines of polygonal areola on the valves. The central rosette is typically big, with five areolae, but it can be smaller. Areolae are modest at the middle of the valve, increasing in size as they near the periphery. Peripheral areolae are generally smaller. Under very high resolutions LM in exceptionally clear frustules reveal tertiary features, such as inner chambers and related poroids. The aperture of the inner chamber gives the unique appearance known as the 'eye-spot' or 'oculus' [50]. Girdle minutely punctate (high magnification), round chromatophores are widely dispersed, the radiating striae with small areolae at the center that increase in size towards the margin, margin in some specimens bore an apiculus, the areolae form an irregular cluster at the center of the valve, which is much less pronounced than the other species [92]. The current materials from Hooghly estuarine waters showed three to four areolae in 10 µm. The diameter of the cell is 120 - 150 µm [30] and 180 - 260 µm [50], however, in the current material, it was found within a range of 105-240 µm.

Coscinodiscus perforatus [34]

(Synonym - *Coscinodiscus perforatus* var. *genuinus* Cleve-Euler)

[85] conducted a detailed comparison of this taxon and *C. radiatus*. The observed specimens were more or less similar to the description. Frustule with short pervalvar axis, valve circular, flat, 150 to 280 µm in diameter in the specimens observed, valve mantle flat with sloped edges in girdle view of larger cells, with one to three rows of areolae, central rosette formed by larger areolae, usually around a hyaline, irregular, central area, though some of the current specimens lacked the hyaline area. Similar to *C. radiatus*, the areolar arrangement is radial, forming decussate arcs in spirals. There are 3 - 4 areolae near the center, 2 - 4 in the mid-radius, and 5 - 6 near the valve margin in 10 µm under high power LM. Cribra is perceptible but not in detail, only in very clear frustules. Empty frustules reveal ring of microrimoportulae, including two macrorimoportulae, disposed in the valve mantle near the margin. Microrimoportulae, one to three in 10 µm, are small circular apertures on valve face,

macrorimoportulae, slightly larger, as larger openings. Small rimoportulae on the valve face near incomplete striae with circular openings.

Coscinodiscus radiatus [34]

(Synonym - *Coscinodiscus radiatus* var. *genuinus* Cleve-Euler)

The diameter of the cells normally varies between 50 - 180 µm [1,92], but diameter observed in this study was mostly within 150 - 210 µm, with smaller individuals in highly dense collections and occasional larger ones at 250 µm. The valves are flat, coin-shaped discs, and have coarse areolae without rosette or centrally demarcated hyaline area. The areolae are almost the same size throughout the valve, with four roughly equal in length of 10 µm, except at the margin, where they are smaller and 6-8 areolae had occupied a length of 10 µm.

Coscinodiscus tumidus var. *tumidus [87]*

(Also accepted as *Thalassiosira tumida* (Janisch) [46] (unassessed), Synonym - *Coscinodiscus tumidus* Janisch (unaccepted)).

The mantle is rounded, the valve face is flat, slight central depression or slightly convex, and the cells are rectangular in outline, one thick thread is created by tying together several connecting threads [51]. Three distinct areolation observed: fasciculate, eccentric, and linear. The strutted processes are dispersed across the valve face, there is one regular marginal ring of the strutted process, which contains three to nine labiates processes, many strutted processes in the valve center are arranged in an irregular ring, occasionally with processes inside the ring [47, 48] The specimens was rarely encountered and were always variable, with diameter ranging between 40 - 85 µm, 10 - 12 areolae and about 5 marginal processes in 10 µm.

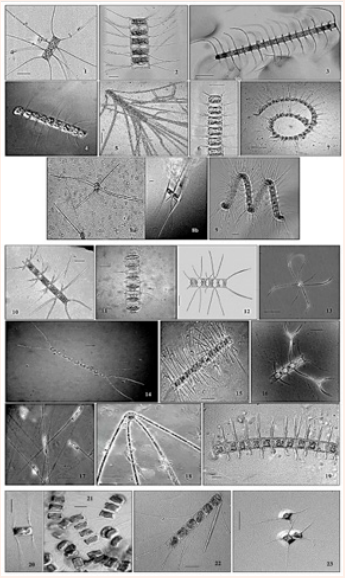
Coscinodiscus wailesii [40]

Cells in the girdle view are cylindrical, often as high as wide, and rectangular in outline at a certain focus. Valves are flattened with a concentric depression near the steep mantle. Numerous chloroplasts are irregular in outline. Prominent central hyaline area is observed on the valve, wide interstriae (hyaline lines) radiate from the central area. Irregular fasciculations are formed, partly by the wide interstriae, originating near the valve center at a labiate process or a small hyaline area (area of solid silica). Cribra are visible with the light microscope. One ring of smaller process is present in the junction zone between the valve face and mantle, and one ring including two larger processes close to the valve margin. Compared to the second ring, the processes in the first ring are more closely spaced. The translucent lines, which are linked to processes, are more noticeable and consistent on the valve mantle than on the valve face [13,48]. Although cell diameters of up to 500 µm has been reported [92], the cells in the current study had a diameter of 250 – 280 µm, with roughly 5 – 6 areolae visible within 10 µm.

Systematic Position and Morphometric Description of the Genus *Chaetoceros* Ehrenberg

The Genus *Chaetoceros* belongs to the following taxonomic hierarchical ranks - Class: Bacillariophyceae, Subclass: Coscinodiscophycidae, Superorder: Chaetocerotanae, Order: Chaetocerotanae incertae sedis, Family: Chaetocerotaceae. In valve view, the member of the genus *Chaetoceros* has oval to semi-circular cells, in girdle view, they are quadrangular, with straight sides and concave, flat, or slightly convex ends, the valve surface is completely or almost flat. a generally seamless, cylindrical, smooth mantle. Each end of the valve's long or apical axis has a long, thick, or thin seta, bristle, or awn on the corners [1]. The opposing setae of adjacent cells fuse securely around their base holding chain, which typically has large or tiny openings or foramina, and overlap close to their origin, typically directly or via a bridge [49, 92] has observed the outer portion of setae to be perpendicular to the chain's axis, the basal portion to be either diagonally outward, or parallel to the pervalvar axis. The chain is terminated by special end cells; the terminal setae are often thicker, shorter, and more parallel to the chain axis than the setae. Seldom are the cells isolated. In most species, the cell wall consists of one or two girdle bands (usually uneven) and two valves. Some species have intercalary bands, which are only visible at extremely high magnification. Pyrenoids can occasionally be clearly seen; chromatophores vary in quantity, size, form, etc., but are consistent for a particular species and help in species identification. The subsequent section is concerned with the species of *Chaetoceros* (Figure 3), many of which belong to the subgenus *Hyalochaete* (thin silicification of the cell walls, thin setae) collected from the sites of sampling.

Figure 3: LM Images of chains with occasional valve view of different *Chaetoceros* species recorded – 1. *C. affinis*, 2. *C. brevis*, 3. *C. coarctatus*, 4. *C. compressus*, 5. *C. concavicornis*, 6. *C. constrictus*, 7. *C. curvisetus*, 8. *C. danicus* (a. top view, and b. valve view), 9. *C. debilis*. 10. *C. decipiens*, 11. *C. diadema* (with resting spores), 12. *C. didymus*, 13. *C. diversus*, 14. *C. laciniosus*, 15. *C. lorenzianus*, 16. *C. messanensis*, 17. *C. minimus*, 18. *C. peruvianus*, 19. *C. pseudocurvisetus*, 20. *C. simplex*, 21. *C. socialis*, 22. *C. subtilis*, 23. *C. tenuissimus*; the scale measures 25 µm in length.



Chaetoceros affinis [42]

(Synonym - *Chaetoceros angulatus* F. Schütt, *Chaetoceros javanicus* Cleve)

Straight and often lengthy colonies, Cells with high mantle, rectangular in girdle view, somewhat concave in the center, foramina are elliptical and thin. Setae are long, narrow, and have a short base. Terminal setae curve gently to the colony axis and are thicker than intercalary ones. The angle at which intercalary setae diverge from the colony axis is between 10 and 30 degrees. At the edge of the colony, setae cross over. There is only one sizable chloroplast in the cell [89]. An apical axis between 15 - 30 µm and pervalvar axis of nearly similar length was documented from among the presently described specimens.

Chaetoceros brevis [88]

(Synonym - *Chaetoceros hiemalis* Cleve)

Straight chains, valves with a central projection that gives the foramen an oblong shape with slight constriction at the center, setae emerge from the margin and run obliquely to the chain axis. In highly clear specimens, the foramina vary in aperture diameter

from 3 to 5 µm. Apical axis length varies from 10 to 12 µm, while pervalvar axis length varies from 20 to 25 µm [47]. Present specimens, however, are measured within 18 to 20 µm. Each cell has one distinct dense chloroplast. It should be noted that *C. brevis* shares many similarities with *C. laciniosus* and differentiating them under normal LM sometimes becomes inconvenient.

Chaetoceros coarctatus [54]

(Synonyms - *Chaetoceros borealis* var. *rudis* Cleve, *Chaetoceros rudis* Cleve)

A robust, straight, heteropolar chain of 12 – 16 cells is typically formed. Chloroplasts have tiny, rounded bodies and are widely distributed. With an apical axis of 27 – 32 µm and a transapical axis of 12–20 µm, frustules appear elliptical and cylindrical in valve view in the present specimens. Every valve has a flat face and an elliptical shape, the mantle is typically high, frequently but not always slightly higher than the girdle. There are either no foramina or very few. The setae at the posterior terminal are shorter than those at the anterior terminal and appear to be quite thick, large, smoothly curved, and heavily spiny. Intercalary setae are often either smoothly curved or straight. Near their tips, the unique intercalary setae curve sharply. Every intercalary seta is oriented toward the posterior end at a 45° angle to the apical axis. According to Lee and [56] these setae arise and fuse within the chain edge and they emerge from the valve margin and are thick and coarse.

Chaetoceros compressus [54]

Usually lengthy, colonies can be straight or somewhat bent. Mantle low, cells rectangular in girdle view. Foramina can range in width [49,50]. distinguished between two types of intercalary setae: common intercalary setae, which deviate nearly perpendicularly to the colony axis, and special intercalary setae, which are long, thick, twisted, and bear enormous spines. After a significant divergence, terminal setae align with the colony axis. Inside the colony margin, setae with a lengthy basal portion cross across. Every cell has several chloroplasts, as was also observed by Lewin and [57]. The observed length of the apical axis within the current specimens varied between 6 to 9 µm, transapical axis was not properly measurable under LM due to lack of clarity.

Chaetoceros concavicornis [59]

(Synonym - *Chaetoceros borealis f. concavicornis* (Mangin) Braaud)

It produces a chain that is straight. Differently shaped alveoli are found in cells, lower valves are flat with setae emerging from within the valve margin, while upper valves are rounder with setae emerging from close to the center. According to [91], apertures have a trapezoid form. The girdle zone is thin, measuring less than one-third of the pervalvar axis' length. All of the setae are bent toward the lower end of the chain, have concave outer lines, and are thin at the base and wider outward [47]. had registered axis width between 12 - 30 µm, cell length of 20 - 30 µm, although the latter in the presently described specimens were a almost always within 25 - 28 µm, width was similar.

Chaetoceros constrictus [38]

The corners of the neighboring cells touch, the chains are straight, and the valve poles are drawn up. The lanceolate apertures narrow significantly in the middle. The terminal setae diverge sharply. Bands are noticeable and there is a noticeable constriction between the valve mantle. Spores at rest have spiky, unevenly vaulted valves, as observed by [48]. Apical axis length varied between 15 - 26 µm while pervalvar axis was of 14 - 27 µm.

Chaetoceros curvisetus [9]

The colony is rather long and curved. In girdle view, cells are rectangular with a low mantle, presently observed apical axis ranged within 10 - 25 µm, pervalvar axis between 10 - 30 µm. The foramina are elliptical and broad. Terminal and intercalary setae have short basal portions and are both long and thin. At the edge of the colony, setae cross over and curve in the same direction, nearly perpendicular to the colony axis. Each cell has one chloroplast [1].

Chaetoceros danicus [9]

Cells have almost equal in size, rounded upper and flat lower valves. According to [50], the upper valve's setae emerge from close to the valve center in the pervalvar direction, abut with a groove between them, turn sharply, and run backward in about outwardly convex curves. The lower valve's setae are somewhat convex toward the exterior and come from inside the valve border. These observations were also reflected among the specimens collected from hooghly estuary. Apical axes between 12 - 22 µm and pervalvar axes bewteen 15 - 25 µm were common among the specimen. According to [1], the central process between the bases of the setae has conical external sections and is subcentral in placement.

Chaetoceros debilis [10]

(Synonym - *Chaetoceros vermiculus* F. Schütt)

This is a common flagellate diatom found in Indian coastal waters. The colonies are spirally coiled and somewhat lengthy. In girdle view, the mantle is low and the cells are rectangular. They have narrow foramina. The setae have a short basal portion and are long and narrow. Perpendicular to the colony axis, the terminal setae are thicker than the intercalary setae. The setae cross just beyond the edge of the colony. Each cell contains a single chloroplast. Cells are arranged in chains and range in size from 10 to 40 µm in diameter [51,30] the current specimens showed pervalvar axis of 12 - 20 µm, with a apical axes ranging from 10 - 27 µm.

Chaetoceros decipiens [8]

(Synonym - *Chaetoceros grunowii* F. Schütt)

Long and straight colony under LM, relatively larger oblong box-shaped in girdle view of cells with a mantle high and a concave valve face, apical axis and pervalvar axis both similar in length and were within 25 - 45 µm range in the observed specimens. Foramina narrow. Long, thick, straight, and devoid of a basal portion are setae. Intercalary sister setae diverge at an angle of 10 to 25° from the colony axis and fuse in the upper region. Terminal setae curve parallel to the colony axis, are thicker and shorter than intercalary setae, and broadly differ from cell angles. At the edge of the colony, setae cross over [89]. mentioned a number of small chloroplasts in cell.

Chaetoceros diadema [39]

(Basionym - *Syndendrium diadema* Ehrenberg)

Colonies are either slightly bent or straight, thin-walled but larger than most. Mantle height, rectangular cells in girdle view. Cell apical axis of 25 - 37 µm and pervalvar axis of 20 - 35 µm was observed among the observed specimens. There exists a central constriction in the narrow foramina. Setae have short basal sections and are thick and short. Compared to intercalary setae, terminal setae are thicker. At the edge of the colony, the setae cross across [31]. stated presence of just one chloroplast per cell.

Chatoceros didymus [36]

(Synonym - *Chaetoceros didymus* var. *genuinus* Gran)

[52] has observed that the cells of *C. didymus* occur in straight chains, usually long. In girdle view the cells are rectangular with raisedcorners, the apertures being of variable width, the valve is flat or slightly concave with a protuberancein the centre,

and a shallow mantle. The cells are elliptic in valve view, generally theintercalary setae are thin and diverge at an angle about 35-40° to the apical axis. The terminal setaeare thicker and directed toward the chain axis. There are two chromatophores per cell. Resting sporesare paired, with smooth valves lacking protuberances, and the setae being thick and coarse. The specimens observed in collections from Hooghly Matla estuary have displayed a similar morphology, and measured 30 - 35 µm in apical axis, 15 – 20 µm across the pervalvar axis), and about 10 µm of transapical length.

Chaetoceros diversus [8]

Short and straight colony, akin to *C. decipiens*, mantle high, oblong cells in girdle view, apical axis in the current specimens within 10µm, at most 12 µm, and pervalvar axis ranges between 8-10 µm, very small or nearly nonexistent foramina, two types of intercalary setae: basal and short. Short, thin, and straight, common intercalary setae diverge at an angle of 30° to 50° to the colony axis. Special intercalary setae are long, thick, strongly curved, and distally parallel to the colony axis. They diverge anteriorly at 45° angle. Terminal setae parallel to the colony axis share morphological similarities with common intercalary setae. At the edge of the colony, setae cross over, according to [53], one chloroplast per cell.

Chaetoceros laciniosus [88]

Usually observed as long and straight colony. Cells are rectangular in girdle view, with elongated corners and a high mantle. Foramina are very wide, with central compression. Setae are long and thin, with a long basal portion. Terminal setae are longer and thicker than intercalary setae. Intercalary setae run almost perpendicular to the colony axis, diverge distally parallel to the colony axis, and terminate parallel to the colony axis. Setae cross over at the colony boundary. Perhaps one chloroplast per cell. These corroborated well with earlier observation made by [89]. Current specimens revealed 10 - 28 µm of apical axis length with a nearly similar pervalvar axis of 12 - 25 µm.

Chaetoceros lorenzianus [42]

(Synonym - *Chaetoceros cellulosus* H. S. Lauder)

With varying lengths, the colonies are straight. In girdle view, cells have extended corners and a low mantle. Wide, octagonal or hexagonal foramina are present. Long and thick, setae lack the basal portions. Compared to the intercalary setae, the terminal setae are shorter. The colony axis is perpendicular to the intercalary setae, or they diverge at an angle between 20° and 70°. Setae cross over near the edge of the colony. According to [13] and [92], chloroplasts are tiny and abundant. This one was widely variable in cell size, with apical axes observed between 15 - 55 µm, nearly identical length of pervalvar axes as well.

Chaetoceros messanensis [6]

(Synonym - *Chaetoceros furca Cleve*)

Straightforward colony, girdle view shows rectangular cells with low mantle. Foramina can be wide, elliptical, or hexagonal. Setae have a short basal part. There are three types of setae: special intercalary setae, which are long and thick, strongly silicified, and fuse for a distance before diverging, common intercalary setae, which are long and thin, and terminal setae, which are short and thin. Common intercalary setae diverge at angles ranging from 30 - 90°, while special intercalary setae diverge at 45° to the colony axis. One terminal seta is curved and perpendicular, while the second diverges at an angle of 60 - 70° to the colony axis. Setae cross over at the colony boundary. Each cell has a single chloroplast, as observed by [47] apical axis is between 6 and 30 µm, and transapical axis 2 to ~7 µm in the present specimens, corroborating well with the observations by Lee and [56].

Chaetoceros minimus [61]

(Synonym - *Rhizosolenia minima* Levander, *Monoceros minimum* (Levander) Valikangas)

Single cells, weakly silicified and exceedingly small, only 2 - 6 µm apical axis, pervalvar axis a longer at 5 - 20 µm in the observed specimens, Cells in girdle view usually appear cylindrical, with a high mantle, and have rounded corners. Each valve has one or two long, thin setae that diverge nearly parallel to the colony axis. [47] and also [24] had noted that there was only one chloroplast, although not every cell was observed with a solitary discernible chloroplast under LM presently.

Chaetoceros peruvianus [5]

Characeristic feature of the cells of *C. peruvianus* is their heterovalvate nature, with a flat lower and a rounded upper valve. The setae on the upper valve emerge from near the valve center in a pervalvar direction, abut with a groove between them, turn sharply, and flow backward in curves that are more or less externally convex. The lower valve's setae begin inside the valve margin and become somewhat convex on the outside. The cell apical axis of *C. peruvianus* measured 10 – 32 µm, with at most 35 µm of pervalvar axis. These dimensions were akin to earlier observation elsewhere on this taxon [13,50,56].

Chaetoceros pseudocurvisetus [58]

In girdle view, cells are arranged in colonies, superficially similar to *C. curvisetus* under low magnification LM, connected by the fusion of subsequent setae and four elevated projections at the borders of the valves, leaving a huge lenticular aperture in the center between the cells [1]. and [94] have observed that each cell has a single chloroplast, an apical axis measuring 12 - 30 µm, and nearly simlar pervalvar axis, however, the latter was sometimes considerably longer in some of the currently observed specimens, at up to 45 µm.

Chaetoceros simplex [37]

Setae are long, thin, straight, and oriented toward the cell's apical axis. Due to solitary nature of the cells, resting spores are readily visible, especially in the onset of premonsoon, resting spores with spiny valves under high magnification [92]. stated that apical axis length varied widely, ranging from 4 to 30 µm. However, specimen collected from the Hooghly-Matla estuary zone showed an axial length of 19 to 22 µm, which was quite conservative.

Chaetoceros socialis [54]

(Synonym - *Chaetoceros socialis* var. *radians* (F. Schutt) P.M. Tsarenko)

Cells form short colonies connected by long setae, occasionally forming spherical colonies embedded in mucus. In girdle view, the cells are rectangular, with a low mantle, smaller sizes compared with many other taxa observed with an equally long apical axis and pervalvar axis within 8 - 10 µm. The foramina are wide and hexagonal. Setae are long and thin, with a short basal part. Two setae diverge at a 20 - 50° angle from the apical axis, while two setae are perpendicular to the axis colony. Setae cross over beyond the colony boundary. Shevchenko et al. [89] reported that each cell had one chloroplast, as was observed in the specimens from Hooghly estuary.

Chaetoceros subtilis [11]

The colony is short. In girdle view, cells are rectangular, intermediary cells fit tightly together, the specimens concerned had registered apical axis of 5 - 9 µm, with

maximum pervalvar axis length of 18 µm, and the mantle is high. No foramina. Setae are long and thin, with a short basal part. Compared to intercalary setae, terminal setae are thicker. Setae do not cross over and diverge at a 45° angle to the apical axis, directed toward one end of the colony. [89] found that each cell had one chloroplast.

Chaetoceros tenuissimus [3]

(Synonym - *Chaetoceros salsugineus* Takano)

Cells can be solitary or form short colonies. Cell apical axis: 4 - 7 µm, with more or less similar pervalvar axis length, girdle view reveals that the cells are rectangular, with a high mantle. Foramina are narrow. Setae are very long and thin, with a short basal part. Intercalary and terminal setae diverge at a 40 - 50° angle from the colony axis. Setae cross over at the colony boundary. One chloroplast per cell [89].

Conclusion

Centric diatoms are considered to be comparatively better suited to serve as proxies to water quality changes in an environment than their pennate counterparts. A study is hence of significance when it deals with species assemblages of such centric diatoms, especially *Coscinodiscus* and *Chaetoceros* which together form among the largest factions within the Class Bacillariophyceae. The presently reported study was another such effort to keep the readers and future workers abreast of the species composition of these two taxa in the estuarine well mixed waters of Hooghly-Matla river complex in the vicinity of the Indian Sundarbans situated on the northwest coast of Bay of Bengal. When dealing with cosmopolitan taxa such as these it is not academically wise to be conclusive as newer introductions can always occur within a given period, but as the study had spanned a decade and half, it does certainly hold ecological credibility and should provide the necessary information on the presence of these two genera within the said ecoregion.

Acknowledgement

The financial assistance from U.G.C., DST, New Delhi and ISRO, Ahmedabad India are gratefully acknowledged. The authors are also thankful to the concerned authorities at Department of Forest and Sundarban Biosphere Reserve, West Bengal for the necessary permissions accorded and assistance offered to the research team through infrastructural and logistical facilities during the long stays and transits within the coastal Bay of Bengal and the remote estuarine islands of the Sundarban deltaic region. There exist no conflicts of interests among neither the authors nor the funding agencies.

References

1. Al-Kandari M, Al-Yamani, FY, Al-Rifaie K (2009) Marine Phytoplankton Atlas of Kuwait's Waters. Published in Kuwait by Kuwait Institute for Scientific Research 351p.
2. Al-Yamani FY, Saburova MA (2011) Illustrated Guide on the Benthic Diatoms of Kuwait's Marine Environment. Published in Kuwait by Kuwait Institute for Scientific Research 364p.
3. Bérard-Therriault L, Poulin M, Bossé L (1999) Guided 'identification du phytoplancton marin de l'estuaire et du golfe du Saint-Laurent incluant également certains protozoaires. Publ spéc can sci. halieut. Aquat 128: 1-387.
4. Biswas B, Sarkar NS (2017) Morphological Descriptors of Different Species of Diatom Cyclotella (Kutzing) Brebisson in the Surface Sediments of Indian Sundarbans. Phykos 47(2): 105-116.
5. Brightwell T (1856) On the filamentous long-horned Diatomaceae, with a description of two new species. Q J Microsc Sci London 4: 105-109.
6. Castracane F (1875) Contribuzione alla florulla delle Diatomee del Mediterraneo ossia esame del contenuto nello stomaco si un salpa pinnata pescata a Messina. Atti Acad Pontif Nuovi Lincei 28: 377-396.
7. Choudhury AK, Pal R (2008) Diversity of planktonic diatoms from West Bengal coast with special reference to taxonomic accounts. Phytomorphology 58(1&2): 29-40.
8. Cleve PT (1873) Examination of diatoms found on the surface of the Sea of Java. Bihang till K Sven vet akad handl 1(11): 1-13.
9. Cleve PT (1889) Pelagisk Diatomeer från Kattegat. In: Petersen CGJ, editor. Det Videnskabelige Udbytte af Kanonbaaden "Hauchs" Togter i de Danske Have Indefor Skagen, I. Aarene 1883-86. Kjøbenhavn: Andr Fred Høst & Sons Forlag p 53-56.
10. Cleve PT (1894) Redogörelse för de svenska hydrografiska undersökningarne Åren 1893-1894 under ledning af Eckman G, Pettersson O, Wijkander A. II. Plankton undersökningar, Cilicoflagellater och Diatomacéer [Including] Contributions to a description of the plankton-flora of Sweden. Bihang till K Sven vet akad handl Afd III. 20(2): 1-16
11. Cleve PT (1896) Redogörelse för de svenska hydrografiska undersökningarne februari 1896 V. Plankton under sökningar: Vegetabilskt plankton. Bihang till K Sven vetensk akad handl 22(5): 1-33.
12. Cleve PT (1904 '1903') Plankton table for the North Sea. CIEM 1903-1904. 216p.
13. Cupp EE (1943) Marine Plankton diatoms of the west coast of North America. Bull Scripps Inst Oceanogr Univ Calif 5: 241-251.
14. Das S, Mukherjee A, Sarkar TK, Ganguly D, Maiti TK, et al. (2011) Depth profile exploration of enzyme activity and culturable microbial community from the oxygen-starved soil of Sundarban mangrove forest, India. Open J Ecol 1(3): 65-72.
15. Das S, Ganguly D, Mukherjee A, De M, Maiti TK, et al. (2012) Depth Integrated Microbial Community and Physico-Chemical Properties in Mangrove Sediments of Sundarban, India. Adv Microbiol 2(3): 234-240.
16. Das S, Ganguly D, Mukherjee A, Maiti TK, Jana TK (2013) A Depth Wise Diversity of Free Living N2 Fixing and Nitrifying Bacteria and Its Seasonal Variation with Nitrogen Containing Nutrients in the Mangrove Sediments of Sundarban, WB, India. Open J Mar Sci 3: 112-120.
17. Das S, Mukherjee A, Chakraborty S, Maiti TK, De M (2015) Influence of varying degree of salinity-sodicity stress on phytoplankton and cultivable microbes in the estuarine water of the Sundarban Mangrove Forest, India. Int J Adv Lif Sci 8(4): 424-429.
18. Das S, Mukherjee A, De TK, De M, Jana TK (2016) Influence of microbial composition on carbon storage capacity of the mangrove soil at the land-ocean boundary in the Sundarban mangrove ecosystem, India. Geomicrobiol J 33 (9): 743-750.
19. Das S, Ganguly D, Chakraborty S, Mukherjee A, De TK (2017) Methane flux dynamics in relation to methanogenic and methanotrophic population in the soil of Sundarban mangrove, India. Mar Ecol 39(2): 1-9.
20. Das S, Ganguly D, Mukherjee A, Chakraborty S, De TK (2017) Soil urease activity of Sundarban mangrove ecosystem, India. Adv in Microbiol 7: 617-632.
21. Das S, Ganguly D, Mukherjee A, Chakraborty S, De TK (2020) Exploration of N2 fixation and denitrification processes in the Sundarban mangrove ecosystem, India. Indian J Geo-Mar Sci 49 (5): 740-747.
22. Das S, Ganguly D, Chakraborty S, Mukherjee A, De TK (2020) The first report of Glomalin from the Sundarban Mangrove Biosphere Reserve, India, a long-term sediment Carbon storage. Reg Stud Mar Sci 39: 101398.

23. Datta D, Deb S (2017) Forest structure and soil properties of mangrove ecosystems under different management scenarios: experiences from the intensely humanized landscape of Indian Sunderbans. Ocean Coast Manag 140: 22-33.
24. De Queiroz K (2007) Species concepts and species delimitation. Syst Biol 56(6): 879-886.
25. De TK, De M, Das S, Chowdhury C, Ray R, et al. (2011) Phytoplankton abundance in relation to cultural eutrophication at the land-ocean boundary of Sunderbans, NE Coast of Bay of Bengal, India. J Environ Stud Sci 1: 169-180.
26. De TK, Sarkar TK, Mukherjee A, Maiti TK, Das S (2011) Abundance and occurrence of phosphate solubilizing bacteria and phosphatase in sediment of Hooghly Estuary, North East Coast of Bay of Bengal, India. J Coast Develop. 15 (1): 9-16.
27. De TK, Mukherjee A, Das S, Chakraborty S, De M (2015) Interrelationship between Planktonic Diatoms and Selected Governing Physicochemical Parameters of the Hooghly Estuary, Bay of Bengal. Int J Mar Sci 5(47): 1-9.
28. De TK, Raman M, Sarkar SK, Mukherjee A (2021) Ecological assessment of Hooghly River considering a few of the more perturbed sites based on some relevant physicochemical and biological variables – A part of the AVIRIS-NG (NASA-ISRO) ground truth verification. Reg Stud Mar Sci 41: 101598.
29. Degerlund M, Huseby S, Zingone A, Sarno S, Landfald B (2012) Functional diversity in cryptic species of *Chaetoceros* socialis Lauder (Bacillariophyceae). J Plankton Res 34(5): 416-431.
30. Desikachary TV (1986-1989) Atlas of diatoms 1-6. Madras: Madras Science Foundation.
31. Duke EL, Lewin J, Reimann BEF (1973) Light and electron microscope studies of diatom species belonging to the genus *Chaetoceros* Ehrenberg. I. *Chaetoceros* septentrionale Oestrup. Phycologia 12: 1-9.
32. Dutta MK, Chowdhury C, Jana TK, Mukhopadhyay SK (2013) Dynamics and exchange fluxes of methane in the estuarine mangrove environment of Sundarbans, NE coast of India. Atmos Environ 77: 631–639.
33. Ehrenberg CG (1839) Über die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen. Abh königl akad wiss Berlin p. 59-147.
34. Ehrenberg CG (1840) Über noch zahlreich jetzt lebende Thierarten der Kreidebildung und den Organismus der Polythalamien. Prep abh königl akad wiss Berlin aus dem Jahre p.1-94.
35. Ehrenberg CG (1843) Verbreitung und Einfluss des mikroskopischen Lebens in Süd- und Nord-Amerika. Abh königl akad wiss Berlin p.291-445.
36. Ehrenberg CG (1845) Mittheilung über 2 neue Lager von Gebirgsmassen aus Infusorien als Meeres-Absatz in Nord-Amerika und eine Vergleichung derselben mit den organischen Kreide-Gebilden in Europa und Afrika. Ber Akad Wiss Berlin p. 57-97.
37. Gough LF (1905) Report on the plankton of the English Channel in 1903. In Anon, editor. Great Britain North Sea Fisheries Investigation Committee. First Report on Fishery and Hydrographical Investigations in the North Sea and Adjacent Waters, 1902-1903. International Fishery Investigations No. 2. - Southern Area. UK: Marine Biological Association of the United Kingdom p.325-377.
38. Gran HH (1897) Bacillariaceen vom Kleinen Karajak fjord. Biblio Bot Stuttgart 42: 1-24.
39. Gran HH (1897) Protophyta: Diatomaceae, Silicoflagellata und Cilioflagellata. In Anon, editor, Den Norske Nordhavs Exped 1876-1878 Zoology and Botany, Christiania: Grøndal & Søns, 7: 1-36.
40. Gran HH Angst EC (1931) Plankton diatoms of Puget Sound. Public Puget Sound Biol Stn 7: 417-516.
41. Gregory W (1857) On new forms of marine Diatomaceae found in the Firth of Clyde and in Loch Fyne, illustrated by numerous figures drawn by Greville RK. Trans R Soc Edinburgh 21: 473-542.
42. Grunow A (1863) Über einige neue und ungenügend bekannte Arten und Gattungen von Diatomaceen. Verh K K Zool-Bot Ges Wien 13: 137-162.
43. *Grunow* A, Cleve PT (1880) Beiträge zur Kenntniss der arctischen Diatomeen. Kungl Sven vetensk akad handl 17(2): 1-121.
44. *Gupta* RK, Das SK (2020) Algae of India, A checklist of Indian diatoms. Salt Lake, Kolkata: Botanical Survey of India Ministry of Environment, Forests & Climate Change Government of India 4: 1-327.
45. Hasle GR, Fryxell GA (1977) The genus Thalassiosira: some species with a linear areola array. In Simonsen R, editor. Proceedings of the Fourth Symposium on Recent and Fossil Marine Diatoms, Oslo. Nova Hedwig Beih 54: 15-66.
46. Hasle GR, Heimdal BR, Fryxell GA (1971) Morphologic variability in fasciculated diatoms as exemplified by Thalassiosira tumida (Janisch) Hasle, comb. nov. Antarct Res Ser, Biol Antarct Seas IV 17: 313-333.
47. Hasle GR, Syvertsen EE (1996) Marine diatoms. In Tomas CR, editor. Identifying marine phytoplankton. San Diego, California: Academic Press p. 5-385.
48. Hasle GR (1993) Nomenclatural notes on marine planktonic diatoms. The family Bacillariaceae. Beih Nova Hedw 106: 315-321.
49. Hendey NI (1964) An introductory account of the smaller algae of British coastal waters. Part 5: Bacillariophyceae (Diatoms). In Ministry of Agriculture, Fisheries and Food. Fishery Investigations Series IV. London: HMSO, p. 317.
50. Hendey NI (1970) Some littoral diatoms of Kuwait. Nova Hedw 31: 101-167.
51. Hendey G, Turquet J, Quod JP, Ten-Hage L, Lugomela C, et al. (2001) Potentially harmful microalgae of the Western Indian Ocean- a guide based on a preliminary survey. IOC Manuals and Guides No. 41. France: UNESCO.
52. Hernández-Becerril DU (1991) Note on the Morphology of *Chaetoceros* didymus and C. protuberans, with some considerations on their taxonomy. Diatom Research, 6(2): 289-297.
53. Hernandez-Becerril DU (1996) A morphological study of *Chaetoceros* species (Bacillariophyta) from the plankton of the Pacific Ocean of Mexico. Bull Nat His Mus 26: 1-73.
54. Lauder HS (1864) Remarks on the marine Diatomaceae found at Hong Kong, with descriptions of new species. Trans Microsc Soc Lond, New Ser 12: 75-79.
55. Lee JH, Byun JH, Lee EH (1992) Taxonomy and Phylogeny of the marine diatom Family Hemidiscaceae in the Korean coastal waters. Korean J Phycol 7 (2): 185-205.
56. Lee SD, Lee JH (2011) Morphology and taxonomy of the planktonic diatom *Chaetoceros* species (Bacillariophyceae) with special intercalary setae in Korean coastal waters. Algae 26(2): 153-165.
57. Lewin JC, Norris RE (1970) Surf-zone diatoms of the coasts of Washington and New Zealand (*Chaetoceros* armatum T. West and Asterionella spp.). Phycologia 9: 143-149.
58. Mangin L (1910) Sur quelques algues nouvelles ou peu connues du phytoplancton de l'Atlantique. Bull Soc Bot France 57: 344-350.
59. Mangin L (1917) Sur les former arctiques faussement décrites sour le nom de *Chaetoceros* criophilus Cast. C R Hebd Seances Acad Sci 164 (20): 770-774.
60. Mann DG (1999) The species concept in diatoms. Phycologia 38: 437-495.
61. Marino D, Giuffre G, Montresor M, Zingone A (1991) An electron microscope investigation on *Chaetoceros* minimus (Levander) comb. nov. and new

observations on *Chaetoceros* throdsenii (Marino, Montresor and Zingone) comb. nov. Diatom Res 6(2): 317-326.

62. Mukherjee A, Chakraborty S, Das S, De TK (2013) Salinity might be the most influential governing factor of cell surface size of *Coscinodiscus* in well mixed tropical estuarine waters. Int J Lif Sci Edu Res 1(2): 81-90.
63. Mukherjee A, De M, Maiti TK, Das S, De TK (2013) Do dominant Diatoms regulate each other's frequency of occurrences in a well-mixed Estuary? - A Study on *Coscinodiscus* and *Chaetoceros* in the waters of North Eastern Bay of Bengal, India. J Energy Environ Sci 127: 209-218.
64. Mukherjee A, Das S, De M, Maiti TK, De TK (2013) A Report on the Micro-Phytoplankton Size Range, Biovolume, Biomass and Geometric shape in the Post "Aila" (Severe Cyclone) waters of estuarine Sundarban, Bay of Bengal, India. J Mar Biol Oceanogr 2(4): 1-13.
65. Mukherjee A, De M, Maiti TK, De TK (2014) Use of dominant centric diatoms of well mixed tropical estuaries as indicators to nutrient rich environments. Int J Adv Lif Sci 7(2): 329-337.
66. Mukherjee A, De TK, Das S, De M (2014) Tropical Cyclones Might Seem to Affect Pennate Diatoms More Than Their Centric Counterparts In Well Mixed Estuaries. Am Int J Res Form Appl Nat Sci 8(1): 31-40.
67. Mukherjee A, Das S, Bhattacharya T, De M, Maiti TK, et al. (2014) Optimization of Phytoplankton Preservative Concentrations to Reduce Damage during Long-Term Storage. Biopreserv Biobank 12(2): 139-147.
68. Mukherjee A, Das S, Chakraborty S, De TK (2015) Laboratory experiment reveals some key factors behind auxospore induction in two ubiquitous centric diatoms of Hooghly Estuary, Bay of Bengal, India. Int J Pure Appl Biosci 3(3): 94-104.
69. Mukherjee A, Das S, Chakraborty S, De TK (2015) Study on mangrove associated estuarine waters of North-eastern Bay of Bengal reveals potential diatom indicators of dissolved inorganic compounds. Braz J Biol Sci 2(3): 155-168.
70. Mukherjee A, Chakraborty S, Das S, Mondal R, Basu S, et al. (2015) A report on salinity-governance of auxospore size in euryhaline diatoms of a well-mixed estuary on North-Eastern Coastal Bay of Bengal. Braz J Biol Sci 2(4): 321-331.
71. Mukherjee A, De TK, Das S, Chakraborty S (2015) Influence of unidirectional circulation of nutrient-enriched water on chain length of selected diatom species in estuarine environment - a batch culture buttressed case study. Int J Adv Lif Sci 8(4): 509-519.
72. Mukherjee A, Das S, Chakraborty S, De TK (2016) A case study on variation in biovolume of phytoplanktonic flora in the estuarine waters Sagar Island, Bay of Bengal. Int J Adv Lif Sci 9(3): 402-427.
73. Mukherjee A, Das S, Chakraborty S, De TK (2016) An ex situ and in vitro approach to delineate pennate diatom species with bioindicator potentials in a well-mixed tropical estuarine ecosystem. Braz J Biol Sci 3(6): 299-317.
74. Mukherjee A, Chakraborty S, Dutta S, Das S, De TK (2016) Salinity tolerance tests on selected estuarine copepod species to understand the effect of dilution and their response to changing environment. Int Res J Nat Appl Sci 3(9): 28-43.
75. Mukherjee A, Chakraborty S. Das S, De TK (2018) Dynamics of dissolved inorganic nitrogen in bioturbated littoral surface sediments at a selected tourist destination of Northern Coastal Bay of Bengal, India. Braz J Biol Sci 5(11): 799-814.
76. Mukherjee A, De TK (2020) In vitro quantification of nitrogen fixation and methane generation in the bioturbated littoral surface sediments of Bakkhali coast north-eastern Bay of Bengal. Geomicrobiol J 38 (2): 127-137.
77. Mukherjee A, Das S, De TK (2022) In vitro demonstration of nitrogenase activity and methanogenesis in non-heterocystous filamentous and unicellular cyanobacteria isolated from estuarine waters. Environ Sustain 5(1): 77-90.
78. Mukherjee A, Ghosh PB, De TK (2022) A quinquennial multivariate monitoring of the brackish water zone of Hooghly estuary, northern Bay of Bengal, India. Int J Chem Environ Sci 3(3): 7-36.
79. Ostenfeld CH. 1902. Phytoplankton fra det Kaspiske Hav (Phytoplankton from the Caspian Sea). Vidensk Meddel Dansk Naturhist Foren p 129-139.
80. Ostenfeld CH (1915) A list of phytoplankton from Boeoton Strait, Celebes. Dansk Bot Ark 2(4): 1-18.
81. Round FE, Mann DG (1980) Psammodiscus nov. gen. based on *Coscinodiscus* nitidus. Ann Bot 46: 367-373.
82. Rynearson TA, Armbrust EV (2004) Genetic differentiation among populations of the planktonic marine diatom Ditylum brightwellii (Bacillariophyceae). J Phycol 40: 34 -43.
83. Sanyal P, Ray R, Paul M, Gupta VK, Acharya A, et al. (2020) Assessing the dynamics of dissolved organic matter (DOM) in the coastal environments dominated by mangroves, Indian Sundarbans. Front Earth Sci 8: 218.
84. Sar EA, Inésen S, Hinz (2008) Fine Morphology of *Coscinodiscus jonesianus* and *Coscinodiscus* commutatus and their transfer to Coscinodiscopsis Gen. Nov. Diatom Res 23 (2): 401-421.
85. Sar EA, Inésen S, Jahn R (2010) *Coscinodiscus* perforatus revisited and compared with *Coscinodiscus radiatus* (Bacillariophyceae). Phycologia 49(4): 514-524.
86. Saravanan V, Godhe A (2010) Genetic heterogeneity and physiological variation among seasonally separated clones of Skeletonema marinoi (Bacillariophyceae) in the Gullmar Fjord, Sweden. Eur J Phycol 45: 177-190.
87. Schmidt A (1878) Atlas der Diatomaceen-kunde Series II: Aschersleben: Verlag von Ernst Schlegel. Heft 15-16 (pls. 57-64).
88. Schütt F (1895) Arten von Chaetoceras und Peragallia. Ein Beitrag zur Hochseeflora. Ber Deutsch Bot Ges 13: 35-50.
89. Shevchenko OG, Orlova TY, Hernández-Becerril DU (2006) The genus *Chaetoceros* (Bacillariophyta) from Peter the Great Bay, Sea of Japan. Bot Mar 49(3): 236-258.
90. Smucker N, Edlund M, Morgan V (2008) The distribution, morphology, and ecology of a non-native species, Thalassiosira lacustris (Bacillariophyceae), from benthic stream habitats in North America. Nova Hedw 87: 201-220.
91. Throndsen J (1978) Preservation and storage. In: Sournia A, editor. Phytoplankton manual. Paris: UNESCO.
92. Tomas CR (1997) Identifying Marine Phytoplankton. Academic Press, Harcourt Brace & Company 874p.
93. VanLandingham SL (1968) Catalogue of the fossil and recent genera and species of diatoms and their synonyms. Part II. Bacteriastrum through *Coscinodiscus*. Verlag Von J Cramer 2 733p.
94. Yu P, Yang L, You QM, Kocioleck JP, Wang KY, et al. (2024) Lineaperpetua gen. nov.: a new diatom genus in the Thalassiosirales supported by morphology and molecular data. J Oceanol Limnol 42(1): 277-290.