

Taxonomic diversity and SEM study of Euglenoids from Brackish Water Ecosystems of Indian Sundarbans Biosphere Reserve

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Abstract

A brief taxonomic account of forty one (41) species of euglenoids recorded from Indian Sundarbans, have been included in the present communication. The taxa belong to 8 species of *Euglena*, 1 species of *Eugleniformis*, 2 species of *Monomorphina*, 3 species of *Trachelomonas*, 9 species of *Lepocinclis* and 18 species of *Phacus*. Collections were done from brackish water ponds of Sundarbans, showing maximum diversity of euglenophytes together with other planktonic species. These Euglenophytes are reported from Indian Sundarbans for the first time, as there is no report of this group from these regions. The collected taxa were identified with light and scanning electron microscopy (SEM) and voucher specimens were assigned to Calcutta University Herbarium (CUH) with accession numbers.

Key words: *Euglena*, *Eugleniformis*, *Lepocinclis*, *Monomorphina*, *Phacus*, *Trachelomonas*

1. Introduction

Euglenophytes are member of unicellular flagellates primarily occurred in freshwater habitat but important in some marine habitats also. Highly eutrophic environments are more suitable for the growth of these groups. These groups are also called euglenozoa or euglenoids. Some of them are heterotrophic specially saprotrophic or phagocytic. These are identified and characterized by two anterior unequal flagella rooted within a canal namely "ampulla" or "gullet". A distinctive cell wall composed of spiral strips termed "pellicle" is the main characteristic feature of euglenophytes. Some species of euglenophytes have hard surroundings on their cell wall, known as "lorica". This group produces distinctive mobility called euglenoid or metabolic movement. This group is very closely related to Kinetoplastida or trypanosomes for the similarity in their SSU rRNA sequences (Marin *et al.*, 2003).

Sundarbans biosphere - the largest mangrove forest in the world is formed from the sediments of three great rivers, the Ganges, Brahmaputra and Meghna, with an area of 10,000 sq. km, lies in India and Bangladesh. Sundarbans is the largest mangrove forest comprising of many islands interconnected by rivers, creeks and canals. The planktonic algal flora of Indian Sundarbans greatly diversified due to their water quality and nutrient variation. Fresh water, brackish water and marine water regions mainly intersect the islands. The free-floating phytoplanktons are widely distributed in these regions especially in brackish water ponds. Large groups of phytoplanktons are microalgae, the photosynthetic organisms containing chlorophyll. Among them one of the major group of unicellular microalgae are euglenoids.

The Indian site lies between 21°31' to 22°53'N and 88°37' to 89° 09'E. Previous studies on phytoplanktons in West Bengal and Indian Sundarbans mangrove forest have been carried out by a group of workers (Maity *et al.*, 1987; Santra and Pal, 1988; Pal *et al.*, 1988; Santra *et al.*, 1989, 1991; Banerjee and Santra, 1999, 2001, 2007; Sen and Naskar, 2003; Manna *et al.*, 2010; Satpati *et al.*, 2013). There are also several reports available on euglenoids from India (Habib and Pandey, 1990; Shaji and Patel, 1991; Anand, 1998; Ratha *et al.*, 2006; Bhakta *et al.*, 2011). Aziz *et al.* (2012) reported two euglenophytes, *Astasia cylindrica* and *Euglena spathirhyncha* from estuarine Sundarbans mangrove forest of Bangladesh. In World scenario, different group of workers have been worked on euglenophytes-one of the most important unicellular flagellates (Conforti, 1994; Cabala, 2003; Alves-da-Silva and Hahn, 2004; Delgado and Sanchez, 2007; Kosmala *et al.*, 2007; Alves-da-Silva and Bicudo, 2009; Araujo *et al.*, 2012; Kouassi *et al.*, 2013; Wolowski *et al.*, 2013). But not a single report is available regarding Euglenophytes of Indian Sundarbans. The principal objective of the present study was to undertake a floristic survey of euglenophytes from different brackish water habitat of Sundarbans ecosystem of India.

2. Materials and Methods

The survey work was performed for 1 year (February' 2013 to January' 2014). Samples were collected from 6 different brackish water habitats of Sundarbans ecosystem viz. Jharkhali, Canning, Sandeskhali, Malancha, Sarberia and Lothian Island. The samples were collected in plastic bottle container and kept cool during transport to the laboratory. The microphotographs were taken and taxonomic identification was made from live material. The light microphotographs were taken under Carl Zeiss Axiostar microscope with the help of Cannon Power shot A80 digital camera. The scanning electron microscopic (SEM) images have been taken with the use of Carl Zeiss EVO 18 (EDS 8100) microscope with Zeiss Inca Penta FETX 3 (Oxford instruments) attachment. The sample material was washed with phosphate saline buffer (PBS) for 2-3 times and with the help of ultra centrifuge at 8000 rpm. One drop of washed material was put on a glass cover slip (Blue Star) and dried at 20 °C. The samples were repeatedly washed with ethanol grade and dried at room temperature. After complete dehydration the cover slips were placed on carbon tape and put in Quorum (Q 150 TES) gold coater to coat the samples with gold. The photographs were taken at different magnification. The latitude-longitude (Germin), pH, temperature (°C) and salinity (parts per thousand/ppt) were measured at the time of sample collection. Taxonomic identifications were made from different monographs and research papers (Smith, 1950; Prescott, 1982; Conforti, 1994; Kim *et al.*, 2000; Cabala, 2003; Alves-da-Silva and Hahn, 2004; Delgado and Sanchez, 2007; Alves-da-Silva and Bicudo, 2009; Araujo *et al.*, 2012; Kouassi *et al.*, 2013; Wolowski *et al.*, 2013).

3. Results

A total of forty one (41) species of euglenoids have been identified as new reports from brackish water habitat of Sundarbans ecosystem. Among them 14 species belong to the family Euglenaceae and 27 species belong to the family Phacaceae. Details about the site of collection, temperature (°C), pH, latitude-longitude and salinity (ppt) of the water at the time of sample collection have been depicted in table 1. The temperature varied from 26.4-30.2 °C and pH ranged from 6.4-9.6. The salinity level was recorded between 6.3-9.5 ppt. The species of *Euglena* were restricted to Canning and Jharkhali whereas *Trachelomonas* was mainly found in Sandeskhali region only. The greatest diversity of *Lepocinclis* was found in Malancha. The species of *Phacus* was mainly shown in Lothian Island and Sarberia region of Indian Sundarbans. All the taxa were planktonic.

Table 1. List of the sites of collection showing latitude, longitude, temperature, pH, salinity and identified taxa.

Serial no.	Sampling site	Name of taxa	Latitude and longitude	Temperature (°C)	pH	Salinity (ppt)
1.	Jharkhali	<i>Euglena gracilis</i>	N 22°01.141', E 088°41.173'	28.4	9.4	9.3
2.	Canning	<i>E. acus</i> var. <i>angularis</i>	N 22°05.588', E 088°39.612'	27.6	8.6	6.3
3.		<i>E. acus</i> var. <i>rigida</i>				
4.	Jharkhali	<i>E. granulata</i>	N 22°01.141', E 088°41.173'	28.4	9.4	9.3
5.		<i>E. pisciformis</i>				
6.		<i>E. geniculata</i>				
7.		<i>E. rostrifera</i>				
8.	Sandeskhali	<i>E. splendens</i>	N 21°42.346', E 088°18.897'	26.8	9.6	9.5
9.		<i>Euglena formisproxima</i>				
10.		<i>Monomorphina pyrum</i>				
11.		<i>M. nordstedtii</i>				
12.		<i>Trachelomonas kelloggii</i>				
13.		<i>T. rugulosa</i>				
14.		<i>T. rugulosa</i> var. <i>meandrina</i>				
15.	Malancha	<i>Lepocinclis acus</i>	N 22°12.459', E 088°42.426'	28.6	6.4	6.9
16.		<i>L. claviformis</i>				
17.		<i>L. fusiformis</i>				
18.		<i>L. fusiformis</i> var. <i>amphirhynchus</i>				
19.		<i>L. texta</i> var. <i>texta</i>				

20.		<i>L. marssonii</i>				
21.		<i>L. ovum</i>				
22.	Lothian Island	<i>L. americana</i>	N 21°42.345', E 088°18.894'	30.2	6.8	7.4
23.		<i>L. oxyuris</i>				
24.		<i>Phacus trypanon</i>				
25.		<i>P. orbicularis</i>				
26.		<i>P. circulator</i>				
27.		<i>P. segretii</i> var. <i>ovum</i>				
28.		<i>P. swirenkoi</i>				
29.		<i>P. helikoides</i>				
30.	Sarberia	<i>P. sesquitortus</i>	N 22°12.457', E 088°42.421'	26.4	7.6	8.7
31.		<i>P. pleuronectes</i>				
32.		<i>P. angulatus</i>				
33.		<i>P. acuminatus</i>				
34.		<i>P. alatus</i>				
35.	Canning	<i>P. pusillus</i>	N 22°05.588', E 088°39.612'	27.6	8.6	6.3
36.		<i>P. viguieri</i>				
37.		<i>P. triqueter</i>				
38.		<i>P. asymmetrica</i>				
39.	Jharkhali	<i>P. longicauda</i>	N 22°01.141', E 088°41.173'	28.4	9.4	9.3
40.		<i>P. tortus</i>				
41.		<i>P. parvulus</i>				

Key for identification of the species and the illustrated taxonomic accounts of these taxa are given below:

1. Cells free-swimming with periplasts.....2
1. Cells without periplast, enclosed in lorica..... *Trachelomonas*
 2. Cells cylindrical with single flagellum.....3
3. Cells cylindrical, fusiform, gradually tapering at one end,attaining different shapes.....*Euglena*
3. Cells longitudinal with tapered end.....*Euglenaformis*
 2. Cells oblique, oval, pear shaped with single flagellum.....4
4. Chloroplasts 2, rigid, U-shaped or sometimes shield like, cells ovoid....*Lepocinclis*
4. Chloroplasts numerous, disc shaped, cells pear shaped.....5
 5. Paramylum 2, placed between the pellicle and chloroplast, cells pear shaped either narrowly or broadly.....*Monomorpha*
 5. Paramylum 2, oblique, cell elliptical.....*Phacus*

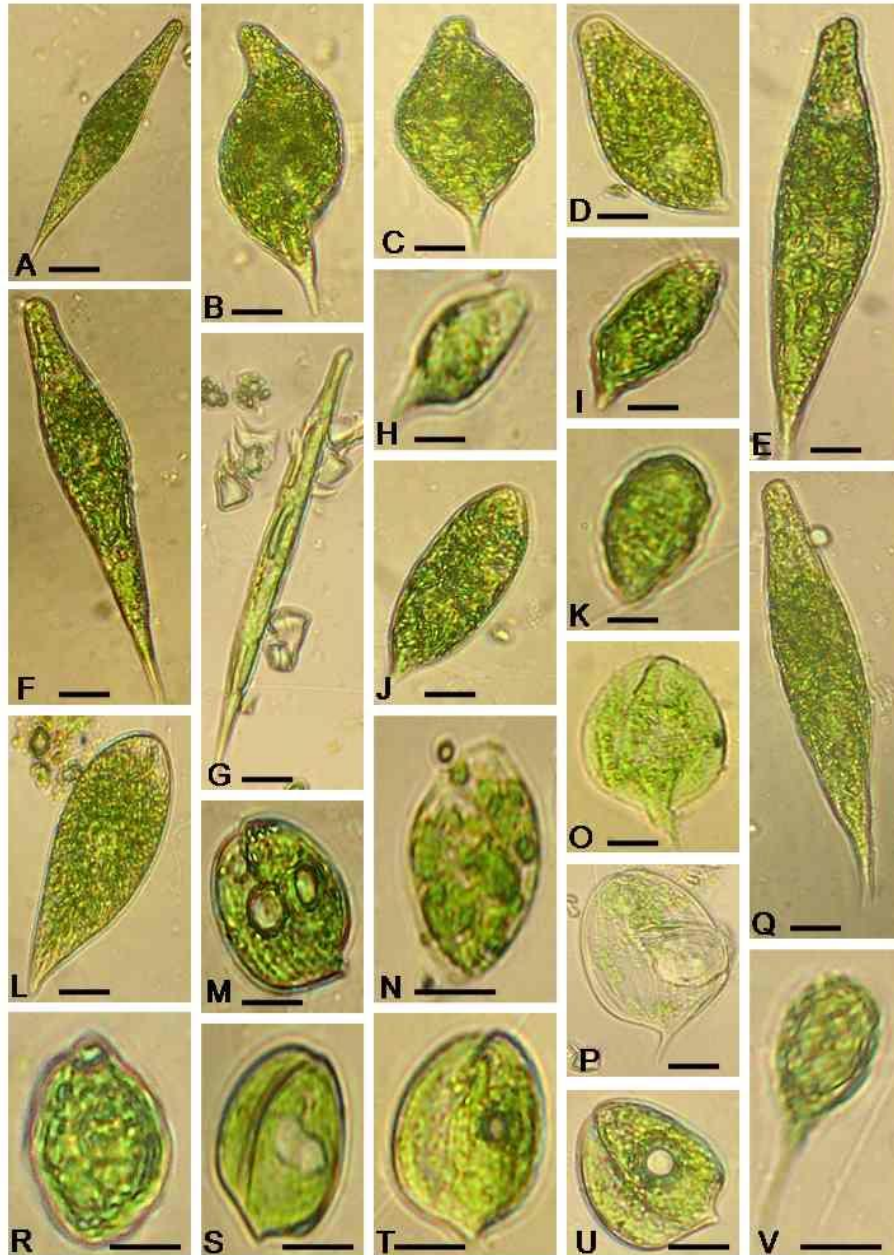


Fig. 1. Light microphotographs of A. *Lepocinclis acus*, B-C. *Euglena gracilis*, D. *E. splendens*, F. *Lepocinclis acus*, G. *Euglena acus* var. *angularis*, H. *Lepocinclis marssonii*, I. *Euglena pisciformis*, J. *Euglena formisproxima*, K. *Lepocinclis texta* var. *texta*, L. *Euglena geniculata*, M. *Phacus acuminatus*, N. *Lepocinclis fusiformis*, O. *Phacus orbicularis*, P. *P.circulatus*, Q. *Euglena acus* var. *rigida*, R. *Trachelomonas kelloggii*, S. *Phacus alatus*, T. *P.angularatus*, U. *P.vigueri*, V. *P. nordstedtii*. (Scale bar: A, E-G, O, Q= 20 μ ; B-D, H-N, P, R-V= 10 μ).

Phylum: Euglenozoa

Class: Euglenophyceae

Order: Euglenales

Family: Euglenaceae

1. *Euglena gracilis* Klebs 1883 (Figs. 1B-C and Fig. 2A)

[Prescott, 1982; Wolowski, 2002; Wolowski *et al.*, 2013]

Cells 70- 75 μ long and 35- 40 μ in diameter, divided into central discoid zone and two conical zones, one anterior and another posterior; cells highly metabolic, changes shape during movement.

SEM observation: The body exhibits a torsion around the main axis as shown in SEM micrograph; 14-15 pellicular strips per 10 μ diameter.

Voucher number: CUH/AI/MW-1

2. *E. acus* Ehrenberg var. *angularis* L. P. Johnson 1944 (Fig. 1G)

[Gojdics, 1953; Starmach, 1983]

Cell 120-250 μ long and 5-17 μ broad, elongated, rod shaped; posterior end sharp pointed and anterior end truncated; chloroplasts numerous, discoid.

Voucher number: CUH/AI/MW-2

3. *E. acus* Ehrenberg var. *rigida* E. Hübner 1962 (Fig. 1Q and Fig. 2C)

[Prescott, 1962; Day *et al.*, 1995; Alves-da-Silva and Menezes, 2010]

Cell 115-125 μ long and 5-15 μ broad, fusiform; anterior end truncated while posterior end slightly curved and pointed; chloroplasts numerous.

SEM observation: Pellicle longitudinally striated as shown in SEM micrograph.

Voucher number: CUH/AI/MW-3

4. *E. granulata* (Klebs) F. Schmitz 1884 (Figs. 2D-E)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *E. polymorpha* P. A. Dangeard 1902

Basionym: *E. velata* var. *granulata* G. A. Klebs 1883

Cells 90-100 μ long and 20-25 μ in diameter, elongated, pyriform, spindle shaped, narrowed gradually towards the posterior end to form a blunt tip; the anterior tip is characterized by an aperture where the flagellum originated.

SEM observation: Periplast spirally striated; pellicle arranged side-by-side and 7-8 in 10 μ in length as shown in SEM micrograph.

Voucher number: CUH/AI/MW-4

5. *E. pisciformis* Klebs 1883 (Fig. 1I)

[Day *et al.*, 1995; Wolowski, 2002; Hu and Wei, 2006; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *E. agilis* H. J. Carter 1856

Cell 21-28 μ long and 7-12 μ broad; short, fusiform in shape with large elongated chloroplasts.

Voucher number: CUH/AI/MW-5

6. *E. geniculata* Dujardin 1841 (Fig. 1L)

[Day *et al.*, 1995; Hu and Wei, 2006; Alves-da-Silva and Menezes, 2010]

Cell 50-70 μ long and 10-20 μ broad; ovovoid in outline; anterior end broad and posterior end fusiform; chloroplasts star shaped.

Voucher number: CUH/AI/MW-6

7. *E. rostrifera* L. P. Johnson 1944 (Fig. 1E)

[Gojdics, 1953; Starmach, 1983; Alves-da-Silva and Menezes, 2010]

Cell 120-140 μ long and 17- 22 μ broad; fusiform; chloroplasts numerous; pellicle spirally striated.

Voucher number: CUH/AI/MW-7

8. *E. splendens* P. A. Dangeard 1902 (Fig. 1D)

[Gojdics, 1953; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Cell 65-95 μ long and 25-30 μ broad, broadly oval to fusiform; posterior end with small projections and anterior end rounded.

Voucher number: CUH/AI/MW-8

9. *Euglenaformis proxima* (Dangeard) M. S. Bennett & Triemer 2014 (Fig. 1J)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *E. proxima* P. A. Dangeard 1902

Cell 48-52 μ long and 10-15 μ wide, fusiform, anterior end broad, posterior end tapering, small discoid chloroplasts.

Voucher number: CUH/AI/MW-9

10. *Monomorphina pyrum* (Ehrenberg) Mereschkovsky 1877 (Fig. 3J)

[Prescott, 1962; Day *et al.*, 1995; Wolowski, 2002; Hu and Wei, 2006]

Taxonomic synonym: *Euglena pyrum* Ehrenberg 1832; *Phacus pyrum* (Ehrenberg) W. Archer 1871

Basionym: *Euglena pyrum* Ehrenberg 1832

Cells 24-26 μ long and 10-15 μ in diameter, cells gradually tapered to the posterior end to form a very short caudus.

SEM observation: Periplast spirally striated; pellicle arranged into 'S' shaped pattern with alternating thick and thin bands as shown in SEM micrograph, 2-3 in 10 μ length.

Voucher number: CUH/AI/MW-10

11. *M. nordstedtii* (Lemmermann) T. G. Popova 1955 (Fig. 1V)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *P. nordstedtii* Lemmermann 1904

Cell 18-20 μ in diameter and 35-40 μ long, napiform, nearly spherical but with a long, straight, sharply pointed caudus; broadly rounded anteriorly; chloroplasts numerous; pellicles spirally striated.

Voucher number: CUH/AI/MW-11

12. *Trachelomonas kelloggii* (Skvortzov) Deflandre 1926 (Fig. 1R)

[Prescott, 1962; Caraus, 2002, 2012]

Lorica rounded tests 30-38 μ long and 23-30 μ in diameter; broadly sub spherical; flagellum aperture without a collar; posterior end slightly broad than the anterior end.

Voucher number: CUH/AI/MW-12

13. *T. rugulosa* F. Stein 1878 (Fig. 3L)

[Caraus, 2002; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Lorica broad, tests 40-50 μ wide and 50-70 μ long; anterior end rounded than the posterior end, apical pore with a collar.

SEM observation: Test enclosed in an ornamented gelatinous shell as shown in SEM micrograph.

Voucher number: CUH/AI/MW-13

14. *T. rugulosa* var. *meandrina* (Conrad) Conrad 1952 (Fig. 3M)

[Starmach, 1983; Wolowski, 2002]

Tests 60-70 μ long and 40-60 μ broad; anterior end neck like and the posterior end broad, lorica surrounded by gelatinous shell.

SEM observation: Gelatinous shell form convoluted margin during movement as observed in SEM micrograph.

Voucher number: CUH/AI/MW-14

Family: Phacaceae

15. *Lepocinclis acus* (O. F. Muller) Marin & Melkonian 2003 (Figs. 1A, F and Fig. 2B)

[Prescott, 1962; Day *et al.*, 1995; Caraus, 2002; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *E. acus* (O. F. Muller) Ehrenberg 1830

Cells 100-120 μ long and 15-20 μ in diameter, elongate spindle shaped; anterior end slightly twisted and posterior end long with fine tapering point.

SEM observation: Pellicle transversely striated with convoluted margin and 18-20 per 10 μ length as observed in SEM micrograph.

Voucher number: CUH/AI/MW-15

16. *L. claviformis* Conforti 1995 (Fig. 2F)

[Prescott, 1962; Alves-da-Silva and Menezes, 2010]

Cell club shaped, anterior end flattened, slightly depressed in the centre; 40-50 μ long and 20-25 μ ; the posterior end gradually narrowed to a conical cauda; cauda 5-7 μ long and 1-2 μ in diameter (thickness). Pellicle spirally striated to the left, sometimes right due to movement; chloroplast discoid; the spirally arranged pellicles fused to form an opening at the anterior end of the cell.

SEM observation: The striae of pellicle were alternately thick and thin; the ridges and furrow were present in the striae; the number of ridge was 8-10 per 10 μ of cell diameter as shown in SEM micrograph.

Voucher number: CUH/AI/MW-16

17. *L. fusiformis* (H. J. Carter) Lemmermann 1901 (Fig. 1N and 2G)

[Prescott, 1962; Wolowski, 2002; Hu and Wei, 2006; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *Euglena fusiformis* H. J. Carter 1859

Cell 30-35 μ long and 25-28 μ broad; ovovoid in outline; chloroplasts numerous dispersedly arranged; pellicle stacked and spirally arranged to the right and a central groove was observed under scanning electron microscope.

Voucher number: CUH/AI/MW-17

18. *L. fusiformis* var. *amphirhynchus* Nygaard 1949 (Fig. 2H)

[Starmach, 1983; Alves-da-Silva and Menezes, 2010]

Cell 32-38 μ long and 22-25 μ broad, fusiform, metabolic; changes shape during movement; posterior and anterior end rounded.

SEM observation: Pellicle spirally striated and stacked, large central lobe due to rotation was observed in SEM micrograph.

Voucher number: CUH/AI/MW-18

19. *L. texta* (Dujardin) Lemmermann var. *texta* Drezep. 1925 (Fig. 1K and 2I)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Cell 35-46 μ long and 25-30 μ broad, ovoid; anterior end rounded and posterior end narrow; chloroplasts numerous.

SEM observation: Pellicle convoluted throughout the surface as shown in SEM micrograph.

Voucher number: CUH/AI/MW-19

20. *L. marssonii* Lemmermann 1905 (Fig. 1H)

[Day *et al.*, 1995; Hu and Wei, 2006; Alves-da-Silva and Menezes, 2010; Caraus, 2012]

Cell 30-37 μ long and 10-12 μ broad; anterior end truncated and posterior end with small projection; paramylon body rounded.

Voucher number: CUH/AI/MW-20

21. *L. ovum* (Ehrenberg) Lemmermann 1901 (Fig. 2J)

[Prescott, 1962; Wolowski, 2002; Hu and Wei, 2006; Alves-da-Silva and Menezes, 2010]

Basionym: *Euglena ovum* Ehrenberg

Cell 25-30 μ long and 20-25 μ broad, broadly ovate, metabolic; anterior and posterior end rounded.

SEM observation: Periplast or pellicle spirally striated and stacked as observed in SEM micrograph.

Voucher number: CUH/AI/MW-21

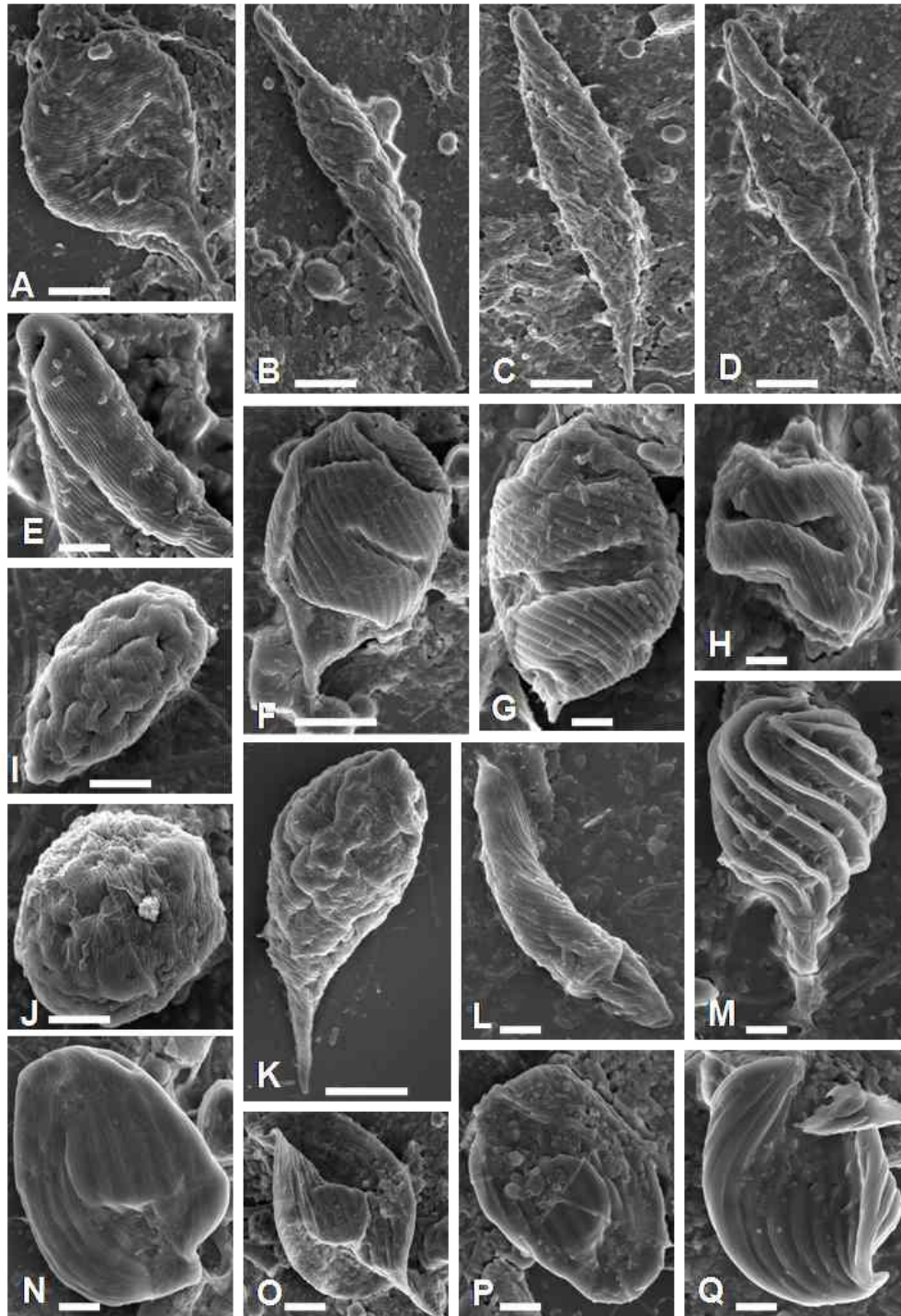


Fig. 2. SEM microphotographs of A. *Euglena gracilis*, B. *Lepocinclis acus*, C. *Euglena acus* var. *rigida*, D-E. *E. granulata*, F. *Lepocinclis claviformis*, G. *L. fusiformis*, H. *L. fusiformis* var. *amphirhynchus*, I. *L. texta* var. *texta*, J. *L. ovum*, K. *L. americana*, L. *L. oxyuris*, M. *Phacus trypanon*, N. *P. orbicularis*, O. *P. circulatus*, P. *P. segretii* var. *ovum*, Q. *P. swirenkoi*. (Scale bar: A-C, F, K= 10 μ ; D= 20 μ ; E, G-J, L-Q= 2 μ).

22. *L. Americana* V. Conforti 1994 (Fig. 2K)

[Prescott, 1962; Alves-da-Silva and Menezes, 2010]

Cell 48-60 μ long and 15-30 μ broad, ovoid; anterior end rounded, posterior end terminated to long cauda of 10-15 μ .

SEM observation: Pellicle spirally striated as observed in SEM micrograph.

Voucher number: CUH/AI/MW-22

23. *L. oxyuris* (Schmarda) B. Martin & Melkonian 2003 (Fig. 2L)

[Prescott, 1962; Hu and Wei, 2006; Alves-da-Silva and Menezes, 2010]

Cell 80- 150 μ long and 10-20 μ broad, elongated, cylindrical.

SEM observation: Pellicle spirally striated throughout the body as observed in SEM micrograph.

Voucher number: CUH/AI/MW-23

24. *Phacus trypanon* Pochmann 1942 (Fig. 2M)

[Starmach, 1983; Caraus, 2002, 2012]

The cells are symmetrical, clavate to weakly flattened; 26-30 μ long and 10-20 μ in diameter. Chloroplasts discoid in shape, scattered in the entire protoplasts except for the part of caudus. The anterior part of cell was broadly rounded and truncated toward the canal opening. The pellicular striae were fused at the anterior pole whereas the posterior part was narrowed into caudus. The caudus was rigid and slightly curved according to the cell movement. The length of caudus was 8-15 μ and thickness of about 1-2 μ in diameter.

SEM observation: The pellicle was spirally striated downward to the right direction. The spirally arranged pellicle was clearly differentiated into ridges and furrow. The ridge has thick and thin striae at both sides as shown in SEM micrograph. The number of ridge was 5-7 per 10 μ of cell diameter. The furrows between ridges were deeply depressed.

Voucher number: CUH/AI/MW-24

25. *P. orbicularis* K. Huebner 1886 (Fig. 1O and 2N)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Cells orbicular in shape with a short cauda (1-1.5 μ in length); the anterior part of the cell broadly rounded; cells 35-50 μ in diameter and 50-80 μ long.

SEM observation: Pellicle longitudinally striated with thick and thin ridges and furrows as shown in both light and SEM micrographs.

Voucher number: CUH/AI/MW-25

26. *P. circulates* Pochmann 1942 (Fig. 1P and 2O)

[Prescott, 1962; Starmach, 1983; Caraus, 2002, 2012]

Cell orbicular to ovoid in shape, sometimes rounded in outline, anterior part is broad and posterior part is extended to form sharply pointed cauda; paramylon body single, large plate like at the middle of the cell; cells 45-60 μ in length and 25-35 μ in diameter.

SEM observation: 10-12 pellicles to 10 μ in diameter, arranged longitudinally into thin bands as shown in both light and SEM micrographs.

Voucher number: CUH/AI/MW-26

27. *P. segretii* var. *ovum* Prescott 1943 (Fig. 2P)

[Prescott, 1982; Starmach, 1983]

Cells 32-40 μ long and 22-24 μ in diameter, broadly ovoid, sometimes rounded; paramylon body single, large, placed at the middle, round.

SEM observation: Pellicle arranged longitudinally into thick and thin bands as shown in SEM micrograph.

Voucher number: CUH/AI/MW-27

28. *P. swirenkoi* Skvortzov 1928 (Fig. 2Q)

[Prescott, 1962; Starmach, 1983]

Cells 24-35 μ long and 16-20 μ in diameter, orbicular in outline, anteriorly broad and posterior portion is extended to form a short caudus; the caudus turns obliquely to the right when seen from the ventral side and to the left when seen from the dorsal side.

SEM observation: Periplast longitudinally striated; pellicle 1-2 in 10 μ length and arranged longitudinally into alternating thick and thin bands as observed in SEM micrograph.

Voucher number: CUH/AI/MW-28

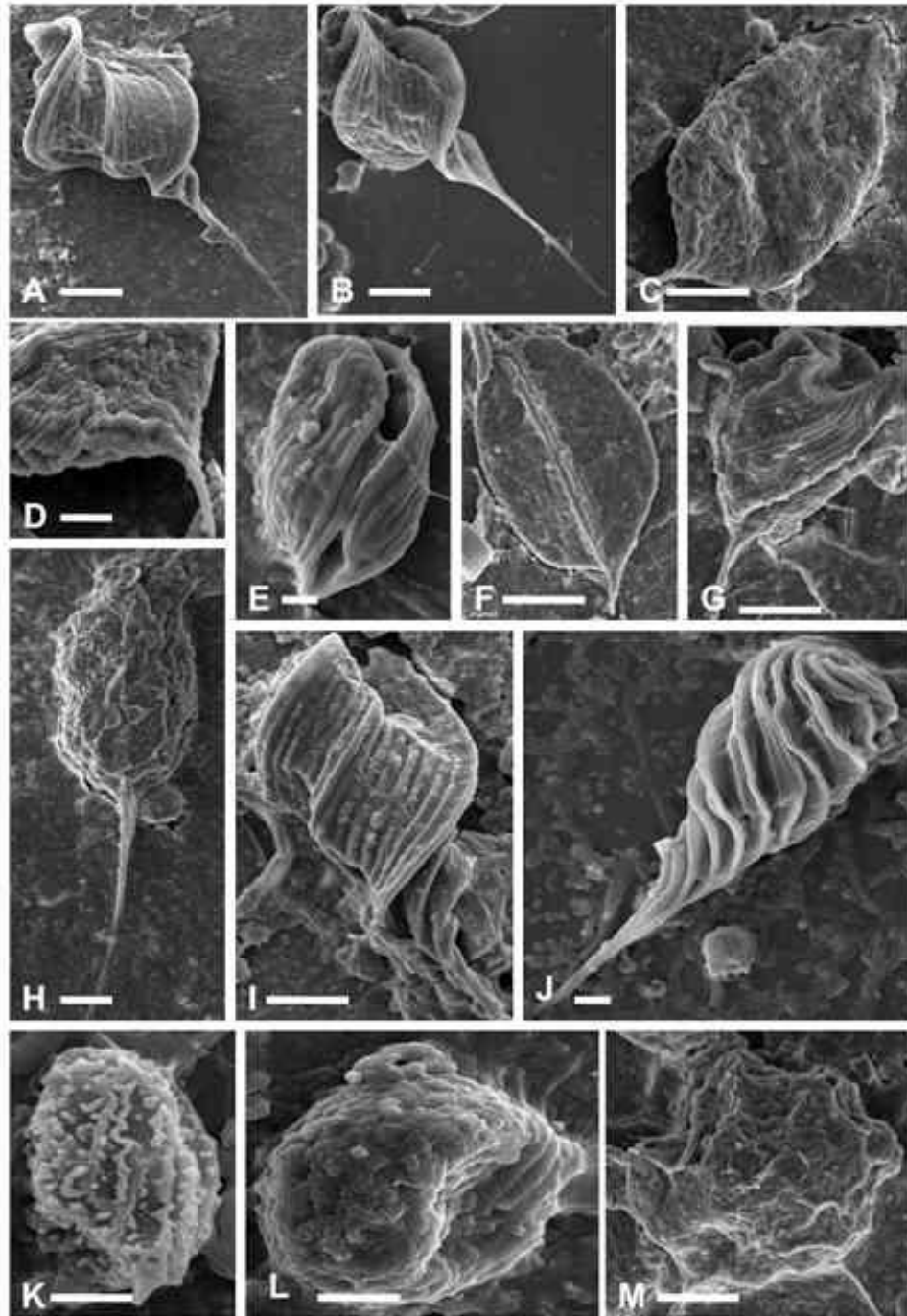


Fig. 3. SEM microphotographs of A. *Phacus helikoides*, B. *P. sesquitortus*, C-D. *P. pleuronectes*, E. *P. pusillus*, F. *P. triquetus*, G. *P. asymmetrica*, H. *P. longicauda*, I. *P. longicauda* var. *tortus*, J. *Monomorphina pyrum*, K. *P. parvulus*, L. *Trachelomonas rugulosa*, M. *T. rugulosa* var. *meandrina*. (Scale bar: A-C, F-I, L-M= 10 μ ; D-E, J= 2 μ).

29. *P. helikoides* Pochmann 1942 (Fig. 3A)

[Prescott, 1962; Day *et al.*, 1995; Caraus, 2002; Wolowski, 2002]

Taxonomic synonym: *P. tortus* var. *helikoides* (Pochmann) Huber-Pestalozzi

Cells elongated, pyriform, sometimes fusiform, twisted throughout their entire length; anterior portion broad and twisted and posterior portion become elongated to form caudus which is about ½ of the cell body in length, cells 38-45 µ in diameter and 70- 95 µ long.

SEM observation: Pellicle striated and extends up to the cauda as shown in SEM micrograph, 5-6 pellicles to 10 µ in diameter.

Voucher number: CUH/AI/MW-29

30. *P. sesquitortus* Pochmann 1942 (Fig. 3B)

[Prescott, 1962; Alves-da-Silva and Menezes, 2010]

Cells 75-85 µ long and 35-40 µ broad; cauda 25- 30 µ long; double torsion of the body distinguishes this with the *P. tortus* (Lemmermann) Skvortzov, instead of single twisting.

SEM observation: The torsion originated at the anterior end and extends to the posterior end and produces two helicoidal rotations as shown in SEM micrograph.

Voucher number: CUH/AI/MW-30

31. *P. pleuronectes* (O. F. Müller) Nitzsch ex Dujardin 1841 (Figs. 3C-D)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *Cercaria pleuronectes* O. F. Müller 1773

Cells 60-65 µ in length and 28-32 µ in diameter, sub orbicular in shape; anterior end is broad and posterior end sharply pointed to form a caudus which is obliquely turned to the right when seen from the ventral side.

SEM observation: Periplast longitudinally striated shown in SEM micrograph; pellicles 15 in 10 µ length.

Voucher number: CUH/AI/MW-31

32. *P. angulatus* Pochmann 1942 (Fig. 1T)

[Day *et al.*, 1995; Alves-da-Silva and Menezes, 2010]

Cells 34-38 µ long and 27-29 µ in diameter; ovoid in outline; anterior and posterior end are ovoid in outline; posterior end broad, concave with short cauda; single paramylon body.

Voucher number: CUH/AI/MW-32

33. *P. acuminatus* A. C. Stokes 1885 (Fig. 1M)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010; Caraus, 2012]

Cell 34-36 µ long and 22-25 µ in diameter, ovoid; posterior end broad with small straight projection; chloroplasts numerous; two paramylon bodies; pellicle longitudinally striated as observed in light micrograph.

Voucher number: CUH/AI/MW-33

34. *P. alatus* G. A. Klebs 1883 (Fig. 1S)

[Wolowski, 2002; Alves-da-Silva and Menezes, 2010; Caraus, 2012]

Cell 32-33 µ long and 22-23 µ broad; posterior end slightly broad and end with short tailpiece; chloroplasts numerous; 1-2 large paramylon body; pellicle longitudinally striated as shown in light micrograph.

Voucher number: CUH/AI/MW-34

35. *P. pusillus* Lemmermann 1910 (Fig. 3E)

[Prescott, 1962; Wolowski, 2002; Alves-da-Silva and Menezes, 2010; Caraus, 2012]

Taxonomic synonym: *P. alatus* G. A. Klebs 1883; *P. parvulus* var. *pusillus* (Lemmermann) Popowa 1955

Cell 23-24 μ long and 10-12 μ broad, oval in outline with fold running along cell; chloroplasts numerous; paramylon bodies two, ring like.

SEM observation: Pellicle slightly spiral to longitudinally striated as observed in scanning electron micrograph.

Voucher number: CUH/AI/MW-35

36. *P. viguieri* All. et. Lef. (Fig. 1U)

[Prescott, 1962; Caraus, 2012]

Cell 28-32 μ long and 20-25 μ in diameter, ovoid in outline; posterior part broad and ends with short tail-piece; chloroplasts numerous.

Voucher number: CUH/AI/MW-36

37. *P. triqueter* (Ehrenberg) Dujardin 1841 (Fig. 3F)

[Prescott, 1962; Wolowski, 2002; Caraus, 2012]

Basionym: *Euglena triquetra* Ehrenberg

Cell 40-48 μ long and 25-30 μ broad, oval, triangular; a characteristic wide keel running along the cell; chloroplasts numerous.

Voucher number: CUH/AI/MW-37

38. *P. asymmetrica* Prescott 1944 (Fig. 3G)

[Prescott, 1962; Starmach, 1983]

Cell 50-60 μ long and 20-25 μ broad, ovate to fusiform in shape; anterior end broad, posterior end terminated to long cauda of 10-15 μ .

SEM observation: Pellicles thick spirally striated as shown in scanning electron micrograph.

Voucher number: CUH/AI/MW-38

39. *P. longicauda* (Ehrenberg) Dujardin 1841 (Fig. 3H)

[Prescott, 1962; Day *et al.*, 1995; Hu and Wei, 2006]

Taxonomic synonym: *Euglena longicauda* Ehrenberg 1830

Cell 60-160 μ long and 30-60 μ broad, ovate, sometimes oblong in shape; anterior end broad, posterior end terminated to long cauda with sharp end; chloroplasts numerous.

Voucher number: CUH/AI/MW-39

40. *P. tortus* (Lemmermann) Skvortzov 1928 (Fig. 3I)

[Prescott, 1962; Caraus, 2002; Wolowski, 2002; Alves-da-Silva and Menezes, 2010]

Taxonomic synonym: *P. longicauda* var. *tortus* Lemmermann 1910

Cell 85-98 μ long and 40-47 μ broad, twisted, broadly spindle shaped, anterior end broad and posterior end spirally twisted to form long cauda, chloroplasts numerous.

SEM observation: SEM study showed spirally striated pellicle throughout the surface.

Voucher number: CUH/AI/MW-40

41. *P. parvulus* G. A. Klebs 1883 (Fig. 3K)

[Caraus, 2002; Wolowski, 2002; Alves-da-Silva and Menezes, 2010; Caraus, 2012]

Cell 15-22 μ long and 8-12 μ wide, oval to elliptical, ended by small blunt process.

SEM observation: SEM study showed periplast obliquely striated and well ornamented.

Voucher number: CUH/AI/MW-41

4. Discussion

Euglenophytes are most important group of microorganisms occupy shallow aquatic ecosystem in large numbers due to high concentrations of organic materials to the environment. The species richness and abundance are two most important factors make this group unique to nutrient rich water body. The present study contributes new records of all these taxa in Sundarbans mangrove reserve forest. In our previous study, we reported other microalgal groups from different habitat of Indian Sundarbans including chlorophytes, cyanobacteria, rhodophytes and seaweeds (Satpati *et al.*, 2011, 2012, 2013, 2014; Satpati and Pal, 2015, 2016; Barman *et al.*, 2015). The present study showed the greatest richness of the genus *Phacus* (18 species) followed by the genus *Lepocinclis* (9 species) and *Euglena* (8 species) in different brackish water habitat of Indian Sundarbans. Alves-da-Silva and Hahn (2001) reported the dominance of *Trachelomonas* and *Phacus* in a nutrient enriched shallow lake of Brazil. Similarly Araujo *et al.* (2012) showed greatest richness of the pigmented euglenophyte species of *Lepocinclis* and *Trachelomonas* from the state of Brazil. Alves-da-Silva and Bicudo (2009) had done a floristic survey of *Cryptoglena*, *Monomorphina* and *Phacus* from the state of Brazil. In the present work, we identified only a single species of the genus *Euglenaformis* (*E. proxima*), 2 species of *Monomorphina* (*M. pyrum* and *M. nordstedtii*) and 3 species of *Trachelomonas* (*T. kelloggii*, *T. rugulosa* and *T. rugulosa* var. *meandrina*) from Sandeskhali region of Indian Sundarbans. The Indian parts of Sundarbans are constantly inundated by marine water and make this ecosystem unique. The variation of salinity and pH in different habitat constantly changes the algal flora of Indian Sundarbans. Due to lack of reports, our attempt was to investigate different groups of algae from Indian Sundarbans Biosphere Reserve for future applications.

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References

- Alves-da-Silva, S. M. and Hahn, A. T. 2004. Study of Euglenophyta in the Jacui Delta State Park, Rio Grande do Sul, Brazil. 1. *Euglena* Her., *Lepocinclis* Perty. *Acta. Bot. Bras.* **18**(1): 123-140.
- Alves-da-Silva, S. M. and Bicudo, C. E. De M. 2009. *Cryptoglena*, *Monomorphina* and *Phacus* (Euglenophyceae) of a reservoir in the State of Rio Grande do Sul, southern Brazil. *Revista Brasil. Bot.* **32**(2): 253-270.

- Alves-da-Silva, S.M. and Menezes, M. 2010. Eugleophyceae. In: *Catálogo de plantas e fungos do Brasil. Vol. 1.* (Forzza, R.C. Eds), pp. 383-404. Rio de Janeiro: Andrea JakobssonEstúdio; Instituto de Pesquisas Jardim Botânico do Rio de Janeiro.
- Anand, N. 1998. Indian freshwater microalgae, Bishen Singh Mahendra Pal Singh, 23A, Dehra Dun, India, pp 50 and 53.
- Araujo, G. J. M., De Lucena Barbosa, J. E. and Barbosa, L. G. 2012. Pigmented Euglenophytes in a natural and shallow lake in the semiarid region of Paraíba State, Brazil. *Brazilian J. Bot.* **35**(1): 17-30.
- Aziz, A., Rahman, M., Ahmed, A. 2012. Diversity, Distribution and Density of Estuarine Phytoplankton in the Sundarban Mangrove Forests, Bangladesh. *Bangladesh J. Bot.* **41**(1): 87-95.
- Banerjee, A. and Santra, S.C. 1999. Plankton composition and population diversity of the Sundarbans Mangrove estuary of West Bengal, India, In Sundarban Mangal (Guabaskhi, Sanyal & Naskar Eds.) Calcutta, pp. 340 - 348.
- Banerjee, A. and Santra, S.C. 2007. Present planktonic panorama in Sunderban estuary, West Bengal, India obeying neotectonic plate movement of Bengal Basin. *Indian Hydrobiol.* **10**(2): 277-282.
- Banerjee, A. and Santra, S.C. 2011. Phytoplankton of the River of Indian Sundarban mangrove estuary. *Indian Biologist* **33**(1): 67-71.
- Barman, N., Satpati, G. G., and Pal, R. 2015. Morphotaxonomic account of cyanobacterial diversity of Indian Sundarbans. *J. Algal Biomass Utiln.* **6**(3): 39-46.
- Bhakta, S., Das, S. K., Nayak, M., Jena, J., Panda, P. K. and Sukla, L. B. 2011. Phyco-Diversity Assessment of Bahuda River Mouth Areas of East Coast of Odisha, India. *Recent Res. Sci. Technol.* **2**(4): 80-89.
- Cabala, J. 2003. Some Interesting Colourless Euglenophytes Found In Southern Poland. *Acta Soc. Bot. Poloniae*, **3**: 243-247.
- Conforti, V. 1994. Study of the Euglenophyta from Camaleao Lake (Manaus, Brazil), III. *Euglena* Her., *Lepocinclis* Perty, *Phacus* Duj. *Rev. Hydrobiol. Trop.* **27**(1): 3-21.
- Caraus, I. 2002. The algae of Romania. *Studiisi Cercetari, Universitatea Bacau, Biologie* **7**: 1-694.
- Caraus, I. 2012. Algae of Romania. A distributional checklist of actual algae. Version 2.3 third revision. . Bacau: Univ. Bacau.
- Day, S.A., Wickham, R.P., Entwisle, T.J. and Tyler, P. A. 1995. Bibliographic check-list of non-marine algae in Australia. *Flora Aust. Suppl. Ser.* **4**: i-vii, 1-276.
- Delgado, J.G. and Sanchez, L. 2007. Euglenophyta from Lower Basin of the Caura River Venezuela. *Acta Bot. Venez.* **30**(2): 277-290.
- Gojdics, M. 1953. The genus *Euglena*. Madison: The University of Wisconsin Press. pp. [i]-viii, [1]-268, 39 pls.
- Guiry, M.D. and Guiry, G.M. 2015. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. <http://www.algaebase.org>; searched on (11.01.2015).
- Habib, I. and Pandey, U.C. 1990. The Euglenineae from Nakatiariver, Bareilly (U.P.) India. *J. Ind. Bot. Soc.* **69**: 387-390.
- Hu, H. and Wei, Y. 2006. The freshwater algae of China. Systematics, taxonomy and ecology. China: www.sciencep.com. pp. [4 pls of 16 figs], [i-iv], i-xv, 1-1023.

- Kim, J. T., Shin, W. and Boo, S. M. 2000. Morphology and Habitat Conditions of *Phacus trypanon* (Euglenophyceae) from Korea. *Algae*. **15**(1): 17-22.
- Kosmala, S., Bereza, M., Milanowski, R., Kwiatowski, J. and Zakrys, B. 2007. Morphological and molecular examination of relationships and epitype establishment of *Phacus pleuronectes*, *Phacus orbicularis* and *Phacus hamelli*. *J. Phycol.* **43**:1071-1082.
- Kouassi, B. A. T., Ouattara, A. and Philippe DA, K. 2013. Euglenozoa occurring in Adzope Reservoir, Cote D'Ivoire. *Turkish J. Bot.* **37**: 1176-1187.
- Marin, B., Palm, A., Klingberg, M. and Melkonian, M. 2003. Phylogeny and taxonomic revision of plastid-containing euglenophytes based on SSU rDNA sequence comparisons and synapomorphic signatures in the SSU rRNA secondary structure. *Protist* **154**: 99-145.
- Maity, H., Bandopadhyay, G. and Santra, S. C. 1987. Algal flora of Saline habitats of Sunderbans, West Bengal and its possible role in reclamation of soil. *J. Indian Soc. Coastal Agric. Res.* **5** (1): 325-331.
- Manna, S., Chaudhuri, K., Bhattacharya, S. and Bhattacharya, M. 2010. Dynamics of Sndarban estuarine ecosystem: eutrophication induced threat to mangroves. *Saline Syst.* **6**: 8.
- Pal, U. C., Naskar, K. R., and Santra, S. C. 1988. A check list of algal flora of Sundarban delta of West Bengal, India. *Phykos*, **27**: 48-53.
- Prescott, G. W. 1944. New species and new varieties of Wisconsin algae, *Farlowia* **1**: 347- 385.
- Prescott G. W. 1962. Algae of the Western Great Lakes area with an illustrated key to the genera of desmids and freshwater diatoms. Revised [Second] edition. Dubuque, Iowa: Wm. C. Brown Company Publishers 135 South Locust Street, pp. [i]-xiii, 1-977.
- Prescott G. W. 1982. Algae of the Western Great lakes Area. Otto Koeltz Science Publishers, Koenigstein, W-Germany. Bishen Singh Mahendra Pal Singh, Dehra Dun, pp. 1-965.
- Ratha, S. K., Jena, M. and Adhikary, S. P. 2006. Euglenophytes from Orissa State, East Coast of India. *Algae*. **21**(1): 61-73.
- Santra, S. C. and Pal, U. C. 1988. Marine algae of Mangrove delta region of West Bengal, India: Benthic forms. *Indian Biol.* **20**(2): 31-41.
- Santra, S. C., Pal, U. C., Das, T. M., Sen, S., Saha, R., Dutta, S. and Ghosh Dastidar, P. 1989. Phytoplanktons of Bhagirathi-Hoogly Estuary: an illustrative account. *Indian Biol.* **21**(1): 1-27.
- Santra, S. C., Pal, U. C. and Choudhury, A. 1991. Marine phytoplankton of the mangrove delta region of West Bengal. *India J. Mar. Biol. Ass.* **33**(1 & 2): 292 - 307.
- Satpati, G. G., Barman, N., Chakraborty, T., and Pal, R. 2011. Unusual habitat of algae. *J. Algal Biomass Utln.* **2**(4): 50-52.
- Satpati, G. G., Barman, N., and Pal, R. 2012. Morphotaxonomic account of some common seaweeds from Indian Sundarbans mangrove forest and inner island area. *J. Algal Biomass Utln.* **3**(4): 45-51.
- Satpati, G. G., Barman, N. and Pal, R. 2013. A study on green algal flora of Indian Sundarbans mangrove forest with special reference to morphotaxonomy. *J. Algal. Biomass Utln.* **4**(1): 26-41.

- Satpati, G. G., Pal, R. 2014. Effects of nitrate, phosphate and salinity stress on cell division, chloroplast morphology and cell wall architecture in a filamentous green alga *Spirogyra punctulata* Jao. *Int. J. Biochem., Photon.* **196**: 414-422.
- Satpati, G. G., and Pal, R. 2015. *Trentepohlia sundarbanensis* sp. nov. (Trentepohliaceae, Ulvophyceae, Chlorophyta), a new chlorophyte species from Indian Sundarbans. *Phykos.* **45**(1): 1-4.
- Satpati, G. G., and Pal, R. 2016. New and rare records of filamentous green algae from Indian Sundarbans Biosphere Reserve. *J. Algal. Biomass Utiln.* **7**(2): 159-175.
- Sen, N. and Naskar, K. R. 2003. Algal flora of Sundarbans Mangal- Daya Publishing house, Delhi.
- Shaji, C. and Patel, R. J. 1991. Phytoplankton Species Diversity of Sabarmati River near Ahmedabad, Gujarat, as index of Environmental changes. *Ann. Biol.* **7**: 15-20.
- Smith, G. M. 1950. The fresh-water algae of the United States, McGraw-Hill book company, Inc., New York, Toronto, London.
- Starmach, K. 1983. *Euglenophyta - Eugleniny*. Warszawa: Panstwowe Wydawnictwo Naukowe. Vol. 3, pp. 594.
- Wolowski, K. 2002. Phylum Euglenophyta. In: *The Freshwater Algal Flora of the British Isles*. An identification guide to freshwater and terrestrial algae. (John, D.M., Whitton, B.A. & Brook, A.J. Eds), Cambridge: Cambridge University Press. pp. 144-179.
- Wolowski, K., Poniewozik, M. and Walne, P. L. 2013. Pigmented Euglenophytes of the Genera *Euglena*, *Euglenaria*, *Lepocinclis*, *Phacus* and *Monomorpha* from the Southeastern United States. *Polish Bot. J.* **58**(2): 659-685.