Species
International Journal for Species
ISSN 2319 – 5746 EISSN 2319 – 5754

ANALYSIS

Study on spatio-temporal variations of phytoplankton cell volume from Indian Sundarban mangrove ecosystem

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Publication History
Received: 09 November 2014
Accepted: 28 December 2014
Published: 21 January 2015

Citation
Subhasmita Sinha, Abhijit Mitra, Sufia Zaman, Kakoli Banerjee. Study on spatio-temporal variations of phytoplankton cell volume from Indian Sundarban mangrove ecosystem. *Species*, 2015, 12(34), 73-80

ABSTRACT

The Indian Sundarbans, at the apex of Bay of Bengal is a mangrove dominated deltaic ecosystem sustaining some 106 species of brackish water phytoplankton. A significant seasonal variation of aquatic salinity, mostly regulated by monsoon is a salient feature of this ecosystem. There is a contrasting difference in salinity between the western and central sectors of Indian Sundarbans, which offers a unique test bed to study the impact of salinity on the cell volume of phytoplankton species. We studied seasonal variations of phytoplankton cell volume in the aquatic subsystem of Indian Sundarbans during 2011 and assigned 12 geometric shapes to 47 species documented from 12 stations in the study area. These stations are distributed in the western and central sectors of the deltaic complex that are significantly different in terms of salinity. The cell volumes of the observed species were more in the hyposaline western sector ($86.89 \mu m^3$ to $271405.63 \mu m^3$) compared to the hypersaline central sector ($85.39 \mu m^3$ to $227153.21 \mu m^3$) of Indian Sundarbans. The cell volumes mostly exhibited a unique seasonal trend with highest value during monsoon followed by postmonsoon and premonsoon. Among 47 phytoplankton species 6 species exhibited significant inverse relationships, and 2 species exhibited significant positive relationships with aquatic salinity. Our results suggest that cell volumes of certain phytoplankton species can be used as indicators of aquatic salinity. We also conclude that the rising salinity in the central sector of Indian Sundarbansmay be a threat to certain species of phytoplankton by way of shrinking their volumes.

Key words: Cell volume, Phytoplankton, Geometric shapes, Aquatic salinity, Seasonal variation.

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1. INTRODUCTION

Biovolume and surface area calculations for phytoplankton cells are important for studying many related ecological parameters (Malone, 1980; Sournia, 1981; Chisholm, 1992), such as biomass, growth, photosynthesis, respiration, assimilation, sinking, grazing, etc. Phytoplankton cell size varies greatly among different genera or even between different individuals. Sizes range from a few micrometers (or even less than 1 mm) to a few millimeters. Hence, there is a wide range of nine orders in magnitude for cell biovolume of phytoplankton. Several automated and semi-automatic methods for biovolume estimation have been described in the literature, such as the Coulter Counter (Hastings et al., 1962; Maloney et al., 1962; Boyd and Johnson, 1995), the micrographic image analysis system (Gordon, 1974; Krambeck et al., 1981; Estep et al., 1986), flow cytometry (Olson et al., 1985; Wood et al., 1985; Steen, 1990; Cunningham and Buonnacorsi, 1992) and holographic scanning technology (Brown et al., 1989). The aquatic phase of Indian Sundarbans in the lower Gangetic region is rich in phytoplankton diversity and till date 106 species have been documented (Mitra et al., 2004). However no studies on seasonal changes in cell volume of estuarine phytoplankton in relation to salinity have yet been carried out and the present report is a baseline documentation of the same from the mangrove dominated Indian Sundarbans region.

2. MATERIALS AND METHODS

Description of the study site

The River Ganga emerges from the Gangotri glacier, about 7010 m above mean sea level in the Himalayas, flows down to the Bay of Bengal and spreads over Bangladesh (which comprises 62% of the total Sundarbans) and India (38% of the total Sundarbans) covering a distance of 2525 km. The Indian part is known as Indian Sundarbans that encompasses a Biosphere Reserve area of 9630 sq. km and houses 102 islands.

The ecology of this area is totally regulated by tidal impact from Bay of Bengal. The tidal action of the sea inundates the whole of Sundarbans to varying depths, pushing back silt to the channels and creeks. Sundarbans delta is one of the dynamic estuarine deltas of the world (Banerjee et al., 2012).

We conducted seasonal survey at 12 stations in the Indian Sundarbans region during 2011 in three months namely May (premonsoon), September (monsoon) and December (postmonsoon). Station selection was primarily based on aquatic salinity (Table 1 and Fig. 1). The discharge of Farakka barrage through Hooghly channel ((the biggest barrage in the Gangetic plain) has made the western sector (stations 1 to 6) relatively low saline (Mitra et al., 2009). On contrary stations 7 to 12 are high saline zone due to complete blockage of the fresh water because of siltation of the Bidyadhari River (Chaudhuri and Choudhury, 1994; Mitra et al., 2011) that used to transfer fresh water to the tidal rivers of central Indian Sundarbans in the 15th century (Chaudhuri and Choudhury, 1994).

Table 1

Sampling stations with coordinates

Station name	Station Code	Geographical Location	
		Longitude	Latitude
Kachuberia	Stn. 1	88°08'04.43"	21°52'26.50"
Harinbari	Stn. 2	88°04'52.98"	21°47'01.36"
Chemaguri	Stn. 3	88°10'07.03"	21°39'58.15"
Sagar South	Stn. 4	88°03'06.17"	21°38'54.37"
Lothian island	Stn. 5	88°22'13.99"	21°39'01.58"
Prentice island	Stn. 6	88°17'10.04"	21°42'40.97"
Canning	Stn. 7	88°41'16.20"	22°18'40.25"
Sajnekhali	Stn. 8	88°46'10.08"	22°05'13.04"
Choto mollakhali	Stn. 9	88°54'26.71"	22°10'40.00"
Satjelia	Stn. 10	88°52'49.51"	22°05'17.86"
Pakhiralaya	Stn. 11	88°48'29.00"	22°07'07.23"
Thakuran	Stn. 12	88°38'45.20"	21°35'33.10"

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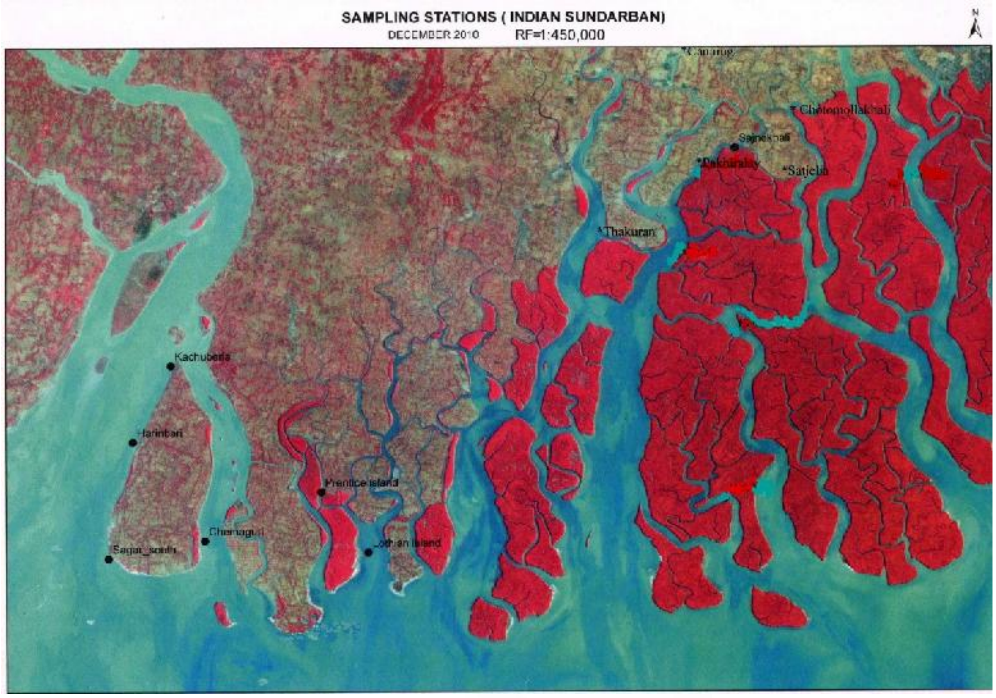
Figure 1
Map showing sampling stations of Indian Sundarban



Salinity

The surface water salinity in the selected stations was recorded during high tide condition by means of an optical refractometer (Atago, Japan) and cross-checked in laboratory using Mohr- Knudsen method. The correction factor was found out by titrating silver nitrate solution against standard seawater (IAPO standard seawater service Charlottenlund, Slot Denmark, chlorinity = 19.376‰). Our method was applied to estimate the salinity of standard seawater procured from NIO and a standard deviation of 0.02% was obtained for salinity. The average accuracy for salinity (in connection to our triplicate sampling) was ± 0.24 psu.

Cell volume

Net samples were collected with a conical nylon net bags (30 cm diameter) made of a 30 no. bolting silk. These samples were preserved in 4% neutral formaldehyde in polyethylene bottles. Samples were observed with a ZEISS research microscope coupled with an image analyzing system. Linear dimensions of the phytoplankton species were measured on the basis of taxonomic information and shape code. For each species the best fitting geometric shape and corresponding equation was used to calculate the cell volume (Sun and Liu, 2003).

3. RESULTS

Salinity

The stations in western and central sectors of Indian Sundarbans exhibited significant differences in aquatic salinity during the study period. In the western sector salinity of surface water ranged from 1.89 psu (at station 1 during September, 2011) to 27.99 psu (at station 6 during May, 2011) and the average salinity was 14.98 ± 9.16 psu. In the central sector the lowest salinity was recorded at station 7 (4.01 psu during September, 2011) and the highest salinity was at station 10 (29.98 psu during May, 2011) with an average value of 20.60 ± 8.82 psu. In both the sectors, the seasonal trend in salinity was premonsoon >post monsoon >monsoon.

ANOVA computed for aquatic salinity exhibits significant differences within the selected stations and also between the two sectors ($p < 0.01$) in the lower Gangetic delta complex.

Cell volume

A total of 47 phytoplankton taxa were identified to species level. The survey of phytoplankton species from the study area exhibited 12 geometric shapes and their cell volume ranged from 86.89µm^3 (*Hemidiscushardmanninus*) to 271405.63µm^3 (*Planktoniella sol*) in the western sector and from 85.39µm^3 (*Asterionella japonica*) to 227153.21µm^3 (*Planktoniella sol*) in the central sector (Table 2).

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Table 2

Cell volume (µm^3) of different phytoplankton species in different seasons of two sectors of Indian Sundarbans

S.No.	Species	Western sector			Central sector		
		A	B	C	A	B	C
1.	*Coscinodiscus eccentricus*	10637.39	14968.71	12477.54	8952.38	12632.06	10132.49
2.	*Coscinodiscus jonesianus*	12132.22	13996.13	12336.21	8797.29	10700.41	9133.41
3.	*Coscinodiscus lineatus*	4196.70	4778.10	4317.48	2250.07	2762.49	2384.49
4.	*Coscinodiscus radiatus*	44451.19	45918.19	45240.19	31950.14	35252.09	33519.31
5.	*Coscinodiscus gigas*	4266.90	4942.07	4387.07	4158.55	4699.30	4316.18
6.	*Coscinodiscus oculusiridis*	3839.30	4551.30	3978.08	3404.25	4046.49	3522.94
7.	*Planktoniella sol*	264994.76	271405.63	269383.6	218202.63	227153.21	225131.2
8.	*Cyclotella striata*	25031.36	26984.78	25962.78	21894.74	24735.60	23381.79
9.	*Thalassiosira subtilis*	770.75	1327.55	966.22	651.18	1209.82	867.82
10.	*Ceratium tripos*	357.90	580.75	442.07	324.78	533.65	413.65
11.	*Skeletonema costatum*	1503.43	1738.43	1636.43	1255.07	1555.88	1420.80
12.	*Paralia sulcata*	19855.18	21165.56	20709.56	19240.80	20768.98	20300.37
13.	*Rhizosolenia crassipina*	3764.91	4726.57	4141.13	3757.13	4301.63	3603.63
14.	*Rhizosolenia setigeara*	4341.69	5465.69	4760.69	4171.14	5334.15	4724.94
15.	*Rhizosolenia alata*	3726.28	4370.98	4098.28	3764.90	4590.08	4152.08
16.	*Ceratium teres*	1186.60	1711.99	1395.95	1005.77	1474.05	1185.05
17.	*Ceratium trichoceros*	994.36	1280.98	1160.36	1009.27	1284.20	1170.16
18.	*Bacteriastrum delicatulum*	39595.75	41915.00	40684.01	36521.99	39088.83	37792.22
19.	*Bacteriastrum varians*	38028.52	42328.52	41028.52	37024.92	42018.74	40750.11
20.	*Bacteriastrum comosum*	36959.33	40688.09	39759.33	35577.78	39671.08	38358.4
21.	*Chaetoceros didymus*	4287.00	5705.20	4652.00	2241.10	3861.23	2259.56
22.	*Chaetoceros peruvianus*	3844.48	4727.96	4161.48	1901.92	2565.09	1832.76
23.	*Chaetoceros compressus*	3170.71	4215.71	3467.71	1649.00	2467.42	1634.5
24.	*Ditylum sol*	1678.78	2048.78	1863.78	1644.05	2018.14	1838.47
25.	*Triceratium favus*	2552.06	3557.06	2856.06	2151.66	2704.98	2338.18
26.	*Triceratium reticulatum*	3704.79	4414.38	3937.79	3188.87	3821.97	3478.13
27.	*Biddulphia sinensis*	16700.84	19441.51	17395.84	15691.40	17228.50	16495.92
28.	*Biddulphia mobiliensis*	27305.85	29792.85	28805.85	26456.24	29066.02	28315.68
29.	*Hemidiscus hardmanninus*	86.89	264.89	112.89	85.80	242.27	108.37

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30.	*Climacosphenia elongate*	8439.61	9428.61	8975.61	8316.51	9318.79	8852.51
31.	*Fragilaria oceanica*	33704.85	36691.85	35704.85	33211.39	36309.34	35155.48
32.	*Rhaphoneis amphiceros*	3618.27	4539.27	3783.27	3213.38	3901.00	3290.73
33.	*Thalassionema nitzschioides*	357.36	598.70	442.36	212.06	404.23	283.30
34.	*Thalassiothrix longissima*	2079.97	2613.97	2279.97	1981.33	2507.89	2152.19
35.	*Thalassiothrix fraunfeldii*	356.87	521.10	425.87	240.10	409.46	299.45
36.	*Asterionella japonica*	98.89	209.70	141.22	85.39	197.536	127.60
37.	*Ceratium extensum*	159.20	283.72	193.72	154.16	266.12	185.46
38.	*Gyrosigma balticum*	2854.95	3230.95	2932.95	2548.63	2969.27	2654.14
39.	*Pleurosigma normanii*	1396.71	1750.71	1520.71	1216.92	1558.98	1327.03
40.	*Pleurosigma elongatum*	49151.35	55262.35	53251.35	41648.81	48377.66	45702.66
41.	*Diploneis smithii*	2404.30	2924.06	2674.95	2228.71	2731.72	2480.27
42.	*Cymbella marina*	391.05	630.09	506.72	386.43	613.50	492.50
43.	*Nitzschia sigma*	404.62	694.05	537.62	318.33	629.39	449.50
44.	*Nitzschia closterium*	425.50	718.91	581.50	439.20	732.92	587.80
45.	*Ceratium furca*	442.74	724.22	586.74	475.34	745.29	613.20
46.	*Trichodesmiumerythraea*	3667.96	4232.77	3927.96	4479.54	5170.93	4868.80
47.	*Chlorella marina*	568.54	742.54	646.54	585.46	758.90	661.50

A= Premonsoon, B= Monsoon and C= Postmonsoon

We observed relatively higher cell volume in the hyposaline western Indian Sundarbans compared to the hypersaline central sector. Almost all the phytoplankton species (except *Rhizosolenia alata, Ceratium trichoceros, Nitzschia closterium, Ceratium furca, Trichodesmium erythraea*and *Chlorella marina*) exhibited relatively higher cell volume in the western sector (Table 2).

In most cases the cell volume showed unique seasonal variations in both the sectors as per the order monsoon >postmonsoon>premonsoon (exceptional species: *Rhizosolenia crassipina, Chaetoceros peruvianus* and *C. compressus* in central Indian Sundarbans).

4. DISCUSSION

Aquatic salinity seems to be the key player in regulating the cell volumes of phytoplankton in the present study area. The relatively lower salinity in the western sector of the Sundarban delta region (Indian part) may be attributed to Farakka barrage that releases fresh water on regular basis through Ganga-Bhaghirathi-Hooghly River System. The central sector, on contrary does not receive the riverine discharge due to massive siltation of the Bidyadhari River that has blocked the fresh water flow in the region (Mitra et al., 2009; Mitra et al., 2011; Raha et al., 2012) Ten year surveys (1999 to 2008) on water discharge from Farakka barrage revealed an average discharge of (3.1 ± 1.2) ×10^3 m^3s^{-1}. Higher discharge values were observed during the monsoon with an average of (2.9 ± 1.2) × 10^3 m^3s^{-1}, and the maximum of the order 4185 m^3s^{-1} during freshet (September). Considerably lower discharge values were recorded during premonsoon with an average of (1.0 ± 0.09) ×10^3 m^3s^{-1}, and the minimum of the order 820 m^3s^{-1} during May. During postmonsoon discharge, values were moderate with an average of (1.9 ± 0.95) ×10^3 m^3s^{-1}. The lower Gangetic deltaic lobe also experiences considerable rainfall (1400 mm average rainfall) and surface runoff from the 60000 km^2 catchment areas of Ganga-Bhagirathi-Hooghly system and their tributaries. All these factors (dam discharge + precipitation + runoff) increase the dilution factor of the Hooghly estuary in the western sector of Indian Sundarbans (Mitra et al., 2011). The central sector does not receive the freshwater input on account of siltation of the Bidyadhari River since the 15th century and the stations in this sector (stations 7 to 12) receive only the tidal waters from the Bay of Bengal. Such significant variations in salinity within the same deltaic lobe caused variation in

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phytoplankton cell volume. We observed significant negative relationships between aquatic salinity and cell volume of *Coscinodiscuseccentricus, C. jonesianus, C. lineatus, C. radiatus, C. oculusiridis* and *Planktoniella sol* (Table 3).

Table 3

Inter-relationship between phytoplankton cell volume and salinity

Species	**Correlation coefficient (r) between phytoplankton cell volume and salinity**			**p value.**		
	A	**B**	**C**	**A**	**B**	**C**
Coscinodiscus eccentricus	-0.9673	-0.9088	-0.6294	<0.01	<0.01	<0.01
Coscinodiscus jonesianus	-0.5355	-0.5821	-0.5055	<0.01	<0.01	<0.01
Coscinodiscus lineatus	-0.6674	-0.6504	-0.6250	<0.01	<0.01	<0.01
Coscinodiscus radiatus	-0.6718	-0.5723	-0.6274	<0.01	<0.01	<0.01
Coscinodiscus gigas	0.0654	-0.1021	0.0790	IS	IS	IS
Coscinodiscus oculusiridis	-0.7708	-0.7077	-0.7550	<0.01	<0.01	<0.01
Planktoniella sol	-0.8030	-0.8463	-0.7965	<0.01	<0.01	<0.01
Cyclotella striata	-0.3647	-0.3334	-0.3611	IS	IS	IS
Thalassiosira subtilis	-0.2364	-0.2766	-0.2103	IS	IS	IS
Ceratium tripos	-0.1692	-0.1171	-0.1924	IS	IS	IS
Skeletonema costatum	-0.1591	-0.0072	-0.0927	IS	IS	IS
Paralia sulcata	-0.3471	-0.3547	-0.3450	IS	IS	IS
Rhizosolenia crassipina	-0.0707	-0.4175	-0.3827	IS	IS	IS
Rhizosolenia setigeara	-0.4142	-0.3765	-0.3360	IS	IS	IS
Rhizosolenia alata	-0.3186	0.0466	-0.2770	IS	IS	IS
Ceratium teres	-0.1247	-0.2556	-0.1973	IS	IS	IS
Ceratium trichoceros	-0.3453	-0.1612	-0.2761	IS	IS	IS
Bacteriastrum delicatulum	-0.2859	-0.3076	-0.2709	IS	IS	IS
Bacteriastrum varians	-0.1518	0.0903	0.1061	IS	IS	IS
Bacteriastrum comosum	-0.2296	-0.2015	-0.2596	IS	IS	IS
Chaetoceros didymus	-0.3033	-0.3837	-0.3691	IS	IS	IS
Chaetoceros peruvianus	-0.3026	-0.2977	-0.3872	IS	IS	IS
Chaetoceros compressus	-0.2859	-0.1558	-0.3836	IS	IS	IS
Ditylum sol	-0.0872	-0.0748	-0.0623	IS	IS	IS
Triceratium favus	-0.3937	-0.0605	-0.3720	IS	IS	IS
Triceratium reticulatum	-0.4089	-0.1785	-0.3317	IS	IS	IS
Biddulphia sinensis	-0.3512	-0.0733	-0.3595	IS	IS	IS
Biddulphia mobiliensis	-0.1966	-0.1630	-0.0486	IS	IS	IS
Hemidiscus hardmanninus	-0.3699	0.3786	-0.3962	IS	IS	IS
Climacosphenia elongate	-0.3814	-0.3488	-0.3487	IS	IS	IS
Fragilaria oceanica	0.6087	0.6917	0.6494	<0.01	<0.01	<0.01
Rhaphoneis amphiceros	-0.3125	0.0127	-0.4025	IS	IS	IS
Thalassionema nitzschioides	-0.3351	-0.1317	-0.3896	IS	IS	IS
Thalssiothrix longissima	0.1337	-0.2601	-0.3458	IS	IS	IS
Thalassiothrix fraunfeldii	-0.3426	-0.2797	-0.3882	IS	IS	IS
Asterionella japonica	-0.2804	-0.3653	-0.3392	IS	IS	IS
Ceratium extensum	0.0439	0.3595	-0.3795	IS	IS	IS
Gyrosigma balticum	-0.3085	-0.3851	-0.3732	IS	IS	IS
Pleurosigma normanii	-0.2107	-0.2793	-0.2186	IS	IS	IS
Pleurosigma elongatum	-0.2648	-0.2591	-0.2329	IS	IS	IS
Diploneis smithii	-0.0587	-0.3192	-0.2034	IS	IS	IS
Cymbella marina	0.0415	-0.3165	-0.3705	IS	IS	IS
Nitzschia sigma	-0.3280	-0.3674	-0.3703	IS	IS	IS
Nitzschia closterium	-0.3477	-0.3463	-0.3847	IS	IS	IS

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Ceratium furca	-0.2220	-0.3118	-0.3300	IS	IS	IS
Trichodesmium erythraea	0.3508	0.4193	0.3436	IS	IS	IS
Chlorella marina	0.7043	0.7633	0.7201	<0.01	<0.01	<0.01

A= Pre monsoon, B= Monsoon and C= Post monsoon

IS- insignificant

It is possible that the salinity has a direct effect on cell morphogenesis. Hillebrand et al. (2006) observed that the height of the centric diatom is reduced at increased salinity. Similar observations were also reported by other researchers (Hillebrand et al., 2006; Roubeix and Lancelot, 2008) who observed a lower size of the species *Thalassiosira pseudonana* when grown at higher NaCl concentration. Many researchers put forward several views on the negative impact of salinity on phytoplankton cell volume. According to some researchers (Pickett-Heaps et al., 1990; Harold, 2002) the elongation of diatom cells during the inter-phase preceding division is driven by turgor pressure, which makes the siliceous components of the cell walls slide apart. At increased salinity, fresh water diatom might not be able to produce the intracellular osmolarity needed to generate the same turgor pressure as at low salinity. Thus if cell elongation is less efficient before each cell division, cell height might decrease faster in high saline water (Roubeix and Lancelot, 2008). This may be a possible cause for lowering of cell volume of the species *Coscinodiscus eccentricus, C. jonesianus, C. lineatus, C. radiatus, C. oculusiridis* and *Planktoniella sol* with the increase of aquatic salinity. However, two species *Fragellaria oceanica*and *Chlorella marina* exhibited significant positive relationships with aquatic salinity (Table 3) and confirms the euryhaline nature of the species. Similar results were obtained while conducting the growth experiment on *Cyclotella meneghiniana* (Pickett-Heaps et al., 1990). According to a classification type of phytoplankton (Harold, 2002) few species of phytoplankton are holoeuryhaline in nature that are able to grow from almost fresh water to marine conditions with a wide range of tolerance. Such species may serve as ideal indicators of salinity through variation of their cell size and volume. The cell volume may, however, vary depending on the adaptive efficiency of the species through variation of turgor pressure and cell morphogenesis at varying salinity.

5. CONCLUSION

The present study is extremely important and can be extrapolated with the practical situation prevailing in the mangrove ecosystem of Indian Sundarbans. The aquatic salinity in the central sector of Indian Sundarbans is gradually rising over a period of 2 decades (Mitra et al., 2009). This is due to complete obstruction of freshwater supply of the Ganga-Bhagirathi-Hugli River as a result of heavy siltation in the Bidyadhari River since the late 15th century (Chaudhury and Choudhury, 1994; Mitra et al., 2011) and rising sea level (Hazra et al., 2002) at the rate of 3.14 mm/yr, which is higher than the global average sea level rise of 2.12 mm/yr. Records show that surface water salinity has increased by 40.46% in central region, and decreased by 46.21% in western region of Indian Sundarbans over a period of 27 years (1980 to 2007) due to blockage of fresh water flow from western Indian Sundarbans to central region (Mitra et al., 2009). Under this situation cell volume of phytoplankton species like *Coscinodiscus eccentricus, C. jonesianus, C. lineatus, C. radiatus, C. oculusiridis*and *Planktoniella sol* can be used as unique indicators of aquatic salinity. However, the tolerance of the species to high saline situation is under question because of their shrinkage in saline condition. On contrary, cell volumes of *Fragellaria oceanica*and *Chlorella marina* showed significant positive correlations with salinity and seem to be better suited species under situation of intrusion of sea water from Bay of Bengal in the southern part of the deltaic Sundarbans.

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