Phytoplankton study from the Sundarbans ecoregion with an emphasis on cell biovolume estimates – a review

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Received 16 August 2013; revised 14 October 2013

Phytoplankton based studies have become a major area of research among plankton biologists in recent times as a responsive entity for climatic change. Sundarbans ecoregion has gained considerable impetus in context of the Indian subcontinent as a major study area due to the mixing conditions prevalent in this area, brought about by the confluence of several important rivers and the coastal waters of the Bay of Bengal. Cellular biovolume has become a more appropriate proxy for phytoplankton estimation as compared to cell count data in the past decade due to their wide applicability in phytoplankton studies. Present study is a literary review of the different phytoplankton related studies that have been carried out from the Sundarbans mangrove ecoregion with an emphasis on cellular biovolume. This review will act as future reference point for plankton biologists working from the Sundarbans ecoregion with emphasis on cell biovolume estimation.

[Keywords: phytoplankton, biovolume estimation, Sundarbans ecoregion, climate change]

Introduction

The emission of greenhouse gases due to fossil fuel burning, industrialization and urbanization enhanced the levels of pCO₂ in aquatic marine habitats to about 390 μatm. If this “business as usual” scenario remains operative, it is predicted to cause an increase in pCO₂ levels to about 700μatm by the end of 2100. Thus an increase in pCO₂ levels will result in a decrease in oceanic pH by 0.2 – 0.6 units, which would subsequently cascade in increasing the sea surface temperature (SST) by 2 – 6°C. The rise in SST could lead to expansion of the water column. There are reports of sea level rise from 1961 to 2003 (1.8± 0.5 mm/year) and especially in the past decade it has been at the rate of 3.0 ± 0.7 mm/year. Such a situation can be deleterious from an ecological viewpoint as it would result in an increased intrusion of saline water in freshwater habitats. In addition, losses of low lying areas may also result in an increased SPM load and consequential decrease in photic zone depth that would eventually affect thermal stratification and the thermocline.

Phytoplankton populations in natural aquatic ecosystems contribute to about 98% of aquatic productivity and about 40% of global productivity.

Phytoplankton, the primary autotrophic component with their dual role in carbon sequestration and oxygen production is functionally the most important biotic entity in aquatic ecosystem and food web dynamic. Phytoplankton photo-physiology is significantly affected by a combination of temperature, availability of light and nutrients (nitrogen, phosphate, silicate and iron) which in turn regulate their community structure and assemblage patterns. Thus, assessment of the phytoplankton community structure as a response to abiotic variables can be an important area of study to understand the ecosystem functioning of natural aquatic habitat from the present scenario of global climate variability.

Significance of phytoplankton cell biovolume

Phytoplankton study can be primarily carried out on the basis of two basic descriptors: standard taxonomic descriptors and morphometric descriptors. In phytoplankton studies, morphometric descriptors can be categorized on an individual (biovolume, surface area, surface/volume ratio) or population as well as for guild hierarchical levels (as body-size abundance distribution or body size spectra, or as
biomass size fractions of micro, nano and pico planktons. Unlike taxonomic descriptors (where a lot of expertise is necessary) in morphometric descriptors, the parameters of estimations are easy to measure as it eliminates the difficulty that arise from heterogeneity of taxonomic composition in different ecosystems. While estimating biomass, often in multi-species assemblages (which is often the case in natural phytoplankton populations) high number of small sized species may actually contribute only a minor fraction whereas a small number of large sized populations may contribute significantly to the total biomass. Thus, cell counts may not be a proper reflection of the relative algal biomass. Accordingly, estimation of biomass using a set of standardized formulae should be used to compare relative abundance of individual species in mixed taxa samples or between samples and systems, study cell cycle processes or to convert phytoplankton biovolume to carbon equivalents. Furthermore, cell biovolume can be used to convert cell count into carbon units for estimation of organic matter in aquatic communities by eliminating the error due to detrital organic matter present in particulate organic carbon. It can be said that although cell count is the more popular method for phytoplankton study, yet the applicability of the same is more suited for diversity assessment. Thus, at present plankton biologists are focusing on biovolume estimates rather than cell counts to understand the species specific responses of phytoplankton populations in natural aquatic ecosystems. Keeping in view of this trend, several automatic and semi automatic methods have been developed including Coulter Counter, micrographic image analysis system, flow cytometry and holographic scanning technology. Although these automated methods are in practice, most literatures that focus on biovolume estimates tends to measure the same on the basis of assigned geometric shapes.

Importance of the Sundarbans Mangrove ecoregion

Sundarbans Mangrove ecoregion is the largest halophytic mangrove block in the world formed by the geological precipitation of the sediment load brought by the Ganges River, the Brahmaputra River and the Meghna River systems. Sundarbans ecoregion in West Bengal constitutes for about 5% of world’s total mangrove vegetation. Intertidal area of Indian Sundarbans stretches to 4264 km² that can be further subdivided into forest sub ecosystem, 1781 km² of aquatic sub ecosystem and the rest for human settlements and related activities. It is the only natural mangrove habitat for the Royal Bengal Tiger (Panthera tigris tigris) that shelters other endangered faunal populations like the estuarine crocodile (Crocodilus porosus), marsh crocodiles (Crocodilus palustris) and marine turtle species like Lepidochelys olivacea, Eretmochelys imbricata and Chelonia mydas. Floral community also includes members of Rhizophoraceae, Avicennaeaceae and Combretaceae with representative taxa such as Heritiera fomes (Sundari), Excoecaria agallocha (Gewa), Ceriops decandra (Goran) and Sonneretia apetala (Keora). Due to this unique congregation of floral and faunal population, the Sundarbans Mangrove ecoregion has been recognized as a world heritage site both by International Union for the Conservation of Nature and Natural Resource (IUCN) in 1989 and UNESCO in 1974. The mangrove vegetation of this region also serves as a natural barrier against the prevalent cyclonic storms. Different models have predicted a global rise in temperature by 1-4°C over the next 100 years, thereby tendering the Sundarbans mangrove region equally vulnerable to temperature rise. It has been reported from the Gangasagar region that about 5.5 km²/year land area has been lost due to sea level rise over the last ten years. This would account for dissolution of land masses which may eventually lead to an increase in suspended matter load in the water column. Such a phenomenon may delimit the photic zone ratio, thereby affecting the phytoplankton population structure and resultant productivity. Thus, this review aims in developing a detailed account of the ecological aspects of phytoplankton population from Sundarbans area with an emphasis on biovolume estimation which will possibly act as a reference source for any future plankton based work from this area. This review will additionally act as an addendum to address and envisage the impact of global climatic changes on natural aquatic ecosystems.

Taxonomic study of phytoplankton assemblages in Sundarbans

Phytoplankton study from the Sundarbans region was initially concentrated on taxonomic identification of different genera with emphasis on diatoms. Prain made a detailed study on the morpho-taxonomic identification of phytoplankton taxa from the deltaic
plains of West Bengal, which also included the Sundarbans ecoregion. Subsequently, other groups also started working on phytoplankton assemblages and prepared detailed accounts of both planktonic and benthic forms from this area. A comprehensive study on the composition and structure of mangrove vegetation including algae was carried out by different groups. Recently, Satpati et al. also prepared morphotaxonomic accounts of planktonic and non-planktonic green algae and seaweeds of the Sundarbans area from habitats ranging from bark of trees and mangrove pneumatophores as well as from aquatic environments. Similar studies were also undertaken in the Bangladesh region of Sundarbans, with a focus mainly on diatoms. In a recent work, a total of 36 diatom taxa were recorded from the Bangladesh counter part of Sundarbans, out of which 14 were claimed to be new reports that included taxa like Amphiprora alata, Chaetoceros spp., Cyclotella comta, Thalassionema nitzschoides, Thalassiosira sp., Lioloma sp., Navicula sp. and Nitzschia spp. These species are increasingly encountered in Sundarbans ecoregion encompassing both India and Bangladesh. The findings probably suggest that phytoplankton taxa that are more resilient to alterations of the physico – chemical habitat constitute the autotrophic components of the Sundarbans mangrove ecosystem.

Studies from an ecological perspective

Phytoplankton population and habitat variability in Sundarbans ecoregion:

In the later part of the 20th century, as the concern over climatic change and eutrophication increased, the research perspective shifted mainly on ecological aspects and ecosystem functioning of the Sundarbans region. Saha et al. studied the photosynthetic activity in the brackish water Jagannath canal in relation to the hydrobiological properties of the study area. Temporal shifts in temperature and salinity on a pre – and post – monsoonal basis were evident from this study. The habitat reported was weakly alkaline with a low euphotic depth of the water column, suggesting the presence of high suspended matter. Green algae dominated the phytoplankton population, followed by diatoms and blue green algae. Unlike most estuaries, no significant correlation could be established between phytoplankton cell counts and Chl a concentration and the authors concluded that the observation may be due to presence of detrital pigments in the habitat. In a subsequent work, fluxes of nutrients from the Hooghly River at the land – ocean boundary of the Sundarbans ecoregion was measured. The findings suggested that high input of litter and sediments from this land – ocean boundary resulted in greater availability of nutrients due to enhanced estuarine transport. It was further reported that monsoonal runoffs accounted for the bulk of the nutrient load that was fluxed into the habitat from the adjoining area. Authors also suggested that organic matter brought down into the riverine system also contributed to the regeneration of inorganic nutrients in the water column due to occurrence of light – limited conditions and auto – heterotrophic coupling. Chaudhuri et al. carried out extensive studies to correlate between different biotic and abiotic components of the Sundarbans ecoregion with an emphasis on monsoon. Study area was located near Jharkhali Island, near Herobhanga Khal at the confluence of the Matla and Vidya rivers. The unique feature of this tidal creek was the absence of any downstream freshwater source. Both abiotic and biotic variables were measured at a depth of 0.5 m and biotic indices were measured to determine the phytoplankton community composition. Habitat was weakly alkaline with a mesohaline to hypersaline transition from monsoon to post monsoon periods. Members of Bacillariophyceae dominated the population, followed by dinoflagellates and chlorophytes which were differed from the communities observed in Jagannath creek. This work for the first time reported the presence of the dinoflagellate Prorocentrum sp., a sub tropical taxa in the ecoregion. Their work also suggested the apparent suitability of this particular study area for phytoplankton growth. In a subsequent work by the same group, roles of physico chemical and biological factors in regulating water column metabolism were also studied from the same area (Herobhanga Khal). Authors studied the nitrate reductase activity by experimentally regulating through application of inhibitors so as to discriminate between nitrogenous and non – nitrogenous productivity. Their findings suggested that the net ecosystem metabolism of this region remain heterotrophic when primary productivity was less than catabolic respiratory carbon consumption. Furthermore, it was reported that in some post
monsoon periods, net ecosystem metabolism became autotrophic when primary productivity was more than respiratory carbon loss.

**Importance of phytoplankton biovolume estimates at Sundarbans ecoregion:**

Work from different regions of the world that have traditionally focused on phytoplankton studies also considered biovolume estimates during routine study. Thus, with this increased focus on biovolume estimation, similar studies were also conducted in the Sundarbans ecoregion. In a work on the diurnal air–water exchange of CO₂ from the Sundarbans, total wet algal biovolume was determined from individual cellular biovolume of dominant phytoplankton species. Analysis of biotic and abiotic parameters rendered this area to be under saturated in relation to dissolved oxygen and heterotrophic with respect to productivity. Saturation levels of CO₂ varied seasonally with no relation between CO₂ emission and removal by biological processes. In a subsequent study by the same group, a comparative study on the abundance and composition of phytoplankton over a two decadal period was carried out from this estuary. Authors estimated the phytoplankton biomass on the basis of biovolume with an emphasis on bloom forming species. It was reported that *Coscinodiscus radiatus* was dominant in this ecosystem that appeared in 2000 as well as in 2007, although the incidence of bloom formation receded from 10 to 2 during 2000 to 2007. Diurnal and seasonal variations were pronounced with tidal cycles playing a regulatory role in such fluctuations. Phytoplankton biovolume showed distinct seasonal patterns with highest levels in post monsoon and lowest levels in monsoon periods.

**Applicability of biomass and biovolume estimates of phytoplankton**

Vadrucci et al. developed a detailed floristic list from different translational water bodies from the Mediterranean region and showed that although several diatom species may be available from different aquatic ecosystems but their cellular biovolume may not remain the same. This may be due to physiological processes or reproductive stages in which the cell may remain at the time of sample collection. Thus, different individuals of the same diatom taxa may vary significantly with regard to cell biovolume due to diminution in size through several generations. This is in agreement with Mcdonald – Pfizer’s diminution law for diatom cell structure. Biogeographically, phytoplankton composition may be similar in contrasting habitats, but the cellular biovolume of individual taxa could vary significantly. On a decadal level, there was a gradual increase in the total cell counts from the Sundarbans region, but cell biovolume showed a different trend. Although the total phytoplankton cell counts increased from 45.15 ± 8.05 X 10⁵/m³ (1990) to 170.77 ± 44.07X 10⁵/m³ (2007) with an intermediate value of 55.24 ± 34.44X 10⁵/m³ in 2000. In contrast maximum biovolume was recorded in 2000 (15.25 ± 9.74 mm³/L) with a relatively lower value of 5.37 ± 3.37 mm³/L in 2007. Thus, it can be said that the population of 2007 was probably represented by smaller sized phytoplankton taxa, although the cell counts were high. A contrasting scenario was reported from Waldo Lake, Oregon, USA where although the phytoplankton population was represented by 5 – 312 algal units/L, yet the average biovolume was 19 X 10⁵ µm³/mL. Such shifts in cellular biovolume may not be only due to size variations but can be also regulated by abiotic variables. Ochoa et al. reported the presence of taxa like *Skeletonema costatum, Coscinodiscus perforatus, Pleurosigma* sp., *Cylindrotheca closterium*, *Gyrosigma* sp., *Amphipora* sp., *Nitzschia* sp., *Prorocentrum gracile* from the Northern Humboldt Current System, some of which are also found in the Sundarbans ecoregion. They suggested that there was a significant increase in cell biovolume at lower temperature (13° - 16°C), with a decrease in cell biovolume for the single dinoflagellate species *Prorocentrum gracile* (22° - 25°C). Mitra et al. collected phytoplankton samples from Indian Sundarbans region and segregated them as representations from western and central regions. A total of 47 taxa were categorized under 12 different shapes and it was reported that cell volume of observed species in the western sector was higher as compared to the central region. Some of the species recorded showed either positive or negative correlation with salinity, suggesting that some of the phytoplankton taxa can be indicative of aquatic salinity. Thus, this work further testifies that cell biovolume of phytoplankton populations is not a constant feature, but may vary significantly on the basis of abiotic variables prevalent in the study area. Recently, we measured cellular biovolume of some selected phytoplankton taxa recorded from the the Mooriganga estuary and adjoining areas in the Indian
Sundarbans ecoregion. The cellular biovolume and area were calculated as per the geometric shapes specified for selected taxa by Hillebrand et al. At least three individual cells were considered for each taxon and mean values for each parameter were taken for calculations. Surface area: volume ratios were highest for *Skeletonema costatum* (729) with the minimum recorded for *Coscinodiscus* sp. (7.5) and

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Phytoplankton taxa</th>
<th>Shape</th>
<th>Formula for Volume estimation</th>
<th>Area</th>
<th>Average biovolm.(mm³)</th>
<th>Average area (mm²)</th>
<th>S/V ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><em>Coscinodiscus</em> sp.</td>
<td>Cylinder</td>
<td>(\frac{2}{3}\pi d^{2}h)</td>
<td>(\pi d^{2})</td>
<td>0.0052</td>
<td>0.039</td>
<td>7.5</td>
</tr>
<tr>
<td>2.</td>
<td><em>Cyclotella</em> sp.</td>
<td>Cylinder</td>
<td>(\frac{2}{3}\pi d^{2}h)</td>
<td>(\pi d^{2})</td>
<td>0.000124</td>
<td>0.0145</td>
<td>117</td>
</tr>
<tr>
<td>3.</td>
<td><em>Bacillaria</em> sp.</td>
<td>Rectangular box</td>
<td>(a.b.c)</td>
<td>(2(a.b+b.c+c.a))</td>
<td>0.0000188</td>
<td>0.00659</td>
<td>351</td>
</tr>
<tr>
<td>4.</td>
<td><em>Thalassionema</em> sp.</td>
<td>Rectangular box</td>
<td>(a.b.c)</td>
<td>(2(a.b+b.c+c.a))</td>
<td>0.0000056</td>
<td>0.00248</td>
<td>443</td>
</tr>
<tr>
<td>5.</td>
<td><em>Thalassiothrix</em> sp.</td>
<td>Rectangular box</td>
<td>(a.b.c)</td>
<td>(2(a.b+b.c+c.a))</td>
<td>0.0000039</td>
<td>0.00223</td>
<td>572</td>
</tr>
<tr>
<td>6.</td>
<td><em>Cocconeis</em> sp.</td>
<td>Prism on elliptic base</td>
<td>(\frac{\pi}{4} a.b.c)</td>
<td>(\frac{\pi}{2} [a.b+(a+b).c])</td>
<td>0.00000154</td>
<td>0.000814</td>
<td>529</td>
</tr>
<tr>
<td>7.</td>
<td><em>Navicula</em> sp.</td>
<td>Prism on elliptic base</td>
<td>(\frac{\pi}{4} a.b.c)</td>
<td>(\frac{\pi}{2} [a.b+(a+b).c])</td>
<td>0.0000289</td>
<td>0.0068</td>
<td>235</td>
</tr>
<tr>
<td>8.</td>
<td><em>Odontella</em> sp.</td>
<td>Prism on elliptic base</td>
<td>(\frac{\pi}{4} a.b.c)</td>
<td>(\frac{\pi}{2} [a.b+(a+b).c])</td>
<td>0.0000543</td>
<td>0.0086</td>
<td>158</td>
</tr>
<tr>
<td>9.</td>
<td><em>Gyrosigma</em> sp.</td>
<td>Prism on parallelogram</td>
<td>(\frac{1}{2} a.b.c)</td>
<td>(a.b+\sqrt{a^{2}+b^{2}}c)</td>
<td>0.0000092</td>
<td>0.0019</td>
<td>207</td>
</tr>
<tr>
<td>10.</td>
<td><em>Nitzschia</em> sp.</td>
<td>Prism on parallelogram</td>
<td>(\frac{1}{2} a.b.c)</td>
<td>(a.b+\sqrt{a^{2}+b^{2}}c)</td>
<td>0.0000018</td>
<td>0.00081</td>
<td>450</td>
</tr>
<tr>
<td>11.</td>
<td><em>Surirella</em> sp.</td>
<td>Half elliptic prism</td>
<td>(\frac{\pi}{4} a.b.c)</td>
<td>(\frac{\pi}{4}(a.b+a.c+b.c)+a.c)</td>
<td>0.000176</td>
<td>0.0135</td>
<td>77</td>
</tr>
<tr>
<td>12.</td>
<td><em>Skeletonema</em> sp.</td>
<td>Cylinder + two half spheres</td>
<td>(\pi d^{2}(h/4+d/6))</td>
<td>(\pi d(d+h))</td>
<td>0.00152</td>
<td>1.2</td>
<td>789</td>
</tr>
<tr>
<td>13.</td>
<td><em>Thalassiosira</em> sp.</td>
<td>Cylinder</td>
<td>(\frac{\pi}{4}d^{2}h)</td>
<td>(\pi d(d/2+h))</td>
<td>0.000216</td>
<td>0.00454</td>
<td>210</td>
</tr>
<tr>
<td>14.</td>
<td><em>Ditylum</em> sp.</td>
<td>Prism on triangle</td>
<td>(\frac{1}{2} l.m.h)</td>
<td>(l.m+3.1.h)</td>
<td>0.0000124</td>
<td>0.00278</td>
<td>224</td>
</tr>
<tr>
<td>15.</td>
<td><em>Triceratium</em> sp.</td>
<td>Prism on triangle</td>
<td>(\frac{1}{2} l.m.h)</td>
<td>(l.m+3.1.h)</td>
<td>0.0000208</td>
<td>0.00704</td>
<td>338</td>
</tr>
<tr>
<td>16.</td>
<td><em>Planktoniella</em> sp.</td>
<td>Cylinder</td>
<td>(\frac{\pi}{4}d^{2}h)</td>
<td>(\pi d(d/2+h))</td>
<td>0.000159</td>
<td>0.00172</td>
<td>11</td>
</tr>
<tr>
<td>17.</td>
<td><em>Chaetoceros</em> sp.</td>
<td>Elliptic prism</td>
<td>(\frac{\pi}{4}a.b.c)</td>
<td>(\frac{\pi}{2} [a.b+(a+b).c])</td>
<td>0.0000097</td>
<td>0.0038</td>
<td>392</td>
</tr>
<tr>
<td>18.</td>
<td><em>Coscinodiscus</em> sp.</td>
<td>Cylinder</td>
<td>(\frac{\pi}{4}d^{2}h)</td>
<td>(\pi d(d/2+h))</td>
<td>0.000108</td>
<td>0.01328</td>
<td>123</td>
</tr>
<tr>
<td>19.</td>
<td><em>Odontella</em> sp.</td>
<td>Prism on elliptic base</td>
<td>(\frac{\pi}{4}a.b.c)</td>
<td>(\frac{\pi}{2} [a.b+(a+b).c])</td>
<td>0.000074</td>
<td>0.0104</td>
<td>141</td>
</tr>
</tbody>
</table>
Planktoniella sp. (11) respectively (Table 1). This suggested that S. costatum was the most buoyant taxa in the water column which was further evidenced from their persistent presence in the water column during the entire sampling period thereby making S. costatum to be more efficient in utilizing PAR (photosynthetically active radiations). Keeping in view the observations of other groups working in this area, these biovolume estimates can be an important parameter to understand the spatial and temporal shifts in phytoplankton populations brought about by the variable physico-chemical status of the habitat in the Sundarbans ecoregion. A comparative dataset on cellular biovolume of similar taxa recorded from geographically separated regions (Table 2) around the world clearly show that cellular biovolume is not a constant feature for phytoplankton taxa. Instead, it may be regulated by available environmental conditions prevalent in study area, as was evident for the data recorded for the Northern Humboldt Current System. Therefore, changes in biovolume also indicate the responsive nature of phytoplankton populations to environmental stressors.

### Table 2 — A comparative account of the cell biovolumes of some selected phytoplankton taxa recorded from different regions of the world.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Stations</th>
<th>Northern Humboldt Current System</th>
<th>Saton Sea, California</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletonema costatum</td>
<td>0.00152</td>
<td>9.1 (13°C - 16°C)</td>
<td>2.23 (22°C - 25°C)</td>
</tr>
<tr>
<td>Coscinodiscus sp.</td>
<td>0.0052</td>
<td>6.49 (13°C - 16°C)</td>
<td>2.58 (22°C - 25°C)</td>
</tr>
<tr>
<td>Pleurosigma sp.</td>
<td>11.22 (13°C - 16°C)</td>
<td>4.45</td>
<td>2.58 (22°C - 25°C)</td>
</tr>
<tr>
<td>Gyrosigma sp.</td>
<td>0.0000092</td>
<td>4.85 (13°C - 16°C)</td>
<td>3.68 (22°C - 25°C)</td>
</tr>
<tr>
<td>Amphipora sp.</td>
<td>6.59 (13°C - 16°C)</td>
<td>6.06</td>
<td>22°C - 25°C</td>
</tr>
<tr>
<td>Nitzschia sp.</td>
<td>0.0000018</td>
<td>6.28 (13°C - 16°C)</td>
<td>3.33 (22°C - 25°C)</td>
</tr>
<tr>
<td>Cylindrotheca closterium</td>
<td>9.13 (13°C - 16°C)</td>
<td>7.25</td>
<td>22°C - 25°C</td>
</tr>
<tr>
<td>Thalassionema nitzeoides</td>
<td>0.0000056</td>
<td>7.15 (13°C - 16°C)</td>
<td>337μm³; 2280 cells/mL</td>
</tr>
<tr>
<td>Procentrum sp.</td>
<td>0.64 (13°C - 16°C)</td>
<td>1120μm³; 76 cells/mL</td>
<td></td>
</tr>
<tr>
<td>Cyclotella sp.</td>
<td>0.000124</td>
<td>1020μm³; 336 cells/mL (&gt; 7.5 µm)</td>
<td>216µm³; 3930 cells/mL</td>
</tr>
</tbody>
</table>

As evident from the flow chart (Fig. 1), the importance of biovolume estimation remain not only restricted to determination of diversity but also help us to understand cell specific responses. It is now a well-established fact that in this present scenario of global climatic changes, variations in water column temperature will result in the alteration of thermocline, which in turn will affect the structure, circulation and productivity of the habitat. This is mainly because warmer, less dense surface waters float on the colder dense water, brought about from the hypolimnion by upwelling and down - welling events. Such shifts in stratification can significantly alter availability of light and resources for phytoplankton growth. In a top – down regulation of phytoplankton assemblages, these changes in climatic conditions can surely play a regulatory role in the photo physiological and ecological functioning of plankton populations in natural lotic aquatic ecosystems. Application of biovolume as estimates of phytoplankton populations in Sundarbans region has gained popularity due to their applicability as biotic proxies of aquatic ecosystems around the world. Unlike other aquatic habitat around the world, due to
the high rate of freshwater inflow from perennial sources, Ekman transport is not pronounced, that reduce upwelling events along coastal West Bengal. As can be expected, such reduction in upwelling events will deter the mixing of hypolimnetic nutrient rich waters, thereby altering nutrient concentrations in the epilimnion as well as the thermocline. As has already been established in the previous sections of this manuscript, cellular biovolumes are highly responsive to the altering physico – chemical habitat of the study area. Thus, regular observations of the spatial and temporal variations of the cell biovolumes of individual phytoplankton taxa can actually act as a more suitable descriptor of the impact of abiotic stress on phytoplankton populations. Accordingly, with an increasing concern over global climate changes, biovolume estimation will be a more logical representative of the actual phytoplankton population of different aquatic ecosystems around the world.

Acknowledgement

Avik Kumar Choudhury acknowledges Department of Biotechnology (Govt. of India) for the provision of a DBT Postdoctoral Fellowship. Punyasloke Bhadury acknowledges IISERK and Ministry of Earth Sciences, Govt of India (HAB project, MLR Program) for the provision of grants to undertake studies on phytoplankton cell biovolume estimation.

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