Australian Journal of Science and Technology

ISSN Number (2208-6404)
Volume 3; Issue 3; September 2019

Original Article

Eutrophication enhances phytoplankton abundance in the Maheshkhali channel, Bay of Bengal, Bangladesh

Saleha Khan[1]*, Roksana Jahan[2], M. Aminur Rahman[3], Md. Mahfuzul Haque[1]

[1]Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh, [2]Department of Marine Fisheries and Oceanography, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, [3]Department of Fisheries and Marine Bioscience, Jashore University of Science and Technology, Jashore-7408, Bangladesh

ABSTRACT

To test the hypothesis "eutrophication enhances phytoplankton abundances," we analyzed the temporal distribution of phytoplankton and its relationship with nutrients and environmental parameters in the Maheshkhali channel, the south-eastern coast of the Bay of Bengal, Bangladesh. The highest abundance of phytoplankton ($33 \times 10^5 \pm 19 \times 10^5$ cells l^{-1}) was found in October during post-monsoon, which might be due to comparatively higher concentration of nitrate-nitrogen (NO_3-N) (11.62 ± 0.43 µM) and phosphate-phosphorus (PO_4-P) (29.17 ± 02.15 µM), those might have increased from freshwater discharge and precipitation. Phytoplankton was found to be significantly positively related with NO_3-N ($r = 0.533$, $P < 0.01$) and PO_4-P ($r = 0.719$, $P < 0.01$), and significantly negatively related with temperature ($r = -0.424$, $P < 0.05$) and salinity ($r = -0.613$, $P < 0.01$). In contrast, the lowest abundances of phytoplankton ($6 \times 10^5 \pm 1 \times 10^5$ cells l^{-1}) were recorded in June, during the early monsoon due to the lowest concentration of NO_3-N (4.3 ± 0.34 µM) and PO_4-P (6.11 ± 2.99 µM). However, moderate phytoplankton abundance ($20 \times 10^5 \pm 1.5 \times 10^5$ cells l^{-1}) was found in August, during the late monsoon when the highest concentration of NO_3-N (15.7 ± 1.8 µM), PO_4-P (29.17 ± 5.15 µM), temperature (31.67 ± 0.29°C), and lower salinity (17.67 ± 1.53) was observed. This result, therefore, suggests that fluctuation of nutrients is crucial in controlling phytoplankton bloom dynamics in the Maheshkhali channel, Bay of Bengal, Bangladesh.

Keywords: Eutrophication, Maheshkhali channel, phosphate-phosphorus, phytoplankton

Submitted: 20-09-2019, **Accepted:** 25-09-2019, **Published:** 27-09-2019

INTRODUCTION

Eutrophication defined as the increased rate of primary production and accumulation of organic matter,[1] usually results from the excessive addition of nutrients that results in an undesirable change in ecosystems, food webs, water quality, and aquatic chemistry.[2,3] Consistent with global features, eutrophication is also a common phenomenon in the coastal area of the Bay of Bengal (BoB) because the bay receives large volume of freshwater that injects loads of nutrients and suspended sediment[4,5] and makes the BoB as a zone prone for algal blooms including harmful ones. The potential toxicity of harmful algal blooms causes fish kills in the coastal area of the BoB by toxin production (i.e., paralytic shellfish poisoning)[6,7] and negative impact on human health.[8,9]

In general, phytoplankton blooms in various coastal waters of the BoB are found throughout the year. The west coast of the BoB, for instance, undergoes periods of strong upwelling during monsoon and delivers cold, nutrient-rich waters from bottom depth result in higher primary production.[10] In contrast, the east coast of the BoB experiences strongly stratified surface layer and restricts the transport of nutrient from deeper layer to the surface during southwest monsoon (June– September) due to enormous influx of freshwater through precipitation and riverine discharge result in lower productivity.[11] The majority of bloom cases are reported in the BoB during the pre-monsoon (February–May).[12] However, the entire BoB is considered to have lower biological productivity than its western counterpart, the Arabian Sea, due to various reasons such as narrow shelf, cloud cover during summer monsoon, turbidity resulting from sediment influx and freshwater-induced stratification.[13-15]

Address for correspondence: Dr. Saleha Khan, Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh, Bangladesh. Phone: +880913822745. E-mail: khansaleha64@gmail.com

The coastal waters of Bangladesh including the Maheshkhali channel are also vulnerable to eutrophication because it receives huge nutrients from river discharge, shrimp culture, agricultural, and industrial effluents which induces the growth of many harmful algal species (i.e., *Dinophysis caudata*, *Dinophysis mitra*, *Alexandrium catenella*, *Lingulodinium polyedrum,* and *Gymnodinium coeruleum*).[16] Although massive fish kills are being seen in this channel during heavy blooms of *D. caudata* in different years since 1998,[16] there are very few studies focusing on eutrophication and harmful algal blooms in the coastal waters of the BoB, Bangladesh. Therefore, the purpose of this research is to analyze the temporal distribution of phytoplankton abundances and its relationship with environmental parameters in the Maheshkhali channel. We hypothesize that eutrophication enhances phytoplankton abundance in the Maheshkhali channel, BoB, Bangladesh.

MATERIALS AND METHODS

Study Area

The present study was carried out in the Maheshkhali channel, situated at the south-eastern coast of the BoB [Figure 1]. Three sampling sites were selected at the mouth of this channel. The channel includes Bakkhali River in the north that brings much of domestic, agricultural and industrial wastes, and opens into the BoB in the south. This channel, like Cox's Bazar coast, has a semidiurnal tidal regime. Its hydrology is also heavily influenced by monsoon wind.[17] The Maheshkhali channel is very important as a large fishing ground and a center for recreation. Different traditional capture fisheries and commercial shrimp farms have developed around the estuary. This channel considered as highly productive because of excessive nutrients invaded from industrial wastes, agricultural lands, rural and urban sewages and from the adjacent shrimp/bivalve farms, which sometimes induces the growth of many harmful algal blooms.[18]

Methods

Water samples were collected from January to December, covering three seasons: Monsoon (June to September), post-monsoon (October to January), and pre-monsoon (February to May). Monthly plankton samples were collected using a 25 µm mesh plankton net. The samplings were made in during daytime at high tide. For qualitative plankton study,

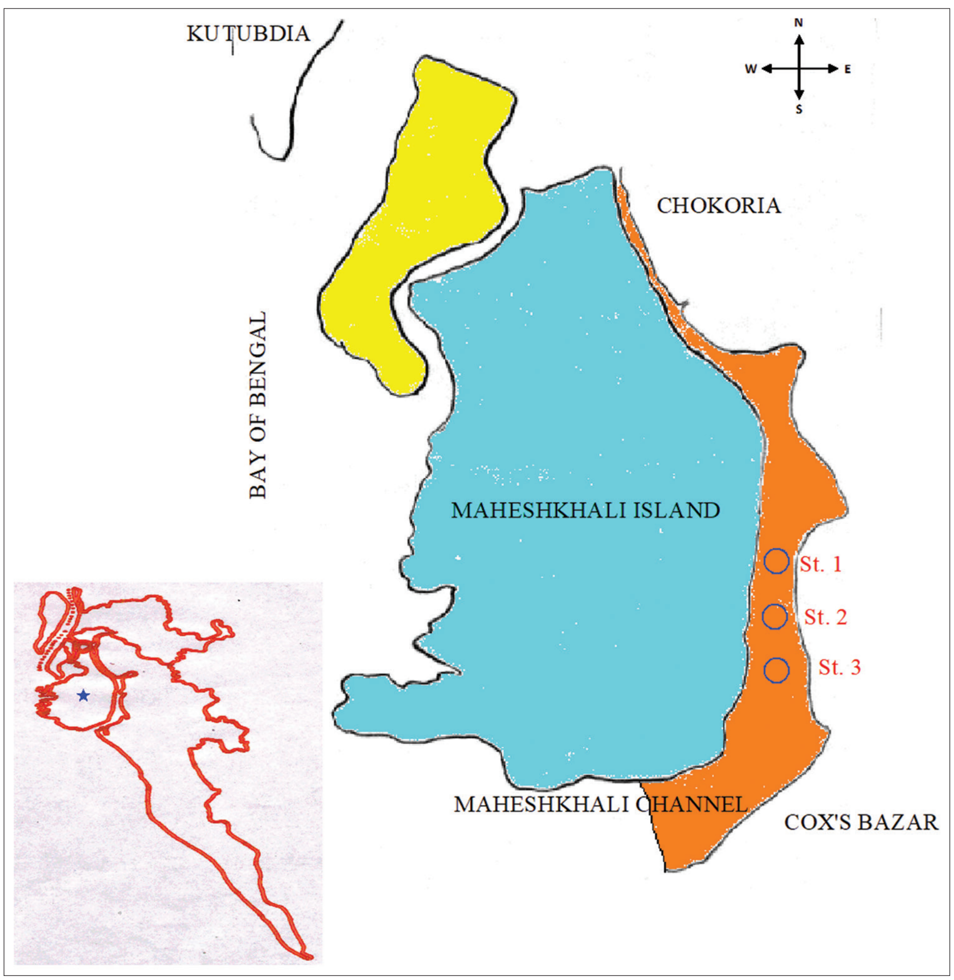

Figure 1: Map showing the sampling stations in the Maheshkhali channel, south-east coast of the Bay of Bengal, Bangladesh

a plankton net was towed just under the water surface for 1 min at a speed of approximately 1 m/s. From the net, the collected samples were drained in a polyethylene bottle and were preserved with 5% buffered formalin in seawater. For quantitative study, a known volume (100 l) of sub-surface water was passed through a plankton net (mesh 25 µm) and the concentrate was collected from the bucket and preserved in 5% buffered formalin in seawater. The quantitative estimation of phytoplankton was done by Sedgewick-Rafter counting chamber (S-R cell) method using an Olympus Binocular Microscope. Phytoplankton was identified up to species level as possible and enumerated as well. Taxonomic characterization was based on Newell and Newell,[19] Taylor *et al*.,[20] and Steidinger and Tangen.[21]

During sampling, surface water temperature and salinity were determined using a Celsius thermometer and a Hand Refractometer, respectively. Nitrate-nitrogen (NO_3-N) and phosphate-phosphorus (PO_4-P) concentration was measured in the laboratory by HACH kit (DR 2010). The correlation between phytoplankton abundance and environmental parameters was conducted by Pearson's correlation in SPSS.

RESULTS

Higher abundance of phytoplankton ($33 \times 10^5 \pm 16 \times 10^5$ cells l^{-1}) was recorded in October during early post-monsoon [Figure 2] followed by November ($27 \times 10^5 \pm 1.3 \times 10^5$ cells l^{-1}) and December ($22 \times 10^5 \pm 0.66 \times 10^5$ cells l^{-1}). The lowest phytoplankton abundance was detected in June during the early monsoon ($6 \times 10^5 \pm 1 \times 10^5$ cells l^{-1}). After that, phytoplankton abundance was progressively increased, and comparatively higher abundances were detected during August ($20 \times 10^5 \pm 3.7 \times 10^5$ cells l^{-1}) and September ($21.61 \times 10^5 \pm 1.4 \times 10^5$ cells l^{-1}). However, comparatively low abundance of phytoplankton was detected during pre-monsoon (February–May) (mean $10 \times 10^5 \pm 2 \times 10^5$ cells l^{-1}). During the study period, about 98 species of phytoplankton belonging to *Bacillariophyceae* (67), *Dinophyceae* (23), *Chlorophyceae* (4), and *Cyanophyceae* (4) were recorded. The dominant species of *Bacillariophyceae* and *Dinophyceae* are shown in Table 1.

Comparatively high temperature was recorded in August (31.67 ± 0.29°C), September (29.67 ± 0.29°C) and April (29.83 ± 0.29°C), whereas lower temperature was observed in October (21.17 ± 0.76°C) and November (20.83 ± 0.29°C) [Figure 3a]. The highest salinity was recorded in April (34) [Figure 3b]. After that, it was gradually decreased to 17.67 ± 1.5 in August, and the lowest salinity was in October (13.67 ± 1.5). The highest concentration of NO_3-N (15.7 ± 1.47 µM) was recorded during August, whereas the lowest concentration (4.3 ± 0.27 µM) was in June [Figure 4a]. After August, NO_3-N was gradually decreased to 9.67 ± 0.43 µM in December. On average, comparatively low concentration of NO_3-N was recorded in pre-monsoon (7.8 ± 1.46 µM). Two peaks of PO_4-P values were found in August (32 ± 4.2 µM) and November (34.43 ± 2.98 µM) [Figure 4b]. The lowest concentration of PO_4-P was recorded in June (6.11 ± 2.44 µM) during early monsoon. Total phytoplankton abundances in the Maheshkhali channel were found to be significantly positively related with NO_3-N ($r = 0.533$, $P < 0.01$) and PO_4-P ($r = 0.719$, $P < 0.01$). It showed significantly negative relation with temperature ($r = -0.42$, $P < 0.05$) and salinity ($r = -0.613$, $P < 0.01$) [Table 2].

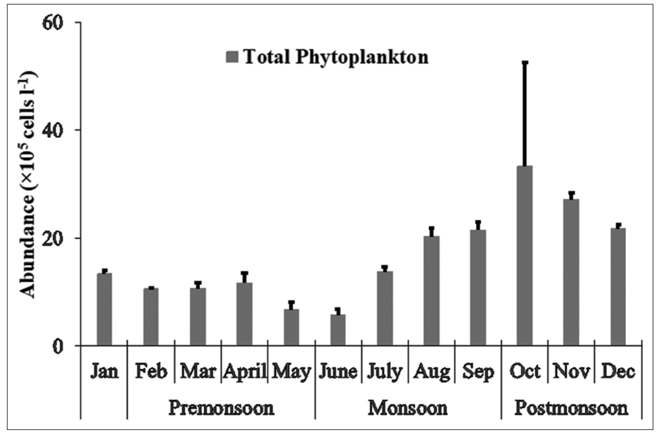

Figure 2: Temporal distribution of total phytoplankton abundances from January to December in the Maheshkhali channel, Bay of Bengal, Bangladesh

Table 1: List of some dominant species obtained in the Maheshkhali channel during the study period

Phytoplankton group	Species
Diatom	*Chaetoceros curvisetus*, *Pseudo-nitzschia delicatissima*, *Skeletonema costatum*, *Asterionellopsis glacialis*, *Odontella mobiliensis*, *Coscinodiscus radiatus*, *Fragilaria striatula*, *Thalassionema fraunfeldii*, *Thalassiosira punctigera,* and *Rhizosolenia alata*
Dinoflagellates	*Ceratium furca*, *Ceratium fusus*, *Ceratium* spp., *Dinophysis caudata*, *Gonyaulax* sp., *Gymnodinium* spp., *Prorocentrum micans*, *Prorocentrum sigmoides*, *Protoperidinium divergens*, *Protoperidinium* spp.

DISCUSSION

Phytoplankton blooms in the Maheshkhali channel were found in October ($33 \times 10^5 \pm 16 \times 10^5$ cells l^{-1})during early post-monsoon [Figure 2] due to higher concentration of NO_3-N and PO_4-P from the Bakkhali river discharge and precipitation. In this study, phytoplankton abundance

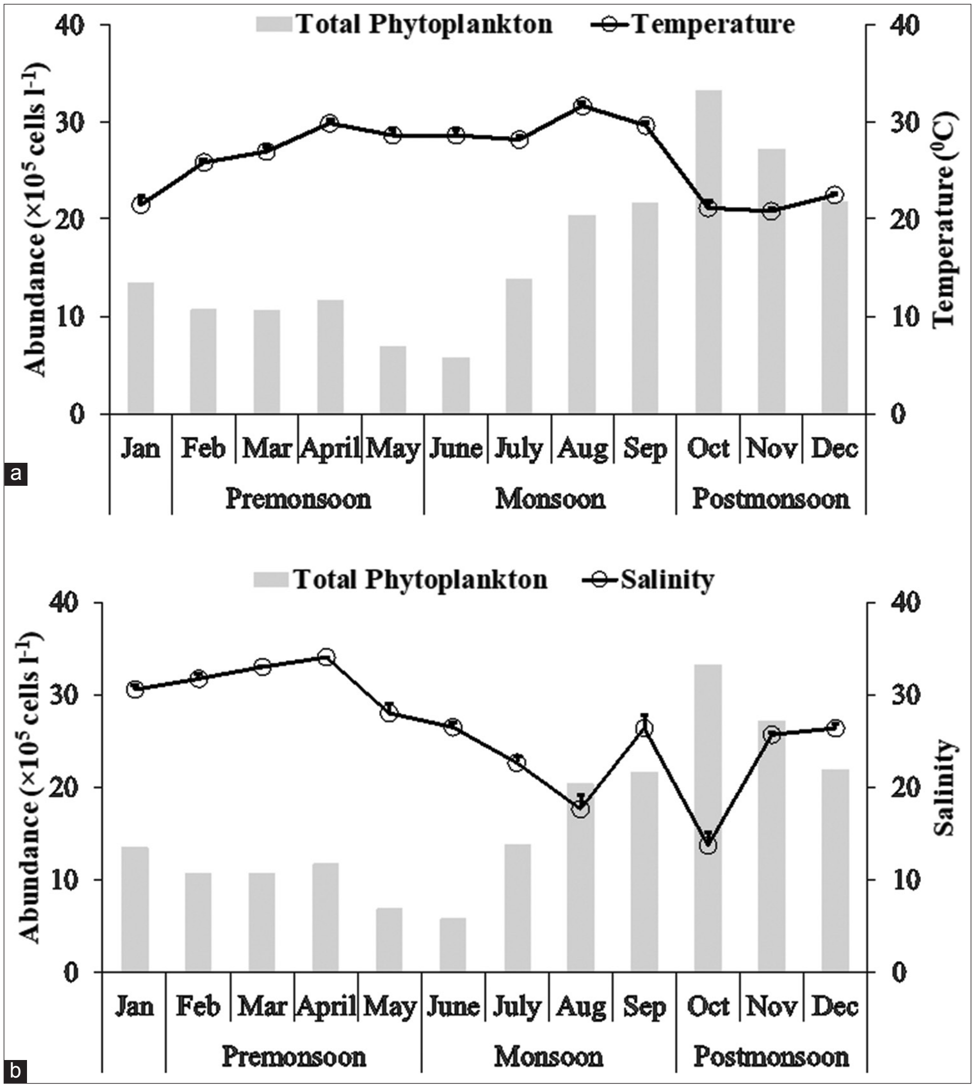

Figure 3: (a) Temporal distribution of total phytoplankton abundances and temperature from January to December in the Maheshkhali channel. (b) Temporal distribution of total phytoplankton abundances and salinity from January to December in the Maheshkhali channel

Table 2: Pearson's correlation coefficient between phytoplankton abundance and water quality parameters

	Phytoplankton	Temperature	Salinity	Nitrate	Phosphate
Phytoplankton	1				
Temperature	−0.424*	1			
Salinity	−0.613**	0.108	1		
Nitrate	0.533**	0.178	−0.575**	1	
Phosphate	0.719**	−0.186	−0.590**	0.750**	1

*Correlation is significant at 0.05 level (two-tailed). **Correlation is significant at 0.01 level (two-tailed)

has significantly positive relation with NO_3-N (r = 0.533, $P < 0.001$) and PO_4-P ($r = 0.719$, $P < 0.001$) [Table 2]. In fact, during post-monsoon, the conditions were favorable, such as bright sunlight and nutrient input from rainfall, which helped in the formation of algal bloom. Consistently, post-monsoon blooms were usually observed in some coastal areas of the BoB including coast of Mangalore, Goa, Tamil Nadu, and Gulf of Mannar, Orissa.[22-25] Ideally, after monsoon, cloud cover is reduced and sunlight irradiance enhanced, and therefore, phytoplankton appeared to benefit from both improved light conditions and nutrient inputs from estuarine mechanisms and river runoff.[15] However,the blooming process in the BoB is mainly influenced by seasonal upwelling and monsoonal forcing that causes high riverine discharge,

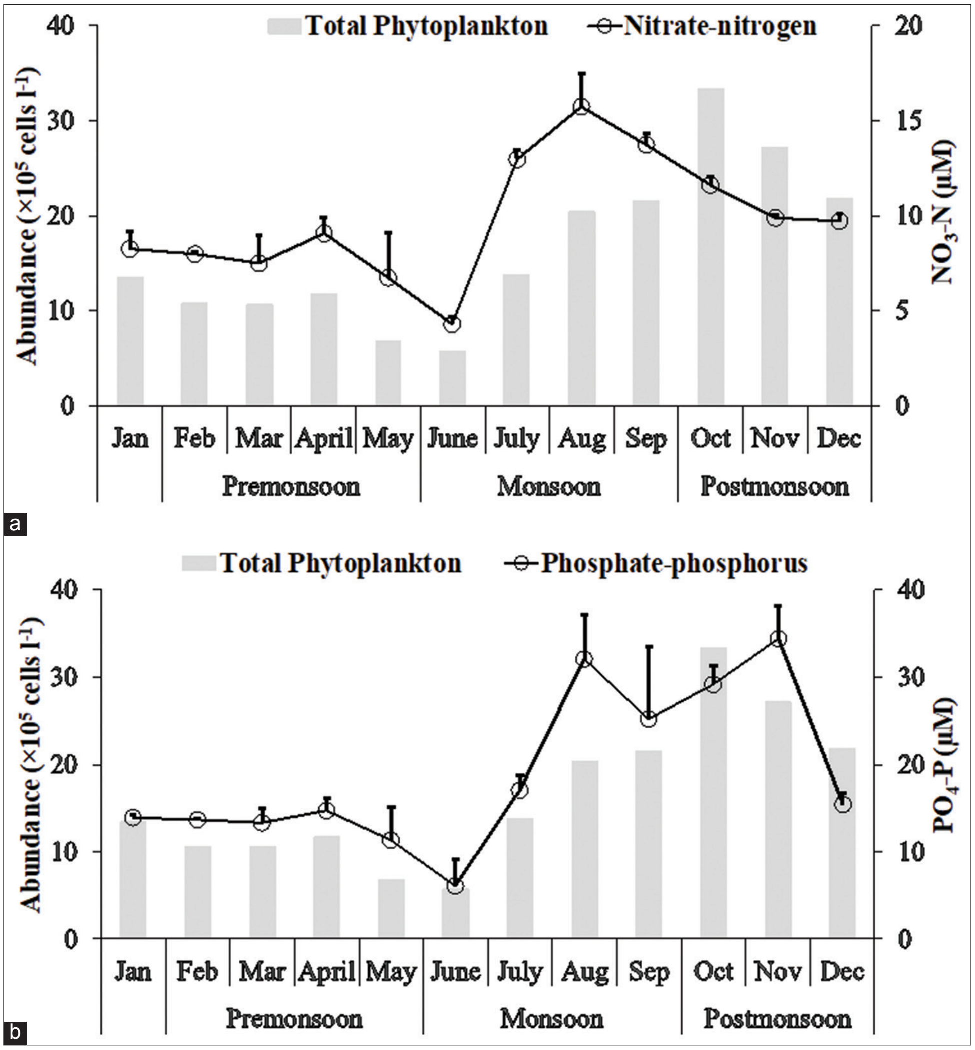

Figure 4: (a) Temporal distribution of total phytoplankton abundances and nitrate-nitrogen from January to December in the Maheshkhali channel. (b) Temporal distribution of total phytoplankton abundances and phosphate-phosphorus from January to December in the Maheshkhali channel

resulting in nutrient-reached water that provides a competitive edge for blooms of phytoplankton species.[12]

In this study, phytoplankton not only significantly positively related with nutrients but also significantly negatively related with water temperature and salinity [Table 2], partially agreeing with the previous studies in the Maheshkhali channel by Jewel *et al.*,[26] who reported the highest cell density and species diversity of phytoplankton in post-monsoon (November), when phosphate and salinity were found to be highest. In the present study, phytoplankton peaks during the lowest level of salinity [Figure 3b] might be due to comparatively higher river discharge during early post-monsoon. Consistently, salinity is the lowest in the northern part of the BoB, where monsoon rains and flow from the Ganga-Brahmaputra-Meghna delta combine to give a great input of freshwater, especially between June and October.[27] Furthermore, phytoplankton in the east coast of the BoB during the northeast monsoon (November-February) is limited by nutrients but not by light.[15] Entrainment of nutrient-rich water by wind mixing is not efficient in the BoB.[28] Consistently, it could be said that phytoplankton blooms in early post-monsoon at the Maheshkhali channel support the phase-I eutrophication model[2] emphasizing that changing nutrient input acts as a signal and responses to that signal is increased phytoplankton abundance. It also follows pressure-state-response approach;[29-31] it relates pressures (i.e., increased nutrients) to primary effects such as increased phytoplankton blooms and secondary effects such as potentially increased harmful algal blooms. For instance, harmful algae (i.e., *Pseudo-nitzschia* spp.) created blooms in November that strongly related with PO_4-P concentration and codominant with other diatom species (i.e., *Chaetoceros curvisetus*, *Asterionellopsis glacialis*, and *Coscinodiscus wailesii*) in the Maheshkhali channel.[18]

Although the highest concentration of NO_3-N in the Maheshkhali channel from the Bakkhali river discharge and precipitation was recorded during the late monsoon, comparatively moderate abundance of phytoplankton (39% lower abundance than October) was observed in August when the highest temperature was observed [Figure 3a]. This might be related to non-efficient utilization of nutrients by phytoplankton under low irradiance due to monsoonal cloud cover.[32] Nutrient uptake is an energy-demanding process and is partly light-dependent.[33] However, there is less occurrence of blooms during monsoon in the west coast of the BoB.[12] The underlying mechanism is that huge river discharge in monsoon stimulate stratification in water column inhibiting coastal mixing and makes the scarcity of nutrients in surface water.[11] Furthermore, the increased river flux during summer and fall inter-monsoon months considerably reduced the depth of light penetration and restricts primary productivity in spite of availability of nutrient.[34] However, the BoB is traditionally considered to be a region of lesser biological productivity primarily from the lack of availability of nitrate in the upper layers arising from strong stratification and weaker winds, which inhibits vertical mixing.[11]

During monsoon, mixotrophic dinoflagellates such as *Ceratium furca*, *C. tripos*, *C. fusus*, *Dinophysis caudata*, and *Prorocentrum micans* were dominant in the Maheshkhali channel;[26] their unique characteristics of vertical migration and heterotrophy are reasonably well-understood.[35-37] Consistently, Patil[38] reported high concentration of dinoflagellates (i.e., *Cochlodinium polykrikoides* and *Gymnodinium catenatum*) during a monsoon break in coastal water off Goa and their concentration decreased with restart of freshwater discharge.

The lowest abundance was detected in June during early monsoon which may be due to the lowest concentration of NO_3-N and PO_4-P, possibly resulted from lower freshwater discharge and precipitation, agreeing with the previous record in Maheshkhali channel by Jewel *et al.*,[26] who reported the lowest phytoplankton abundances in June associated with lower nutrients. Comparatively lower abundance was detected during pre-monsoon (February–May) due to the lower nutrients and comparatively high water temperature [Figure 3a]. A similar pattern was reported by Paul *et al*.[39] in that higher temperature (>30°C), calm waters and lower nutrients are prevalent in the BoB during spring inter-monsoon (April–May) and also attributed that this condition is ideal for the growth of cyanobacteria. A similar pattern was reported by Rivera-Monroy *et al*.[40] in that depression in primary productivity occurred during dry months of February–May. In contrast, the majority of bloom cases in east coast of the BoB have been reported during pre-monsoon, mostly dominated by diatom (i.e., *Asterionella japonica*) and cyanobacteria (*Trichodesmium erythraeum*); warm waters and low nutrients during pre-monsoon are known to favor *Trichodesmiun* blooms.[41]

CONCLUSION

Consistent with our hypothesis, it is attributed that higher concentration of NO_3-N and PO_4-P from Bakkhali river discharge and precipitation enhanced phytoplankton abundance in October during early post-monsoon in the Maheshkhali channel. Along with nutrients, lower salinity resulted from freshwater discharge and lower temperature in surface water might have an impact on bloom formation. Inversely, lower abundances of phytoplankton were observed during early monsoon (June) and pre-monsoon due to comparatively lower concentration of NO_3-N and PO_4-P. During that period, comparatively higher water temperature and salinity were also observed. Furthermore, moderate abundance of phytoplankton was observed during late monsoon (August), although the highest concentration of NO_3-N and PO_4-P was recorded. The underlying mechanism was likely that huge river discharge might have caused higher turbidity that inhibited light penetration and restricted phytoplankton abundance. Therefore, it is observed that nutrient could enhance phytoplankton abundance along with suitable environmental parameters. However, further studies are needed to understand phytoplankton community response to the changing nutrients levels as well as environmental parameters in the Maheshkhali channel of the BoB.

ACKNOWLEDGMENT

The research was supported by a grant from the Ministry of Science and Technology, Government of the People's Republic of Bangladesh.

REFERENCES

1. Nixon SW. Coastal marine eutrophication: A definition, social causes, and future concerns. Ophelia 1995;41:199-219.
2. Cloern JE. Our envolving conceptual model of the coastal eutrophication problem. Mar Ecol Prog Ser 2001;210:223-53.
3. Rabalais NN. Eutrophication. In: Robinson AR, McCarthy J, Rothschild BJ, editor. The Global Coastal Ocean: Multiscale Interdisciplinary Processes, the Sea. Vol. 13. Ch. 21. Cambridge, MA: Harvard University Press; 2004. p. 819-65.
4. Gordon AL, Giulivi CF, Takahashi T, Sutherland S, Morrison J, Olson D. Bay of Bengal nutrient-rich benthic layer. Deep Sea Res II 2002;49:1411-21.
5. Mukhopadhayay SK, Biswas H, De TK, Jana TK. Fluxes of nutrients from the tropical river hoogly at the land-ocean boundary of sundarbans, NE coast of Bay of Bengal, India. J Mar Syst 2006;62:9-21.
6. Godhe A, Karunasagar I, Karunasagar I. *Gymnodinium catenatum* on West cost of India. Harmful Algal News 1996;15:1.
7. Iyer CS, Robin RS, Sreekal MS, Kumar SS. *Karenia mikimotoi* bloom in Arabian sea. Harmful Algal News, 2008;37:9-10.
8. Karunasagar I, Gowda HS, Subburaj M, Venugopal MN, Karunasagar I. Outbreak of paralytic shellfish poisoning in

Mangalore, West coast of India. Curr Sci 1984;53:247-9.
9. Karunasagar I, Joseph B, Philipose KK, Karunasagar I. Another outbreak of PSP in India. Harmful Algae News 1998;17:1.
10. de Sousa SN, Dileepkumar M, Sardessai S, Sarma VV, Shirodkar PV. Seasonal variability in oxygen and nutrients in the central and eastern Arabian sea. Curr Sci 1996;71:847-51.
11. Kumar SP, Murleedharan PM, Prasad TG, Gauns M, Ramaiah N, de Souza SN, *et al*. Why is the Bay of Bengal less productivity during summer monsoon compared to the Arabian sea? Geophys Res Lett 2002;29:2235.
12. D'Silva MS, Anil AC, Naik RK, D'Costa PM. Algal blooms: A perspective from the coasts of India. Nat Hazards 2012;63:1225-53.
13. Qasim SZ. Biological productivity of the Indian Ocean. Indian J Mar Sci 1977;6:122-37.
14. Radhakrishna K. Primary productivity of the Bay of Bengal during March-April 1975. Indian J Mar Sci 1978;7:58-60.
15. Gomes HR, Goes IJ, Siano T. Influence of physical processes and freshwater discharge on the seasonality of phytoplankton regime in the Bay of Bengal. Cont Shelf Res 2000;20:313-30.
16. Haque MM, Hossain MA, Khan S. Harmful Algal Blooms Associated with Mass Mortality of Fishes in the Bay of Bengal, Bangladesh. Florida, USA: 10th International Conference of Harmful Algae; 2002.
17. Hossain MS, Lin CK. Land Use Zoning for Integrated Coastal Zone Management: Remote Sensing, GIS and RRA approach in Cox's Bazar coast, Bangladesh. Bangkok, Thailand: ITCZM Publication Series, No.3, Asian Institute of Technology; 2001.
18. Jewel MA, Khan S, Haque MM. Seasonal dynamics in the occurrence and abundance of *Pseudo-nitzschia* species in the Maheshkhali channel of the Bay of Bengal, Bangladesh. Bangladesh J Fish Res 2005;9:169-74.
19. Newell GE, Newell RC. Marine Plankton. London: Hutchinson and Co. Ltd.; 1977.
20. Taylor FJ, Fukuyo Y, Larsen J. Taxonomy of harmful dinoflagellates. In: Hallegraeff GM, Anderson DM, Cembella AD, editors. Manual on Harmful Marine Microalge. IOC Manuals and Guides No. 33. Paris: UNESCO; 1995. p. 283-309.
21. Steidinger KA, Tangen K. Dinoflagellate. In: Tomas CR, editor. Identifying Marine Phytoplankton. San Diego: Academic Press; 1997.
22. Sanilkumar MG, Thomas AM, Philip AA, Hatha M, Sanjeevan VN, Saramma AV. First report of *Protoperidinium* bloom from Indian waters. Harmful Algal News 2009;39:15.
23. O'Herald. NIO Discovers Toxic Algal off Goa. Goa: O'Herald Newspaper; 2001.
24. Anantharaman P, Thirumaran G, Arumugam R, Kanna RR, Hemaltha A, Kannathasan A, *et al*. Monitoring of *Noctiluca* bloom in Mandapam and Keelakarai coastal waters, South-East coast of India. Recent Res Sci Tech 2010;2:51-8.
25. Gopakumar G, Sulochanan B, Venkatesan V. Bloom of *Noctiluca scintillans* (Maccartney) in Gulf of Mannar, Southeast coast of India. J Mar Biol Ass India 2009;55:75-80.
26. Jewel MA, Haque MM, Haq MS, Khan S. Seasonal dynamics of phytoplankton in relation to environmental factors in the Maheshkhali channel, Cox's Bazar, Bangladesh. Bangladesh J Fish Res 2002;6:173-81.
27. Kay S, Casesar J, Janes T. Marine dynamics and productivity in the Bay of Bengal. In: Nicholls R, Hutton C, Adger W, Hanson S, Rahman M, Salehin M, editors. Ecosystem Services for Well-being in Delta. Cham: Palgrave Macmillan; 2018. p. 263-75.
28. Shenoi SS, Shankar D, Shetye SR. Differences in heat budgets of the near-surface Arabian Sea and Bay of Bengal: Implications for the summer monsoon. J Geophy Res 2002;107:3052.
29. Bricker SB, Clement CG, Pirhalla DE, Orlando SP, Farrow DT. National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries. National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Service. Maryland: Silver Spring; 1999.
30. Bricker S, Longstaff B, Dennison W, Jones A, Boicourt K, Wicks C, *et al*. Effects of nutrient enrichment in the nation's estuaries: A decade of change. National estuarine eutrophication assessment update. In: NOAA Coastal Ocean Program Decision Analysis Series 26 National Centers for Coastal Ocean Science. Maryland: Silver Spring; 2007.
31. Whitall D, Bricker S, Ferreira J, Nobre AM, Simas T, Silva M. Assessment of eutrophication in estuaries: Pressure-state-response and nitrogen source apportionment. Environ Manage 2007;40:678-90.
32. Patil JS, Anil AC. Temporal variation of diatom benthic propagules in a monsoon influenced tropical estuary. Cont Shelf Res 2008;28:2404-16.
33. Kooistra WH, Gersonde R, Medlin LK, Mann DG. The origin and evolution of the diatoms: Their adaptation to a planktonic existence. In: Falkowski PG, Knoll AH, editors. Evolution of Primary Producers in the Sea. Amsterdam: Elsevier, Academic Press: 2007. p. 207-49.
34. Kumar SP, Narvekar J, Nuncio M, Kumar A, Ramaiah N, Sardesai S, *et al*. Is the biological productivity in the Bay of Bengal light limited? Curr Sci 2010;98:1331-9.
35. Baek SH, Shimode S, Kikuchi T. Reproductive ecology of dominant dinoflagellate, *Ceratium furca* in the coastal area of Sagami Bay. Coastal Mar Sci 2006;30:344-52.
36. Bake SH, Shimode S, Kikichi T. Growth of dinoflagellate, *Ceratium furca* and *Ceratium fusus* in Sagami Bay, Japan: The role of temperature, light intensity and photoperiod. Harmful Algae 2008;7:163-73.
37. Latz MI, Jeong HJ. Effect of red tide dinoflagellate diet and cannibalism on the bioluminescence of the heterotrophic dinoflagellates *Protoperidinium* spp. Mar Ecol Prog Ser 1996;132:275-85.
38. Patil JS. Diatoms in benthic and pelagic environment. In: Studies on Ecology of Diatom. PhD Thesis. Goa: University of Goa; 2003. p. 47-50.
39. Paul JT, Ramaiah N, Sardessai S. Nutrient regimes and their effect on distribution of phytoplankton in the bay of Bengal. Mar Environ Res 2008;66:337-44.
40. Rivera-Monroy VH, Madden CJ, Day JJ, Twilley RR, Vera-Herrera F, Alvarez-Guillen H. Seasonal coupling of a tropical mangrove forest and an estuarine water column: Enhancement of aquatic primary productivity. Hydrobiologia 1998;379:41-53.
41. Devassy VP, Bhattathiri PM, Qasim SZ. *Trichodesmium* phenomenon. Indian J Mar Sci 1978;7:168-86.