A review of the physicochemical features and phytoplankton community of the Bay of Bengal: Bangladesh perspective

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Abstract:

As primary producers, phytoplankton form the basis of the marine food web. Coastal environments are highly fluctuating given the anthropogenic interactions and nutrient input from the adjacent landmass, which affects the dynamics and diversity of the phytoplankton populations leading to rapid changes in their composition. The Bay of Bengal (BoB) is the largest bay in the world, and forms the coastline of multiple South Asian countries, including Bangladesh, India, and Myanmar. The BoB is strongly influenced by seasonal monsoon, freshwater discharge from numerous rivers, and severe tropical cyclones. These unique physicochemical parameters of BoB, frequent anthropogenic interactions and impact of climate change in this region underscore the importance of understanding the microalgal dynamics and diversity in this region. Bangladesh is a small country in South Asia, which is geographically bordered to the south by ˜710 km long coastline formed by the BoB. The BoB coast plays a key role in the socioeconomic fabric of Bangladesh, as a large population depends on fishing and frequent tourism in these regions. This region is particularly sensitive to climate change, and global warming is predicted to increase the frequency of extreme weather events and sea-level rise. Given these factors, it is of utmost importance to understand the key players in the primary productivity of coastal Bangladesh, how they influence the upper trophic level consumers like fish, and the factors that affect their composition and dynamics. Here, we reviewed the physicochemical features of BoB and the current understanding of the phytoplankton communities in this bay. We further discussed the importance to chart the diversity and seasonality of phytoplankton communities in the coastal region of Bangladesh.

Introduction:

The Bay of Bengal (BoB) is the world's biggest bay, with 1.4 billion people living along its shoreline in Bangladesh, India, Thailand, and Myanmar. It is a huge but shallow bay in the northeast of the Indian Ocean that covers approximately 2,173,000 square kilometers. It lies between 5 ° and 22 ° north latitude and 80 ° and 90 ° east longitude. It borders India and Sri Lanka to the west, Bangladesh to the north, and Myanmar (Burma) and the northern part of the Malay Peninsula to the east. The bay is roughly 1,000 miles (1,600 kilometers) long and more than 8,500 feet deep on average (2,600 meters), with a maximum depth of 15,400 feet (4,694 meters). A number of major rivers flow into the Bay of Bengal, including the Ganges-Brahmaputra-Meghna (GBM) on the north and the Mahanadi, Godavari, Krishna, and Kaveri (Cauvery) on the west [1]. A wide U-shaped basin with a south entrance to the Indian Ocean characterizes the bottom topography. The Arabian Sea and the Bay of Bengal are twin seas that caress the western and eastern boundaries of the Indian subcontinent. The Andaman and Nicobar groups are the only islands that separate the bay from the Andaman Sea [2].

Physicochemical features of the Bay of Bengal:

The BoB's distinct characteristics, such as large amounts of riverine fresh water discharges, monsoonal clouds (Monsoon: (June-August), Post-monsoon: (September-November), Winter: (December –February), Pre-monsoon: (March –May), rainfall, and weak surface winds, result in strong salinity stratification. The monsoons dominate the climate of the BoB. The bay creates northeast winds (the northeast monsoon) that are typical of the winter season from November to April which is the result of continental high-pressure system. The rain-bearing southwest monsoon dominates the northern summer (June–September), when high temperatures create a low-pressure system across the continent and a following air flow from the sea [1].

From January to July, surface current circulation is normally clockwise, then from August to December it directs counter-clockwise, according to reversible monsoon wind patterns. Monsoon winds and rain influence the East India Coastal Current moves north-eastwards down the western coast of BoB from February to September and south-eastwards from October to January, is the Bay's most powerful characteristic circulation [3-6]. Because of the heavier southwest monsoons, currents to the northeast tend to last longer and flow faster. Up-welling is a significant vertical circulation in the Bay of Bengal. Subsurface water is conveyed to the surface during this process, and a downward movement is referred to as down-welling or sinking. Up-welling and down-welling are periodical phenomena in the bay, caused by monsoon winds that rush from the southwest in the summer and then change direction to the northeast in the winter. Up-welling occurs throughout much of India's east coast due to the constancy of the monsoon, particularly from the southwest, and the direction of the coastlines. As a result, on India's east coast (western cost of BoB), upwelling happens in the summer and down-welling occurs in the winter, whereas on the eastern portion of the BoB and the Bangladesh, Myanmar coast, upwelling occurs in the winter and down-welling occurs in the summer. The time span and severity of vertical water flow on both western and eastern sides of the BoB, however, are not as considerable as on the Somali or North and South American coastlines. However, it has a significant impact on the sea's food economy due to its effects on nutrient dynamics and biological populations [4,7,8].

The BoB exports fresh water on a net basis. The north has the lowest salinity because monsoon rains and run from the GBM delta incorporate to offer a large fresh water influx, mostly between June and October (Figure 1). Surface currents along both coastlines spread fresh water southward, as does progressive mixing with saltier seas below [9-11]. Surface salinity in the open section of the Bay ranges from 32% to 34.5%, whereas it fluctuates from 10% to 25% near the coastal zone [1,12-14] (Figure 1). However, in river estuary or delta, the surface salinity drops to 5% or less [15,16]. Throughout the year, the coastline water is substantially diluted, but the amount of water conveyed by the river declines during the winter. Salinity drops to 1% in the GBM Delta shore during the summer and rises to 15% to 20% during the winter [16]. The salinity progressively rises from the shore to the open section of the Bay. Surface salinity near the mouths of several big rivers, such as the Ganges, Brahmaputra, and Irrawaddy, as well as other Indian rivers, such as the Krishna, Godavari, Cauvery, and Mahanadi, fluctuates greatly from day to day, mostly in summer [15-17]. Water salinity varies vertically as well. The impact of fresh water is felt up to depths of 200-300m. The salinity steadily grows downhill from the surface, and at about 200-300m it approaches 35 percent, and at approximately 500m it exceeds 35.10 percent, but at 1,000m it lowers somewhat and hits 34.95 percent. Salinity drops as depth increases, and at 4,500m it is near to 34.7 percent [4,18].

The temperature in the offshore areas, on the other hand, is consistently warm and constant throughout the year, with a slight decrease in the north (Figure 1) [1]. The average yearly surface water temperature is around 28°C. The highest heat (30°C) is recorded in May, while the lowest temperature (25°C) is recorded in January-February (Figure 1). However, the yearly temperature range is not considerable, with temperatures varying by roughly 5°C in the north and 2°C in the south [12,19-21].

Severe tropical cyclones (TCs), which occur yearly with maximum frequency during the inter-monsoon months of April–May and October–November, also have an impact on the BOB., The average site of tropical cyclone formation migrated southward in July to December. Comparing to the post-monsoon (October–December) season, tropical cyclone scheme is substantially reduced during the monsoon (June–September) season [22]. TCs in the BoB causes severe storm surges that impact the coastal regions, and Bangladesh, among other countries experiences the most severe impact of storm surges in terms of lives lost and other damages [23]. The main factors contributing to these severe surges in the coastal BoB includes shallow coast, high astronomical tides, favorable cyclone track and large number of river inlets including the GBM, which is the world's largest river system [23]. A storm in the River delta, Ganges in November 1970 killed a large number of people and cattle. A storm of equal size destroyed Bangladesh's eastern coast in April 1991, while another severe cyclone damaged in October 1999 in the coastal Indian state of Orissa. During the summer and the beginning of winter, water spouts are common in the bay [1,24]. In May 2009, a powerful cyclonic cyclone named 'Aila' struck offshore 15 districts in Bangladesh's south-western region, killing approximately 150 people and destroying 2 million dwellings and 3 million acres of agricultural land and crops. The severe cyclonic storm 'Sidr' causes massive devastation in the southern portion of Bangladesh, killing around 3000 people in November 2007 [24].

Bangladesh is located to the north of the BoB. It is located in the world's biggest delta, with flat terrain, and is interwoven with a complex system of rivers, including the great Ganges, Brahmaputra, and Meghna, as well as numerous tidal canals that convey a huge amount of sediment downstream, establishing one of the world's most productive ecosystems [25]. The shoreline is 710 kilometers long and is made up of the port of diverse biological and economic structure, such as mangroves (the world's biggest mangrove forest encompasses 6,017 kilometers^2) and tidal flats. Estuaries, sea grass, around 70 islands, accreted land, beaches, a peninsula, rural communities, urban and industrial regions, and ports are all present. Bangladesh's coastal zone is divided into three sections based on geographic features: (a) the eastern zone, (b) the central zone, and (c) the western zone. The semi-active delta is overlapping by many canals and streams in the western area known as the Ganges tidal plain. The center area has the most vigorous and constant accretion and erosion processes. The Meghna River Estuary is located in the same zone. The eastern section is characterized by a steep terrain that is more sturdy than the others [26,27]. The beach at Cox's Bazar is sandy with a gradual slope and is the longest natural sea beach on the planet, stretching 120 kilometers. Many rivers and canals pour into the south-eastern section of the Bay of Bengal, carrying fresh water to the open sea. The combination of fresh and salt water lowers the pH and salinity of the water. So far, around 60 islands have been identified in the coastal zone. Because of the GBM river system's dynamic river flow, the bulk of the islands are situated in the central coastal zone. Three upazilas, Hatia, Sandweep, and Maheshkhali, as well as Bhola, an administrative district, make up the zone's four larger islands. St. Martin is a tiny island about 9.8 kilometers southeast of the mainland, with a 7.5-square-kilometer size. Classification of St. Martin's as a coral island was subject to controversy – and previous reports suggest it is likely a continental sedimentary island [28]. However, the sandstone rocky reefs that surround the island harbor many diverse reef building coral species [29,30] with symbiont algal communities, coral associated flora and fauna, and – which has been subjected to degradation likely due to intense human activity and climate change [31]. A total number of 177 char lands have also been identified in the coastal zone [32,33].

The Sundarbans, the world's single largest deltaic mangrove forest, is located off the coast of Bengal on the delta of the GBM rivers established at the estuarine phase. The forest encompasses 10,000 km^2, with around

6,017 km^2 in southern Bangladesh and the remainder in southeastern West Bengal state, northeastern India, and has been on the UNESCO World Heritage list since 1997. The forest is situated between latitudes 21°30'N and 22°30'N, and longitudes 89°00'E and 89°55'E, just south of the Tropic of Cancer. The tract stretches roughly 160 miles (260 km) west-east along the BoB from the Hugli River estuary in India to the western portion of the Meghna River estuary in Bangladesh, and it continues inland for around 50 miles (80 km) at its widest point. It encloses low, heavily wooded, marshy islands by a network of estuaries, tidal rivers, and streams crossed by many channels [34,35]. Sundarbans have a diverse range of mangrove species [36,37]. The main vegetation in mangrove wetlands is sundari, gewa or gengwa (*Excoecaria agallocha*), nipa palms (*Nypa fruticans*), and other halophytic (salt-tolerant) plants [38].

Sundarbans mangrove forest soils vary from typical inland soils in that they are exposed to the impacts of salt and waterlogging, both of which influence the plants naturally. Soils are semi-solid and inadequately compacted in certain locations. The pH scale goes from 5.3 to 8.0. Despite the fact that the Sundarbans soil is generally medium grained, sandy loam, silt loam, or clay loam, the grain size distribution is very varied. The sodium and calcium concentrations of the soil range from 5.7 to 29.8 meq/100g dry soil and are lower in the east and higher in the west. The soil's accessible potassium concentration is modest, ranging from 0.3 to 1.3 meq/100g dry soil. In dry soil, organic matter concentration ranges between 4% and 10% [25,35,39-41]. Sundarban's western flank (west of the Indian Sundarban region) has a greater salinity regime [42] and a reduced salinity regime exists on the eastern side of Sundarban (east of the Bangladesh Sundarban region) [43], whereas the central Sundarban, which spans both India and Bangladesh, is polyhaline in character. [44]. In the case of Sundarban, the salinity pattern varies both seasonally and spatially. The fluctuation is both constant and noticeable. During the pre-monsoon, there is a large rise in salinity due to increased evaporation and a decrease in upstream freshwater discharge. The salinity of river water falls during the post-monsoon season, and soluble salts are diluted. A salinity gradient runs north-south, with an increasing tendency from the interior to the sea. [45,46].

The forest is categorized as tropical wet forest since it is located south of the Tropic of Cancer and is limited by the northern boundaries of the Bay of Bengal. The Sundarbans have more temperate temperatures than the surrounding land areas. The average yearly maximum and lowest temperatures range from 30° to 21° C. Temperatures are at their highest from mid-March to mid-June, and at their lowest in December and January. The average maximum temperature during the warmest months has been reported at 32.4°C in Patuakhali, in the Sundarbans' east [39,47,48].

Globally, the annual mean near-surface air temperature has risen by around 0.7 °C between 1901 and 2018, and is expected to rise by 2.4-4.4 °C by the end of the century under various warming scenarios, compared to the average temperature between 1976 and 2005 [49]. For the 45-year period from 1960 to 2005, sea surface temperatures (SST) rose by 0.2–0.3 °C along the Indian shore of the Bay. They predict a 2–3.5 °C temperature increase by the end of the century[50-53]. Thermal expansion is the primary source of sea level rise, and researchers have seen a rising rate of increase of 12–13mm/decade for the northern Indian Ocean [54]. The maximum far-achieving results of sea stage upward push are threats to coasts and coastal human beings due to coastal erosion, inundation, and saltwater intrusion into freshwater reasserts and habitats, which can be a first-rate difficulty now no longer most effective in Bangladesh and the Maldives, however additionally in Sri Lanka, Sumatra, and different coastal regions of the BoB, which might also additionally revel in notably extra sea-stage upward push than the worldwide mean [52,53,55,56].

Climate change causes ocean acidification (OA) [57]. OA is described as a long-term drop in seawater pH caused mostly by human increases in atmospheric carbon dioxide (CO_2). The ocean absorbs roughly 30% of the CO_2 released to the atmosphere by human activities such as fossil fuel combustion, cement production, deforestation, and land-use change. CO_2 dissolves in water, forming carbonic acid (H_2CO_3) and lowering ocean pH (owing to an increase in hydrogen ion concentration, or H+) [57]. One of the primary driving causes of OA is excessive CO_2 emissions. Atmospheric CO_2 concentrations are predicted to reach 467–555 ppm by the year 2050, causing surface ocean pH to fall to 7.8 on average [58]. The carbonate system in the Bay of Bengal is quickly changing. According to a recent research, the average pH value in the Bay of Bengal is about 7.73. Between 2012 and 1994, the pH value fell by 0.2. (pH 7.95). There is also a growing tendency [57,59,60].

Anthropogenic activities have boosted nitrogen and sulfur inputs to the atmosphere, resulting in significant fluxes of ammonia, NO_x, and sulphur dioxide (about 4, 2, and 2 Tmol y^{-1}, respectively) to the atmosphere [61]. The heart of anthropogenic activity is the combustion of fossil fuels and the combustion of biomass, which have raised nitrogen and sulfur fluxes above natural levels [62-64]. These gases are chemically converted into nitrate and sulphate aerosols in the atmosphere, which eventually settle in the ocean and lower the pH of the surface waters. Because these species have a very brief lifetime in the atmosphere (a few days to a week), they will be deposited close to their source(s), typically the adjacent land and coastal waters. Atmospheric inputs of HNO3, H2SO4, and NH3 are significant in coastal waters, contributing to coastal acidification as well as large-scale climatic changes [65-68]. As a result, they are seen as an environmental issue for both terrestrial and marine environments [69-71].

Phytoplankton Diversity in the Bay of Bengal:

Phytoplankton are vital ecological markers that govern marine life [72,73]. Historically, the BoB has been thought to be less ecologically productive than its cousin, the Arabian Sea. Because the BoB is one of the biggest tropical basins that is landlocked in the north, semi-annual monsoons regularly impact it, causing unique seasonal variations in physicochemical characteristics [74]. Because the Bay is located in a tropical climate, phytoplankton development is generally influenced by monsoonal cloud cover and the presence of suspended sediments caused by river flow, which can reduce light availability for primary production [75,76]. Furthermore, vertical mechanisms transferring nutrients into euphotic layers are usually poor in the BoB, owing to high stratification and weak upwelling [77]. Cyclones and mesoscale eddies, on the other hand, can disrupt top layer stratification and deliver deep nutrients to the euphotic zone [74,78-83].

Primary production by coastal phytoplankton accounts for almost 15% of worldwide oceanic output [84]. Diatoms dominate the the northwestern (NW) and southwestern (SW) coast of Bay of Bengal (BoB) (Table 1) [2,83,85-106]. For many years, diatoms were classified as either a class (Bacillariophyceae) or a phylum (Bacillariophyta), with only two orders corresponding to centric and pennate diatoms (Centrales and Pennales). Round overhauled the classification and promoted the major classification units to classes, keeping the centric diatoms in a single class, Coscinodiscophyceae, but splitting the former pennate diatoms into two separate classes, Fragilariophyceae and Bacillariophyceae [107]. The number of centric diatom (Coscinodiscophyceae) species was higher than that of pennate (Fragilariophyceae and Bacillariophyceae) diatoms. However, sometimes pennate diatoms were more abundant than centric diatoms [85,99]. The species of classes Dinophyceae (Dinoflagellates), Cyanophyceae (Blue-green algae), Chlorophyceae (Green algae), and Silicoflagellates (Golden algae and Golden-brown algae) showed both spatial and seasonal variation alongside the NW and SW coastal area of BoB [2,83,85-106,108,109]. Phytoplankton attained their maximum population density during pre-monsoon, whereas minimum population was observed during monsoon [85,106] and sometimes in winter in NW cost [86]. *Thalassiosira, Nitzschia, Guinardia, Anabena, Thalassionema, Microcystis, Merismopedia, Leptocylindrus, Chaetoceros, Peridinium, Amphora, Skeletonema, Paralia, Aphanocapsa, Dictyocha, Trichodesmium, Lauderia, Chlorella, Gomphosphaeria, Ditylum, Synedra, Odentella, Thalassiothrix, Eucampia, Helicotheca,* and *Menuira* genera are dominant in SW costal region during monsoon whereas *Thalassiosira, Nitzschia, Chaetoceros, Microcystis, Merismopedia, Thalassionema, Peridinium, Nostoc, Thalassiothrix, Ditylum, Synedra, Lauderia, Menuira, Gomphosphaeria, Chlorella, Helicotheca, Trichodesmium, Skeletonema, Odentella, Eucampia, Protoperidinium, Paralia, Aphanocapsa, Guinardia,* and *Amphora*genera are dominant in NW costal area during monsoon [87,89,96]. The most common groups observed throughout the season were diatoms*Chaetoceros atlanticus* , *Chaetoceros curvisetum, Coscinodiscus granii, Coscinodiscus wailesii, Coscinodiscus marginatus* , and *Guinardia flaccida* of Coscinodiscophyceae order,*Nitzschia longissima, Nitzschia seriata* of Bacillariophyceae order, and *Asterionellopsis glacialis* of Fragilariophyceae order in a study in SW coast [85]. Thangaradjou *et al* described the prevalence of diatoms such as*Asterionella glacialis* , *Chaetoceros affinis* , *Ditylum brightwelli* , *Skeletonema costatum* , *Chaetoceros lascinosus, Navicula clavata* , and *Triceratium reticulatum*from NW coastal region that may explain the observed high population density and species diversity during the pre-monsoon season. *Coscinodiscus centralis* , *Diatoma vulgare* , and *Rhizosolenia alata* are plentiful throughout the summer season. *Prorocentrum micans* , a dinoflagellate, was seen only during the premonsoon season, and the cyanophyceae species composition did not alter much across seasons [89]. Choudhury *et al* depicted *Asterionella japonica, Cyclotella meneghiniana, Coscinodiscus perforates,* and *Ditylum brightwellii* in NW coast throughout the seasons [86]. *Skeletonema costatum* was abundant throughout the year in 2008–2009 in Kalpakkam, east coast of India (SW) [93]. *Thalassiothrix longissima, Cocconeis* sp., *Navicula* sp., *Nitzschia sigma* , *Biddulphia heteroceros* , *Coscinodiscus eccentricus* , *Coscinodiscus gigas, Guinardia delicatula* , *Melosira sulcata* , *Paralia* sp., *Rhizosolenia alata* , *Rhizosolenia setigera* , *Rhizosolenia styliformis* , and *Skeletonema costatum* species were dominant all throughout the seasons from March, 2010 to February, 2012 in coastal site in NW BoB [96]. During the monsoon season in Gopalpur port (NW costal area), *Asterionellopsis glacialis, Thalassionema nitzschioides, Paralia sulcata, Thalassiosira sp.,* and *Licmophora abbreviate* were predominant. Post-monsoon was dominated by *Hemiaulus sinensis* , *Nitzschia closterium* , *Thalassiosira punctigera* , *Chaetoceros danicus* , *Protoperidinium* sp., and *Guinardia striata* but pre-monsoon was dominated by *Thalassiosira sp* ., *Skeletonema costatum* , *Pseudonitzschia* sp., *Noctilluca scintillans* , *Chaetoceros curvisetus* , and *Chaetoceros* sp. [101]. *Thalassiosira decipiens* , *Thalassionema nitzschioides* , *Chaetoceros* sp. *Protoperidinium* sp. were dominant in January (Winter), *Thalassiosira decipiens, Thalassionema nitzschioides, Thalassiothrix frauenfeldii, Coscinodiscus* sp. *Protoperidinium* sp. were dominant in June (pre-monsoon) and *Skeletonema costatum, Thalassionema nitzschioides* , *Thalassiothrix frauenfeldii, Thalassiosira decipiens* were dominated in December (post-monsoon) in Kakinada Bay (SW coast of the Bay of Bengal) in 2012 [110].

The composition and relative quantity of phytoplankton varies from location to location, as well as from decade to decade in the Sundarbans region [84]. Here, diatoms were discovered to be more common than dinoflagellates throughout the seasons [84,92,111-114]. Centric diatoms genera such as *Coscinodiscus, Chaetoceros, Thalassiosira, and Cyclotella* , as well as pennate diatom genera such as *Navicula, Nitzschia, Pleurosigma,* and *Thalassionema* dominate the Sundarbans assemblage [84,111,113,115-117]. Dinophyta, Cyanophyta, and Chromophyta are present at different times of the year [92,112,117-119].

Temperature, salinity, pH, and macronutrient concentrations such as nitrate, phosphate, and silicate are all important regulators of phytoplankton biomass, productivity, and community structure [93,120-122]. The excess of two nutrients: phosphorus and nitrogen, which is typically created by nutrient runoff from land (animal waste, fertilizers, sewage), water pollution, particularly the discharge of poorly treated or untreated industrial waste into waterway, the exceedingly high temperatures experienced due to global warming increases the algae population in aquatic habitats where it is known as algal bloom [123,124]. According to a study of bloom occurrences in Indian waters from 1908 to 2009, a total of 101 instances have been documented [125]. Blooms have been caused by at least 39 different species, the most frequent of which being *Noctiluca scintillans* and *Trichodesmium erythraeum* . The blooming of *Cochlodinium polykrikoides, Karenia brevis, Karenia mikimotoi, Noctiluca scintillans, Trichodesmium erythraeum, Trichodesmium thiebautii, Gymnodinium nagasakiense* , and *Chattonella marina* has been linked to significant fish mortality in Indian seas (east and west coastal areas of India) [125-133]. In January 2015, a monospecies bloom of the diatom *Asterionellopsis glacialis* was found in the coastal waters of Kalpakkam, Tamil Nadu, India [134]. The impact of a multispecies bloom caused by the centric diatoms *Coscinodiscus radiatus* , *Chaetoceros lorenzianus* , and the pennate diatom *Thalassiothrix frauenfeldii* on phytoplankton and microzooplankton (the loricate ciliate tintinnids) was studied in the coastal regions of Sagar Island, the western part of Sundarban mangrove wetland, India [135].

A perspective on importance of marine phytoplankton research in Bangladesh:

Bangladesh is a small, yet heavily populated country in South Asia. The coastal zone of Bangladesh encompasses approximately 32% of the country, where 35 million people live. People live in the coastal towns and villages that include numerous small islands created at the interface of the rivers and BoB [27]. A large number of people (~3 million people) also live in the Sundarbans region [136]. The population here directly interacts with the coastal area for livelihood through fishing activities. At the same time, there is a continuous, large influx of tourists from home and abroad that visit this area for recreational purposes - specifically the Cox's Bazar, Sundarbans and St. Martin's Island are the most frequented places in this region. Phytoplankton community - namely eukaryotic and prokaryotic photosynthetic communities play a vital role in sustaining the primary production in the coastal region, and a key component of the marine food web. Given the unique biogeography of BoB coast and the extent of anthropogenic interactions with this region, understanding the phytoplankton population in this region remains a vital area of research which is largely under-explored till date.

Fishing is a key source of economic income in the coastal region. The BoB provides 15% of fishing out of all the fish yields in Bangladesh (DoF Fish Week 2020; http://fisheries.gov.bd/). It is well-recognized that fishery yields are constrained by primary production in an aquatic ecosystem [137]. Chlorophyll *a* as a proxy of primary production, has been strongly associated with fisheries yield in coastal areas in the Northwest Atlantic and several different fisheries areas, for example [138]. It is therefore important to understand the phytoplankton biomass, taxon-specific contribution to the phytoplankton biomass, the length of food chains connecting phytoplankton and fish, and efficiency of trophic transfers - for marine resource management in the coastal BoB. The strong seasonal influences and anthropogenic impact on the BoB coast of Bangladesh could lead to rapid changes in the phytoplankton dynamics in this region, thereby affecting the fisheries production within the short term. Understanding the temporality and spatial patterns in phytoplankton dynamics in this region is therefore of paramount importance to aid in the management of fisheries stocks.

Harmful algal blooms (HABs) in the coastal systems across the world cause significant ecological and economic impact, and increased anthropogenic input and global warming is predicted to increase the frequency and severity of such blooms [139,140]. HABs are a significant economic and public health concern for several reasons: toxic HAB species can kill fish and other marine animals through the direct action of toxin and hypoxia - thereby posing significant environmental and ecological concerns [141]. The toxin produced by HAB algae can move up the food chain leading to bioaccumulation that can affect public health [141]. The toxin can also cause illness to those who come into direct contact of the HAB infested water or the aerosols containing the toxins. Together, these can lead to significant ecological damage, economic loss and also loss of revenues from tourism. The coast of Bangladesh is heavily influenced by anthropogenic input, and thus is likely subject to HABs. Yet, research on the biological and physicochemical factors underpinning emergence of HABs in this region is largely absent. This is a major concern for a country subject to intensified climate change related hazards like inundation of the coastal landmass and increased severity and frequency of extreme weather events like cyclones and storm surges [142]. The BoB coast is generally poorly studied in this regard, and unpreparedness for expansion of HABs in poorly monitored areas will be a key concern in the future [143]. The coastal region of Bangladesh receives a large influx of nutrients from rivers, industrial and agricultural effluents, and activities like shrimp hatcheries, which can lead to eutrophication and intense growth of many harmful algal species. In addition, seasonal rainfall and occasional flood water can also carry nutrients of agricultural, industrial and sewage origin as runoff through the rivers that empty into the Bay. Limited data on HAB forming species in the coastal Bangladesh suggests that many potential HAB formers are present, including dinoflagellates *Dinophysis caudata* , *D. mitra* , *Alexandiraum catenella* ,*Linulodinium polyedrum* and *Gymnodinium coeruleum*[144]. Evidence of massive fish kill in the coastal region of Maheshkhali Island due to *D. caudata*bloom (>1.1X10^6 cells/L) also exists that goes back to 1998-1999 [144]. Studies in the coast of India have reported incidence of algal blooms going back to 1984 [132], and several studies from this region have reported presence of diverse potential HAB forming dinoflagellates in this region (see previous section for details). The enormous nutrient input in BoB coast, and the available data on the phytoplankton diversity suggests that algal blooms are possibly a frequent event in this region, which is possibly influenced by nutrient input from inland. It is also likely that many of the species, although not presently a HAB former, can act as a seed for future blooms due to population triggering physical processes like cyclones, eddies and intensified nutrient input [132]. Studying the phytoplankton diversity and monitoring the potential HAB forming species, their recurrence and toxin profile will significantly benefit the local economy and environment through forecasting, prevention and policy implementation.

From a public health point of view, algal blooms have another potentially deadly consequence for Bangladesh.

*Vibrio cholerae,*the causative agent of recurrent, massive cholera epidemics in Bangladesh is known to use diverse cyanobacteria and eukaryotic phytoplankton as environmental reservoirs [145]. The slime and surface films produced by some algal species can promote long term colonization and survival of *V. cholerae* species in the coastal waters. Blooms of algae fueled by increased nutrient input might allow rapid proliferation of the dormant forms of *V. cholerae* , which can rapidly assume transmissible and infectious states. This, along with extreme weather events like storm surge can carry the pathogenic *Vibrio* inland, which can contaminate the freshwater sources used by the people living in the coastal region [146]. Understanding the phytoplankton reservoirs and the mechanistic underpinning of the association of *Vibrio* with diverse phytoplankton and their long term persistence therefore has important implications for ensuring mitigation and prevention of cholera epidemics in the coastal regions of Bangladesh. Along with the diversity and seasonal dynamics of different phytoplankton, studies on the zooplankton and other species that might harbor *V. cholera* and how the species is transferred to carriers like mollusks, crustaceans and fishes are also necessary.

The coast of Bangladesh harbors crucial yet fragile ecosystems like the Sundarbans harboring the largest mangrove ecosystem in the world. 60% of the Sundarbans lies within Bangladesh, and approx 2.5 million people depend on this region for securing their livelihood [116]. Mangrove forests are extensively researched given importance as key carbon sinks, stabilizer of the coastal regions in the face of natural disasters, and nurseries and refuges for fishery resources. Microorganisms play important roles in delivering these services - and phytoplankton are crucial components of these microbial assemblages as primary producers. Primary production by phytoplankton sustain fishery resources in the mangrove, with higher larval retention and productivity in the mangrove regions compared to the adjacent marine environment [147]. Chromophytic phytoplankton, specifically diatoms dominate the phytoplankton assemblages in Sundarbans ecosystem - a study in the Sundarbans within Bangladesh identified as many as 134 phytoplankton species, out of which 99 were diatom species [116]. Studying the phytoplankton assemblages of Sundarbans is therefore important to understand the productivity, biogeochemical cycling and environmental health of this region. In addition, the highly dynamic nature of this ecosystem makes it an ideal study system to understand the adaptive and stress response of diverse phytoplankton to rapidly changing biotic and abiotic factors. Given the pivotal role of mangroves in coastal productivity and carbon sink, and the location of Sundarbans in a country extremely vulnerable to global warming and sea-level rise, there is scope to establish Sundarbans as a model mangrove ecosystem to study the response of phytoplankton as part of the mangrove microbiome to global climate change and anthropogenic activity.

Finally, a key point that needs to be made is that the role of viruses in modulating the phytoplankton population in this region remain largely unexplored. Viruses are an integral component of almost every environment where they can control algal and bacterial growth, thereby influencing global-scale biogeochemical cycles [148]. Viruses are known to be the most abundant biological entities on the planet, with an estimated ˜10^{30} viral particles in the global ocean [149]. Despite the importance of viruses in the marine ecosystem [150], not a single study to date looked at the role of viruses in modulating the phytoplankton population of coastal Bay of Bengal. Viruses infecting both prokaryotic and eukaryotic phytoplankton are abundant in the marine system, and they can vary greatly in size and nucleotide types. While viruses are generally considered much smaller than bacteria, recent studies revealed viruses that are extremely large, harbor up to thousands of genes, and are aptly known as 'giant viruses' [151,152]. Studies have indicated that numerous giant viruses infect important phototrophic and heterotrophic microbial eukaryotes in the ocean [153]. As viruses are thought to modulate ecological events like algal blooms, promote host diversity, and are key player in the biological carbon pump [154], understanding the diversity and dynamics of viruses, and their relationship with individual phytoplankton taxa remain a key aspect that is missing from the phytoplankton research efforts in the Bay of Bengal.

Competing interests:

The authors declare no competing interests.

Figure legends:

Figure 1: Maps representing seasonal variations in Chlorophyll a content, Salinity, and Sea Surface Temperature (SST) in the Bay of Bengal. Google Earth Engine was used to access the satellite data. Daily images were used and averaged to get the mean seasonal variations. ArcGIS pro software was used to visualize the data. Winter (December - February), Pre-monsoon (March – May), Monsoon (June – August), Post-monsoon (September – November).

Figure 1:

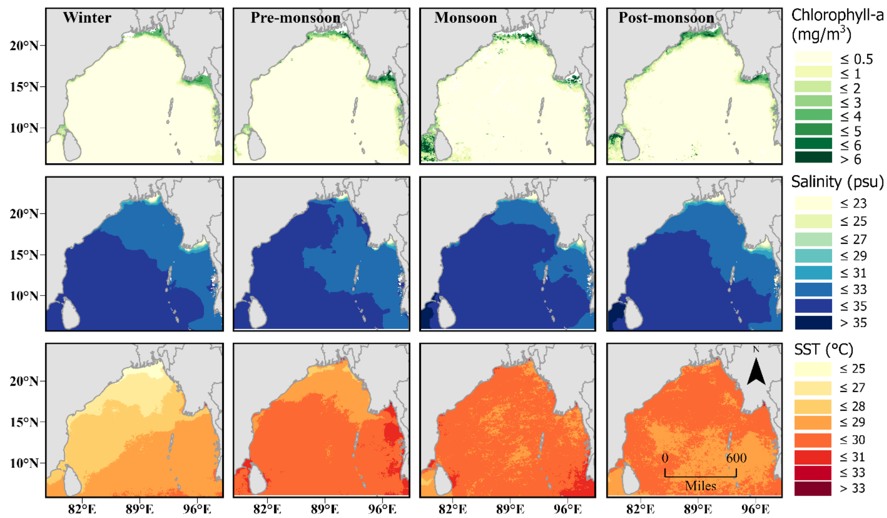

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Table 1: Phytoplankton diversity throughout the seasons in costal and offshore religions of Bay of Bengal (BoB).

Region and Classsification			Winter (December-February)	Pre-monsoon (March-May)	Monsoon (June-August)	Post-monsoon (September-November)
Area	Phyla	Classes	Genera	Genera	Genera	Genera
Coastal area	Bacillariophyta (Diatoms)	Coscinodiscophyceae (Centrales)	Bacteriastrum, Bellerochea, Biddulphia, Chaetoceros, Coscinodiscus, Ceratulina, Cocconeis, Ditylum, Diatoma, Ditulum, Fragilaria, Guinardia, Gomphonema, Gossleriella, Hemiaulus, Lampriscus, Lauderia, Leptocylindrus, Odontella, Palmeria, Proboscia, Pseudosolenia, Rhizosolenia, Skeletonema, Navicula, Stephanodiscus, Stephanopyxis, Streptotheca, Triceratium, Rhaphoneis, Schroederella, Bacteriostrum, Paralia, Schuettia, Thalassiosira	Bacteriastrum, Bellerochea, Biddulphia, Chaetoceros, Coscinodiscus, Cocconeis, Ditylum, Diatoma, Ditulum, Ceratulina, Fragilaria, Guinardia, Gomphonema, Gossleriella, Hemiaulus, Lampriscus, Lauderia, Navicula, Odontella, Palmeria, Paralia, Proboscia, Rhizosolenia, Skeletonema, Stephanodiscus, Stephanopyxis, Triceratium, Thalassiosira, Aulacodiscus, Rhaphoneis, Schroederella, Bacteriostrum	Actinocyclus, Aulacoseira, Bacteriastrum, Biddulphia , Chaetoceros, Coscinodiscus, Cocconeis, Climacosphenia, Ceratulina, Ditylum, Diatoma, Ditulum, Eucampia, Fragilaria, Guinardia, Gomphonema, Gossleriella, Hemiaulus, Helicotheca, Leptocylindrus, Pseudosolenia, Paralia, Navicula, Rhizosolenia, Skeletonema, Stephanodiscus, Stephanopyxis, Streptotheca, Thalassiosira, Rhaphoneis, Schroederella, Schuettia, Proboscia	Actinocyclus, Aulacoseira, Bacteriastrum, Bellerochea, Biddulphia, Chaetoceros, Climacosphenia, Ceratulina, Cocconeis, Coscinodiscus, Ditylum, Diatoma, Ditulum, Fragilaria, Gomphonema, Gossleriella, Guinardia, Hemiaulus, Lampriscus, Lauderia, Leptocylindrus, Odontella, Palmeria, Proboscia, Pseudosolenia, Navicula, Rhizosolenia, Skeletonema, Stephanodiscus, Stephanopyxis, Streptotheca, Triceratium, Bacteriostrum, Ceratualina, Paralia, Schuettia, Thalassiosira
		Bacillariophyceae (Pennales)	Amphipora, Amphipleura, Amphora, Bacillaria, Nitzschia, Pleurosigma, Gyrosigma, Cyclotella, Melosira, Odentella, Pinnularia, Planktonella, Synedra	Amphipora, Amphipleura, Amphora, Bacillaria, Nitzschia, Gyrosigma, Cyclotella, Surirella, Leptocylendrius, Melosira, Odentella, Pinnularia, Planktonella, Pleurosigma, Synedra	Amphipora, Amphipleura, Amphiprora, Actinocyclus, Amphora, Bacillaria, Nitzschia, Pleurosigma, Gyrosigma, Cyclotella, Synedra, Surirella, Diploneis, Leptocylendrius, Pinnularia, Planktonella	Amphipora, Amphipleura, Amphiprora, Amphora, Actinocyclus, Bacillaria, Nitzschia, Pleurosigma, Cyclotella, Surirella, Diploneis, Melosira, Odentella, Pinnularia, Planktonella, Synedra
		Fragilariophyceae (Pennales)	Asterionella Asterionellopsis, Thalassionema,	Asterionella, sterionellopsis, Thalassionema,	Asterionella, Asterionellopsis, Thalassionema,	Asterionellopsis, Thalassionema
		Dinophyceae	Alexandrium, Ceratium, Dinophysis, Peridinium, Prorocentrum, Protoperidinium, Porocentrum	Ceratium, Dinophysis, Gymnodinium, Peridinium, Prorocentrum, Protoperidinium, Porocentrum	Alexandrium, Ceratium, Peridinium, Protoperidinium, Peridinium, Prorocentrum, Porocentrum	Alexandrium, Ceratium, Dinophysis, Peridinium, Prorocentrum, Protoperidinium, Porocentrum
	Dinoflagellata (Dinoflagellates)	Cyanophyceae	Aphanocapsa, Chroococcus, Gloeocapsa, Trichodesmium, Anabaena, Microcystis, Oscillatoria, Spirulina	Aphanocapsa, Chroococcus, Gloeocapsa, Trichodesmium, Anabaena, Microcystis, Oscillatoria, Spirulina	Microcystis, Merismopedia, Anabena, Nostoc, Trichodesmium, Gomphosphaeria, Aphanocapsa, Gloeocapsa, Chroococcus, Oscillatoria, Spirulina	Aphanocapsa, Chroococcus, Gloeocapsa, Trichodesmium, Anabaena, Microcystis, Oscillatoria, Spirulina
	Cyanobacteria/ Cyanophyta (Blue-green algae)	Chlorophyceae	Chlorella, Chlamydomonas, Pediastrum, Ulothrix, Oedogonium, Monoraphidium, Microspora, Volvox	Chlorella, Chlamydomonas, Pediastrum, Ulothrix, Oedogonium, Monoraphidium, Microspora, Volvox	Chlorella, Chlamydomonas, Pediastrum, Ulothrix, Oedogonium, Monoraphidium, Microspora, Volvox	Chlorella, Chlamydomonas, Pediastrum, Ulothrix, Oedogonium, Monoraphidium, Microspora, Volvox
	Chlorophyta (Green algae)	Chrysophyceae (Golden algae, Silicoflagellate)	Distephanus	Distephanus	Distephanus	Distephanus
Offshore area	Chromophyta	Dictyochophyceae (Golden-brown algae, Silicoflagellate)	Dictyocha	Dictyocha	Dictyocha	Dictyocha

Figure 1: This is a caption