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Investigation of the Variation of Ocean Color and Phytoplankton Functional Types in the Bay of Bengal

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ABSTRACT: The monthly and inter annual variability of Ocean color products and Phytoplankton Functional Types (PFTs) are examined in the Bay of Bengal (BoB) from satellite data (2000-2020). Monthly Chlorophyll-a, Color Dissolved Organic Matter (CDOM), Photosynthetic Active Radiation (PAR) and Suspended Particulate Matter (SPM) data of merged satellites are used in this study. Ten PFTs (Microplankton, Nanoplankton, Picoplankton, Diatoms, Green Algae, Dinoflagellates, Prymnesiophytes, prokaryotes, pico-eukaryotes, Prochlorococcus; 3 phytoplankton size classes (PSC), 7 phytoplankton taxonomic compositions (PTC) are derived from individual monthly Chlorophyll-a. All data are averaged over the BoB region. We have found that the average Chlorophyll-a was decreasing (0.35 mg/m^3 to 0.25 mg/m^3) from the year of 2000 to 2020; whereas CDOM shows a sinusoidal relation from the year of 2000 to 2020; PAR has showed a decrease until 2014 then increase; SPM shows a rapid exponentially increasing trend from 2013. The highest Chlorophyll-a is found in the monsoon season (August) due to the high load of river discharge, cloudy environment, and associated favorable conditions; the lowest Chlorophyll-a is found in summer (April) due to the increased sunlight and PAR. Diatoms are the most dominant group in the BoB, which is going to be replaced by smaller planktons like Prochlorococcus species. Chlorophyll-a has a strong relationship with CDOM whereas PAR has a negative relationship with Chlorophyll-a and CDOM. Prokaryotes and Prochlorococcus have showed negative correlation with other functional groups.

Keywords: Ocean Color; Chlorophyll-a; CDOM; PAR; SPM; PFTs; PSC; PTC

INTRODUCTION

Satellite ocean color provides valuable information about the ocean from satellites that measure the color of the ocean surface. The data is mainly derived from the absorption and reflection of water and other constituents like phytoplankton, dissolved organic matter and sediments. In aquatic environments, phytoplankton are the main primary producers. Within the marine environment, they play a vital role in the carbon cycle, with their biomass production and sequestration nearly matching the combined output of all terrestrial plants (Field et al., 1998). Understanding the distribution of phytoplankton groups is essential for comprehending their role in marine ecosystems. Despite advancements in techniques for identifying and measuring phytoplankton diversity from space over the past two decades, their utilization remains somewhat restricted. Phytoplankton are categorized into various taxonomic groups, each characterized by distinct size, morphology, and pigment content. These attributes are influenced by factors such as physiological state, scattering, and light absorption, which can be observed through satellite-based detection methods.

In recent years, satellite remote sensing has enabled the determination of phytoplankton functional groups or community structure through a range of published methodologies. Numerous approaches have been devised to differentiate "phytoplankton functional types" (PFTs), facilitating the retrieval of diverse phytoplankton taxonomic compositions (PTC), phytoplankton size classes (PSC), and particle size distributions (PSD).

Algorithms have been developed on abundance- (Brewin et al., 2010, 2011; Hirata et al., 2011; Uitz et

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al., 2006), absorption (Bracher et al., 2009; Bricaud et al., 2012; Ciotti & Bricaud, 2006; Fujiwara et al., 2011; Hirata et al., 2008; Roy et al., 2013; Sadeghi et al., 2012), scattering-based (Kostadinov et al., 2009), and radiance-(Alvain et al., 2005, 2008; Li et al., 2013). PFTs are conceptual groups of phytoplankton species that share a common ecological function. Now a days, many satellite models are created to categorize algal cells according to the spatially observed optical variable. Plankton are classified into practical groups based on its biogeochemical roles to simplify the depiction of the enormous variation of plankton. Today there are different biogeochemical models that include typically three to ten functional plankton categories, including a few of the models can retrieve up to one hundred or more (Bopp et al., 2013; Laufkotter et al., 2015).

Phytoplankton can be represented as microplankton (>20μm), nanoplankton (<20μm and >2μm) and picoplankton (<2μm and >0.2μm) based on their size. The size class is the basis of taxonomic and functional groups. Microplanktons (diatoms, dinoflagellates) are the dominant group in coastal waters contributing to the fisheries whereas nano- (green algae, prymnesiophytes) and pico-planktons (prokaryotes, eukaryotes) are mainly found in the open ocean. In the offshore oligotrophic waters where nutrients are low, larger plankton cannot survive and smaller plankton contribute to the carbon cycling (Sammartino et al., 2015).

The distribution of PFTs is typically depicted using Chlorophyll-a, a fundamental component of phytoplankton, that are frequently used as a phytoplankton biomass indicator (Huot et al., 2007). While discrete sampling methods are unable to comprehensively cover the ocean both spatially and temporally, satellites offer a solution to this limitation. However, satellite-derived data require validation for accuracy. To achieve a global perspective, scientists utilize globally available pigment data collected from various research cruises to derive different phytoplankton groups, a method known as the abundance-based model (Hirata et al., 2011). Radiance-based models categorize PFTs according to their shape, magnitude, normalized water-leaving radiance (nLw(λ)) or the remote-sensing reflectance (Rrs(λ)) detected by satellites. The absorption-based models depend to the amount of phytoplankton absorption [$a_{ph}(\lambda)$] or some extent on the spectral response. Scattering-based models obtain data on all the particles, not just backscattering phytoplankton response. The (Hirata et al., 2011) abundance-based model has been used to calculate 10 PFTs (3 PSC, 7 PTC) from the Chlorophyll-a.

Presently, Phytoplankton ship-based research in the Bay of Bengal (BoB) is very limited, only few have been done in the East Indian coast. So, ocean color data is widely used for the chlorophyll-a estimation. Objective of this study is- (i) to investigate the phytoplankton concentration (chlorophyll-a) as well as PFTs in the BoB, (ii) to analyze chlorophyll-a along with Color Dissolved Organic Matter (CDOM), Photosynthetic Active Radiation (PAR), Suspended Particulate Matter (SPM), and (iii) to study the seasonal variation of the PFTs.

DATA AND METHODS

Study Area

BoB, the largest bay in the world, has several large rivers (The Ganges, Brahmaputra, Mahanadi, Krishna, Godavari, Kaveri, etc.) flowing into it (Fig. 1). On the northern part the Ganges-Brahmaputra-Meghna (GBM, the largest delta of the world) river adds lots of sediments to the bay and is responsible for the Bengal fan which extends up to 3000 km underwater. The GBM River is the main source of nutrients in the estuaries which are responsible for the growth of phytoplankton near the surface and subsurface waters along the coasts (Chowdhury et al., 2021). The freshwater inputs along with the nutrients and suspended particles make it highly dynamic and complex. Though this region has been studied very little till now. The BoB is familiar with various oceanographic processes along with massive freshwater discharge (Varkey et al., 1996). The bay is not productive as much as its adjacent Arabian Sea, where stratification causes nitrogen limitation and biological productivity is low (Gauns et al., 2005; Prasanna Kumar et al., 2007; Vinayachandran, 2009).

Satellite Data and Processing

Chlorophyll-a, Color Dissolved Organic Matter (CDOM), Photosynthetic Active Radiation (PAR) and Suspended Particulate Matter (SPM) data are used in this study. They are the monthly averaged level 3 (L3) data (resolution 4km) from 2000-2020. Data has been downloaded from (https://hermes.acri.fr/) the GlobColor project of European Space Agency (ESA).

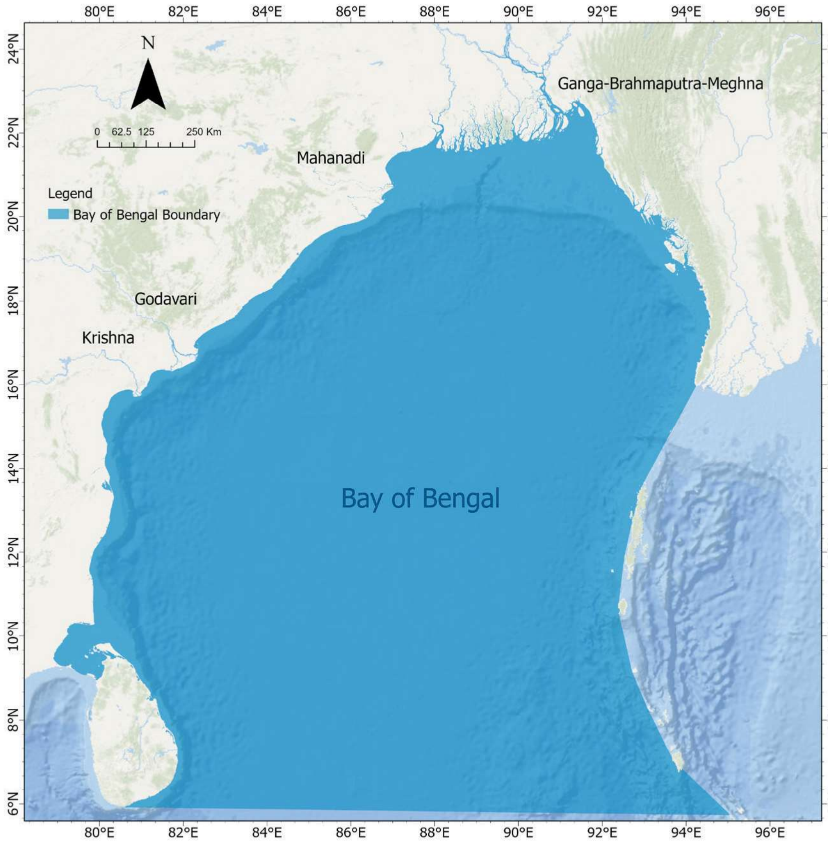


Figure 1: Bathymetry of the Study Area with the Boundary According to International Hydrographic Organization (IHO)

The datasets are merged from different ocean color satellite sensors including SeaWiFS (1997-2010), MODIS Aqua (2002-present), MERIS (2002-2012), VIIRS NPP (2012-present), OLCI-A (2016-present), VIIRS JPSS-1 (2017-present), OLCI-B (2019-present). These datasets are freely available for educational and research purposes. In this research, the chlorophyll a product CHL1 means "Case-1" waters where phytoplankton concentration dominates over inorganic particles. It has used Weighted Average Method (AVW) and Garver, Siegel and Maritorena Model (GSM) for L3 merging. Color Dissolved Organic Matter (CDOM) has used Average (AV) and GSM method at 443 nm reference wavelength, Suspended Particulate Matter (SPM) has used the AVW method and Photosynthetic Active Radiation (PAR) has used AV and AVW method for L3 merging. More details are in the globcolor product user guide (Garnesson et al., 2019).

The downloaded data are in NetCDF format, so R software is used for extracting the information. The data is averaged for the BoB region (Fig. 2, 5^{o} to 23^{o} N & 77^{o} to 95^{o}E). After that, the monthly average data is found for the entire region from 2000-2020. In this research, the seasons are assumed as summer (March-May), Monsoon (June-August), Autumn (September-November), and winter (December-February).

PFT Algorithm Overview

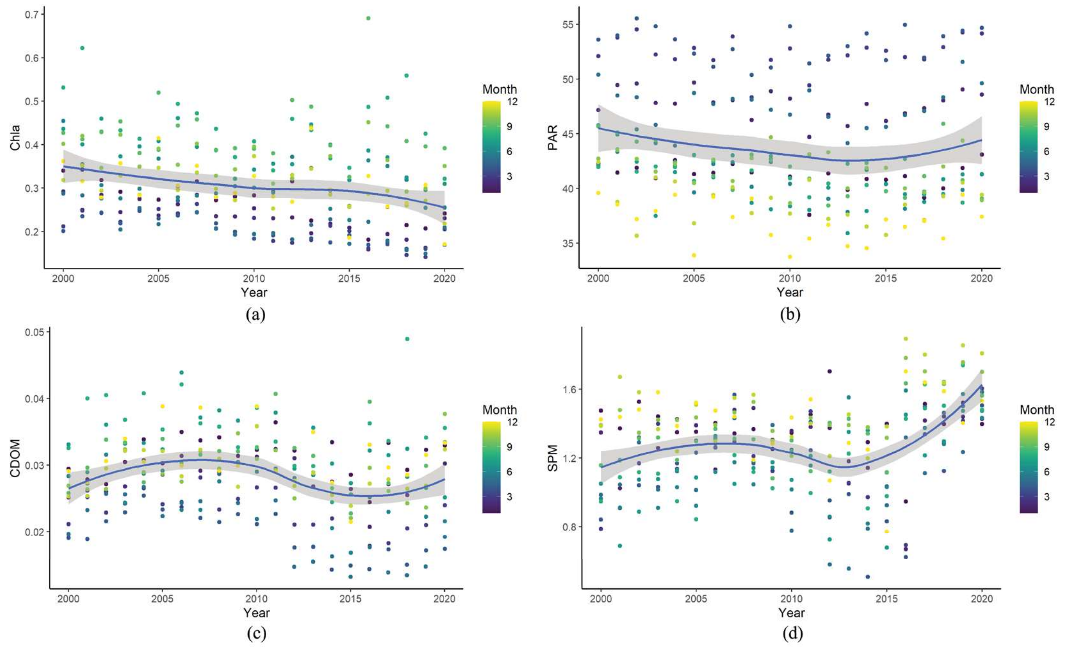
There are mainly four types of algorithms that derive PFTs from Chlorophyll which include abundance, absorption, scattering, and radiance based. Here, the (Hirata et al., 2011) algorithm which is abundance based is used to calculate 10 PFTs (microplankton, nanoplankton, picoplankton, diatoms, dinoflagellates, prokaryotes, pico-eukaryotes, prymnesiophytes, green algae, prochlorococcus) from the chlorophyll-a. The model uses pigment data of phytoplankton that are derived within High Performance Liquid Chromatography (HPLC) in situ data from the global ocean. This model used 3966 in-situ observations (the NERC AMT cruise, the JAMSTEC BEAGLE cruise, the NASA NOMAD, the NASA SeaBASS, the SEEDS II cruise, the HU Oshoro-maru cruise) where 70 percent was used for algorithm development and 30 percent was kept for validation.

(Hirata et al., 2011) PFT model equations are applied to monthly averaged Chlorophyll-a data to get the monthly PFTs of the region.

Result

Chlorophyll-a, PAR, CDOM, SPM Trend

The distribution of chlorophyll-a in the BoB is impacted by the phytoplanktonic organisms., following the succession of coastal areas with an increase in monsoon, a decrease in winter and lowest in the summer (Bandyopadhyay et al., 2017). The average Chlorophyll-a in the BoB shows a negative trend during the study period (Fig. 2a). Chlorophyll-a is minimum in the summer season when the temperature is higher and more active sunlight. Chlorophyll-a is maximum in the monsoon season when high nutrients are available from the river runoff. The yearly average Chlorophyll-a in the BoB decreased from 0.35 mg/m^3 to 0.25 mg/m^3 from 2000 to 2020. The average monthly Chlorophyll-a was low (0.141 mg/m^3) in March 2019 and high (0.690 mg/m^3) in September 2016. Rahman et al., (2019) showed that chlorophyll-a is relatively low in the open ocean and higher near the coasts of the BoB. Average PAR in the BoB showed a negative trend until 2014, and then a positive trend till 2020 is observed (Fig. 2b). PAR was higher in the summer and lower in the winter. The average PAR in the BoB was as low as 33.73 einstein/m^2/day in December 2010 and as high as 55.54 einstein/m^2/day in April 2002. During this timeline the average PAR was 43.64 einstein/m^2/day. Average CDOM showed a sinusoidal curve (Fig. 2c), where the CDOM was most likely to be affected by the river runoff. This might result from the climate and precipitation behavior in this region. The higher CDOM is found in the monsoon and lower in the summer season (Das et al., 2017). The average monthly CDOM was as low as 0.013 m^{-1} in May 2015 as high as 0.048 m^{-1} in August 2018. During this timeline the average CDOM of this region was 0.028 m^{-1}. Average SPM in the BoB increased exponentially from 2013, where it showed a positive trend from 2000 to 2007 then a negative trend from 2013 (Fig. 2d). Average SPM in this region is found to be as high as 1.89 g/m^3 in November 2016 and as low as 0.50 g/m^3 in April 2014. During this timeline the average SPM was 1.27 g/m^3.



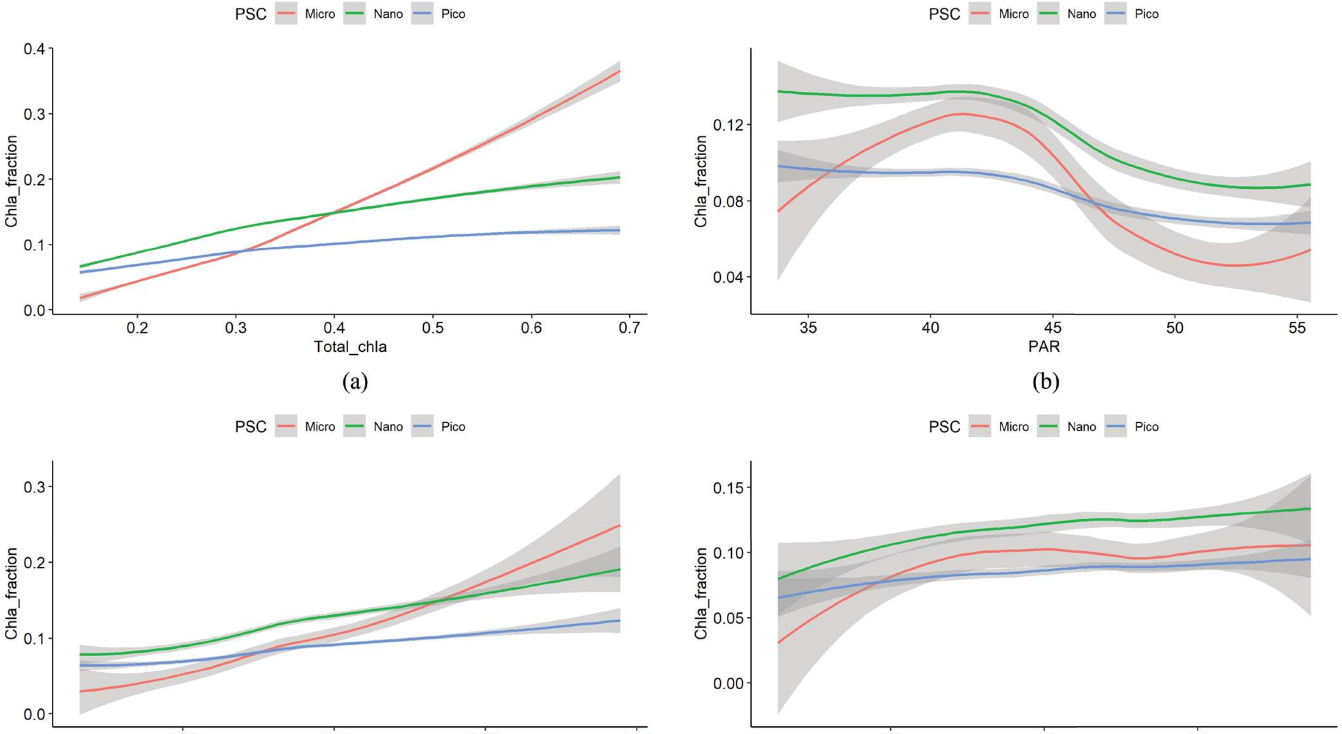
(a) (b)

(c) (d)

Figure 2: Ocean Color Trends in the BoB from 2000-2020; (a) Chlorophyll-a, (b) PAR, (c) CDOM, (d) SPM. The Color Dots Showing the Monthly Average of BoB, January (Dark Blue) to December (Yellow). Chlorophyll-a is Lowest in Summer and Highest in Monsoon and has Shown a Negative Trend While PAR is Highest in Summer and Lowest in Winter and has Shown a Negative Trend Until 2013. CDOM and SPM have Shown Similar Characteristics, Highest in Monsoon and Lowest in Summer. PAR has Shown a Unusual Exponential Trend after 2013

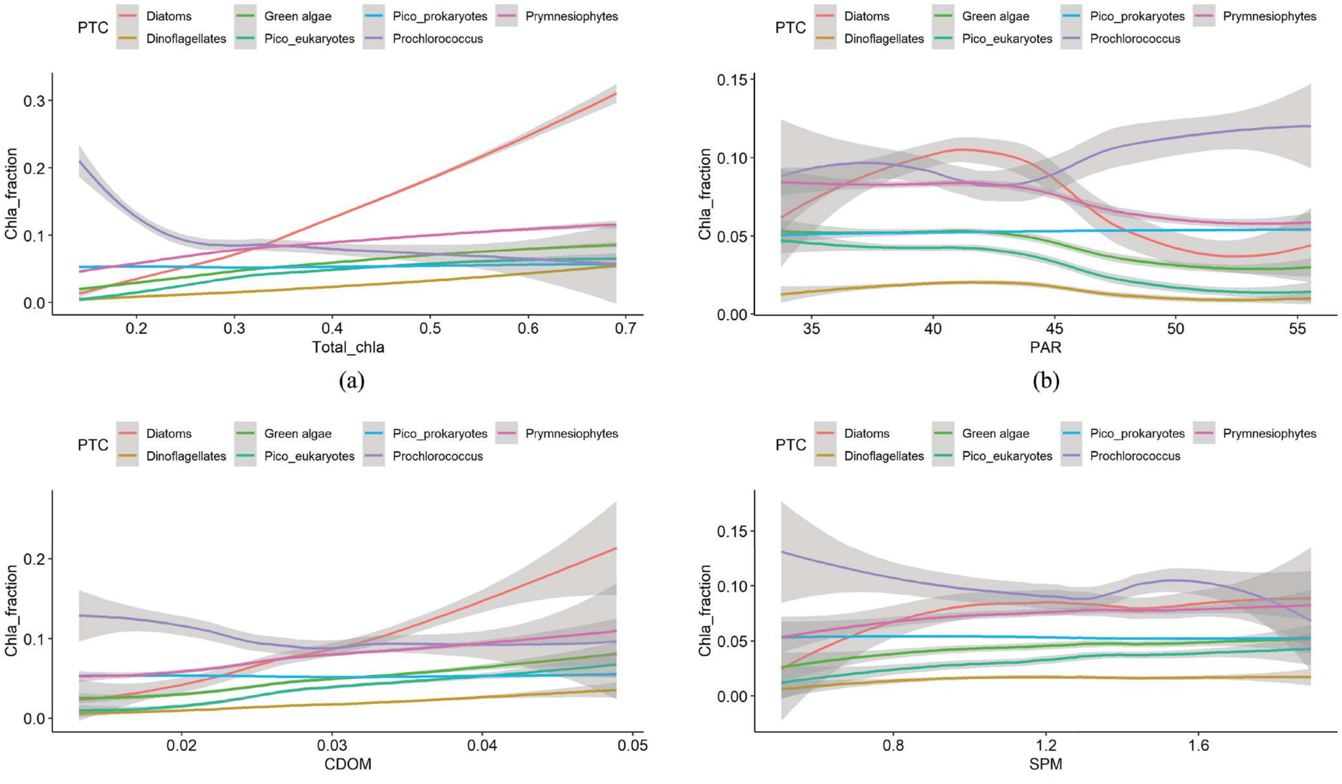
Variability of PFTs in the BoB

The BoB ecosystem heavily relies on the physical system and local processes. The PSC and PTC with the total Chlorophyll-a, CDOM, PAR and SPM are compared. Different PFTs have shown different behavior with different parameters. Compared to the PSC, it is observed that with the increase of total Chlorophyll-a microplankton, nano- and pico-plankton increased, but microplankton increased exponentially (Fig. 3a). This means microplankton mainly contributed to chlorophyll-a percentage. With the increase of average total Chlorophyll-a in the BoB, diatoms showed an exponential increase, Prochlorococcus showed an exponential decrease and then a normal decrease, other PTC were also increasing (Fig. 4a). When PAR was increasing nano- and pico-plankton was decreasing, but microplankton was increasing within a certain amount PAR and then decreased (Fig. 3b). With the increase of PAR diatoms showed a rapid increase and after a certain amount of PAR it decreased (Fig. 4b). Microplankton increased more rapidly with CDOM than nano- and pico-plankton (Fig. 3c). Diatoms were increasing exponentially with the increase of CDOM where Prochlorococcus showed a negative decrease, other PTC showed a normal increase (Fig. 4c). Prochlorococcus showed the opposite of diatoms, others showed a decrease and Pico prokaryotes had no effect at all. All PSC were increasing with SPM (Fig. 3d). While the SPM has been increasing, diatoms showed a rapid increase up to a certain level and then showed no effect at all, Prochlorococcus was decreasing, and other PTC were slightly increasing (Fig. 4d).



(a) (b) (c) (d)

Figure 3: Variability of PSC with (a) Chlorophyll-a, (b) PAR, (c) CDOM, and (d) SPM. With the Increase of Chlorophyll-a, All the Phytoplankton Size Classes are Increasing, But the Microplankton Showed More Positive Response Than the Others. Chlorophyll-a is Maximum at a Certain PAR (40-45 einstein/m²/day), After that it was Decreasing. With the Increase of CDOM and SPM the Micro-, Nano-, and Pico-Planktons are also Increasing



(a) (b)

(c) (d)

Figure 4: Variability of PTC with (a) Chlorophyll-a, (b) PAR, (c) CDOM, and (d) SPM

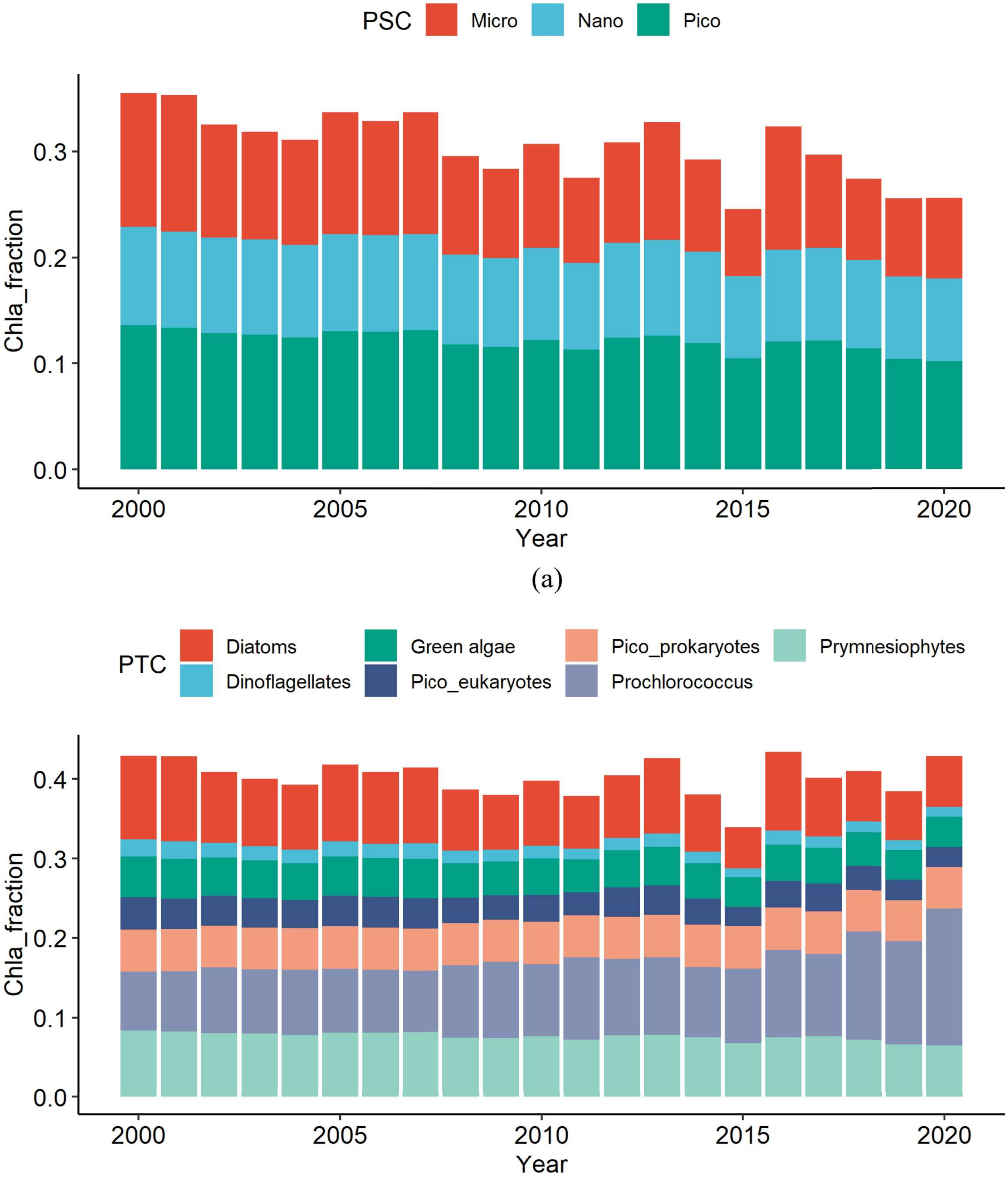
PFT Trend in the BoB

Chlorophyll-a was decreasing in the BoB, while phytoplankton size class and functional groups were also decreasing (Fig. 5a & 5b), but the dominant open ocean functional group Prochlorococcus was increasing (Fig. 5b).

The microplankton group showed the highest value 0.129 mg/m^3 in 2001 and it was decreasing, where it shows the lowest value 0.063 mg/m^3 in 2015, then a rapid increase occurred until 2016 and after that it decreased (Fig. 5a). Diatoms were the most dominant microplankton group in the BoB where it showed as high as 0.107 mg/m^3 and as low as 0.052 mg/m^3. Dinoflagellates showed as high as 0.022 mg/m^3 and as low as 0.011 mg/m^3 (Fig. 5b).

The nanoplanktons were the dominant size group in the BoB, which showed as high as 0.136 mg/m^3 in 2000 and as low as 0.102 mg/m^3 in 2015. It showed a gradual decrease in 4-5 years and then a sudden increase occurred and after that followed the decrease trend as well. But over time it has been decreasing (Fig. 5a). Green algae showed as high as 0.052 mg/m^3 and as low as 0.037 mg/m^3. Prymnesiophyte showed as high as 0.084 mg/m^3 and as low as 0.065 mg/m^3 (Fig. 5b).

Picoplankton has been found as high as 0.093 mg/m^3 in 2000 and as low as 0.078 mg/m^3 in 2015 (Fig. 5a). Prokaryotes showed as high as 0.054 mg/m^3 and as low as 0.052 mg/m^3. Pico eukaryotes were as high as 0.040 mg/m^3 and as low as 0.024 mg/m^3 (Fig. 5b). The Prochlorococcus group had been gradually increasing day by day from 2000 to 2020. It showed the lowest value 0.074 mg/m^3 in 2000 and highest value 0.173 mg/m^3 in 2020 (Fig. 5b). Nearly all PFTs have been showing the lowest in April and the highest in August except the prokaryotes and Prochlorococcus.



(a)

(b)

Figure 5: PFT Trend in the BoB; (a) PSC, (b) PTC. From 2000-2020, While Chlorophyll-a is Decreasing the Microplanktons are Decreasing More Rapidly. (b) Shows that the Diatoms are Decreasing Most, and Prochlorococcus Species are Showing Dominance

Seasonal and Year-to-Year Variability of Chlorophyll-a and PFTs in the BoB

To investigate the seasonal variability, the months of April and August have been used. April was the month of lowest Chlorophyll-a value/Phytoplankton biomass and August was the month of highest Chlorophyll-a value/Phytoplankton biomass. To see the fluctuation of Chlorophyll-a and PFTs, a five-year difference has been selected. A high Chlorophyll-a value was observed in 2000 and over the year it has been decreasing, so has the PFTs (Fig. 5, Fig. 2a).

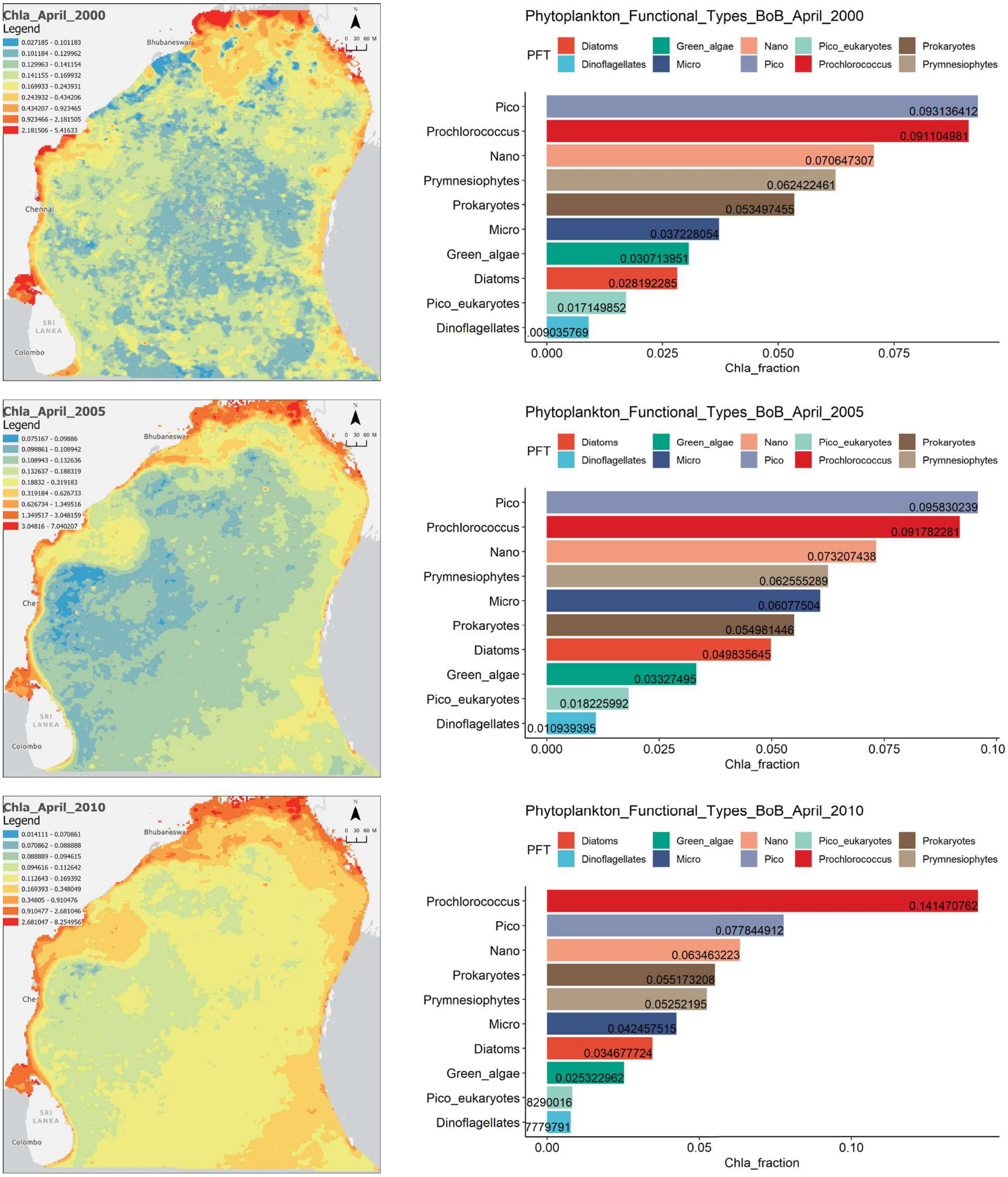


Figure 6a: Variation of Chlorophyll-a (left) and PFTs (right) in April from 2000-2010

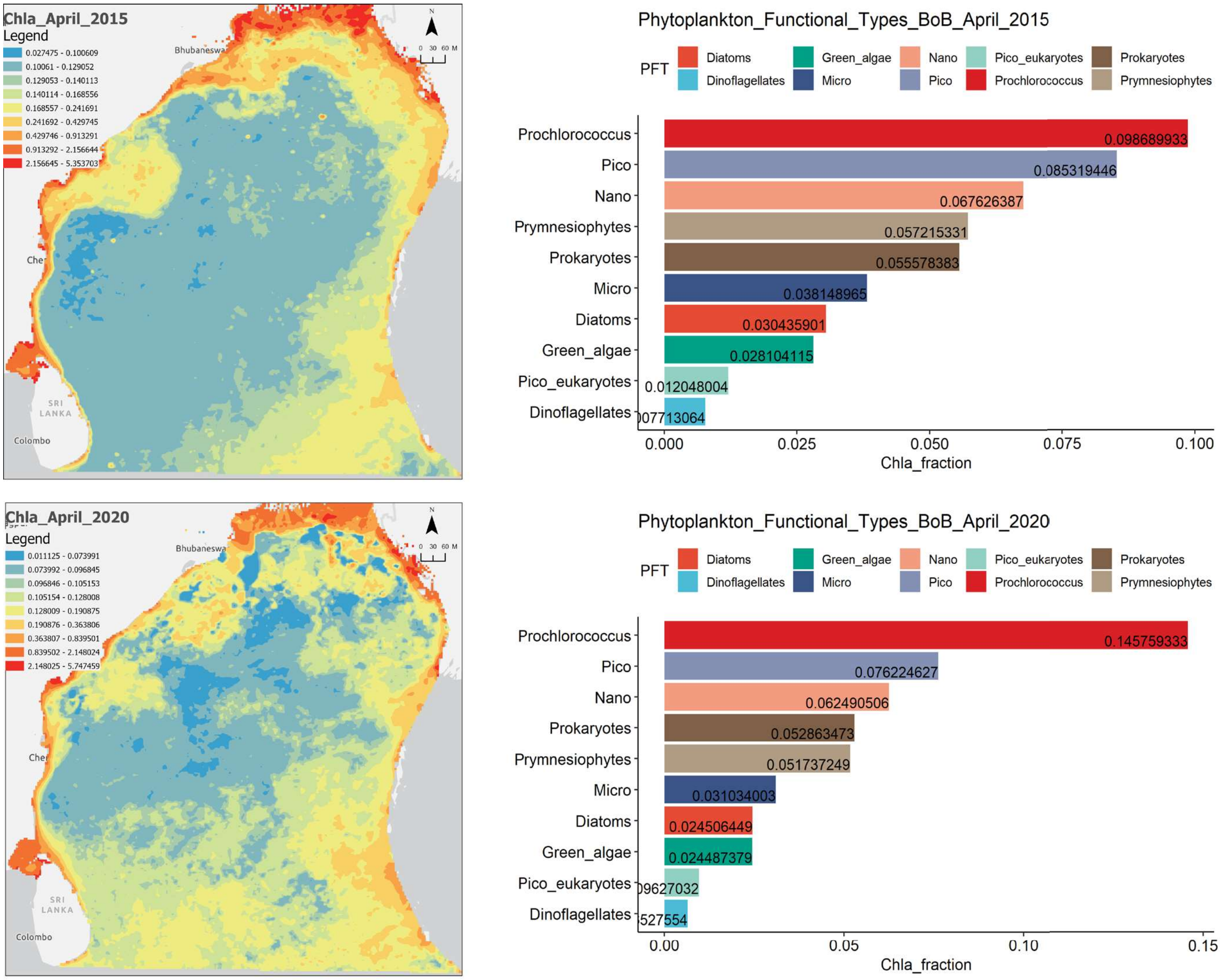


Figure 6b: Variation of Chlorophyll-a (left) and PFTs (right) in April from 2015-2020

Figure 6a and 6b shows that in the month of April, where there was low Chlorophyll-a, the picoplankton has been showing dominance and dinoflagellates were the least dominant group among all. From 2010-2020 the Prochlorococcus species has shown dominance.

Figure 7a and 7b shows that in the month of August, when Chlorophyll-a was at its peak, the microplankton were the dominant group, in which diatoms have been contributing most. But Dinoflagellates were the least dominant group in both April and August.

Chlorophyll was higher in the coastal part, especially in the northern Bay of Bengal and lower in the open ocean. In figure 6 and 7, the red color represents the larger planktons like diatoms and the blue color represents the smaller planktons like Prochlorococcus (spatial distribution of chlorophyll-a). And we can see with time the microplankton is decreasing and picoplankton dominates.

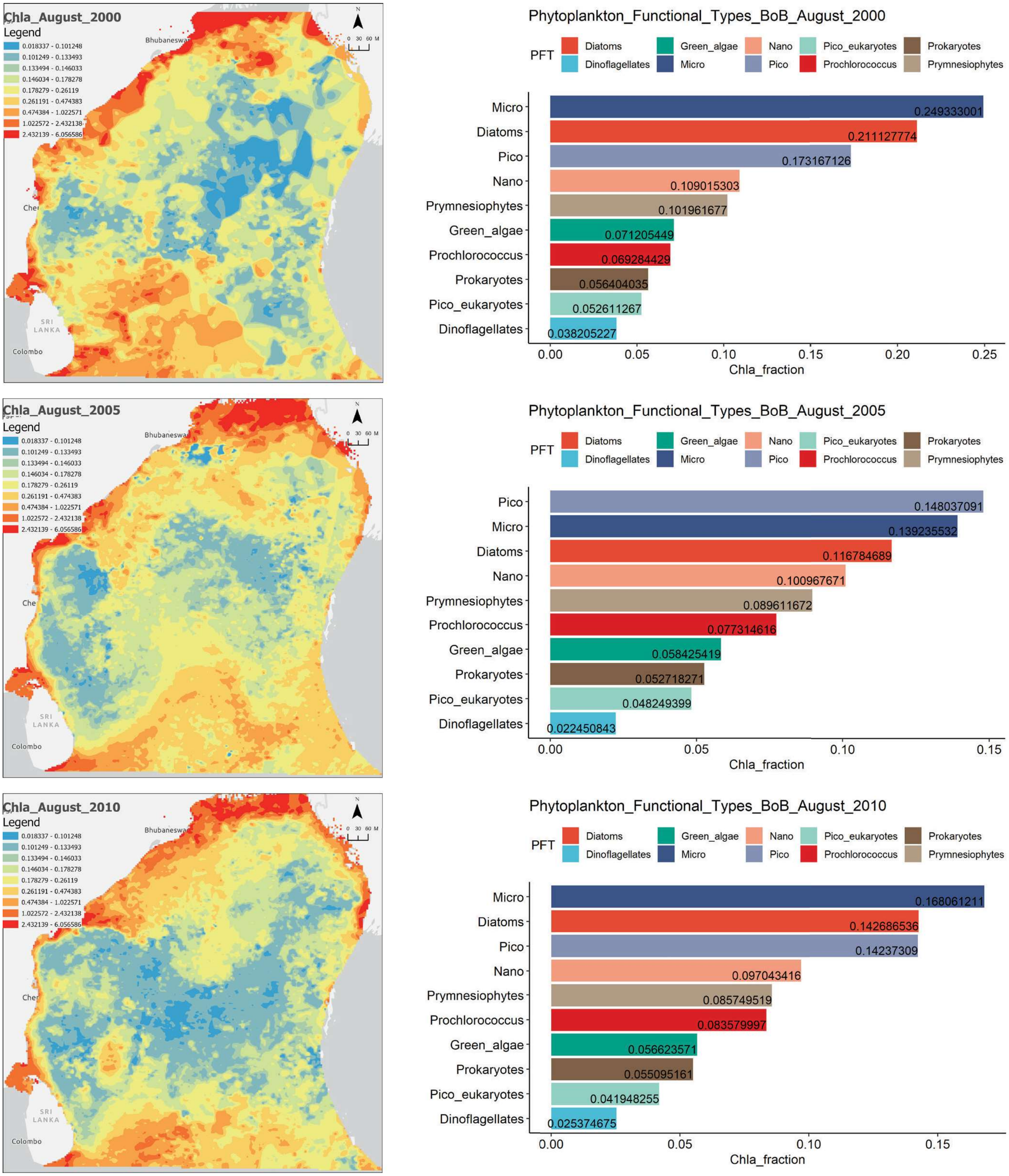


Figure 7a: Variation of Chlorophyll-a (left) and PFTs (right) in August from 2000-2010

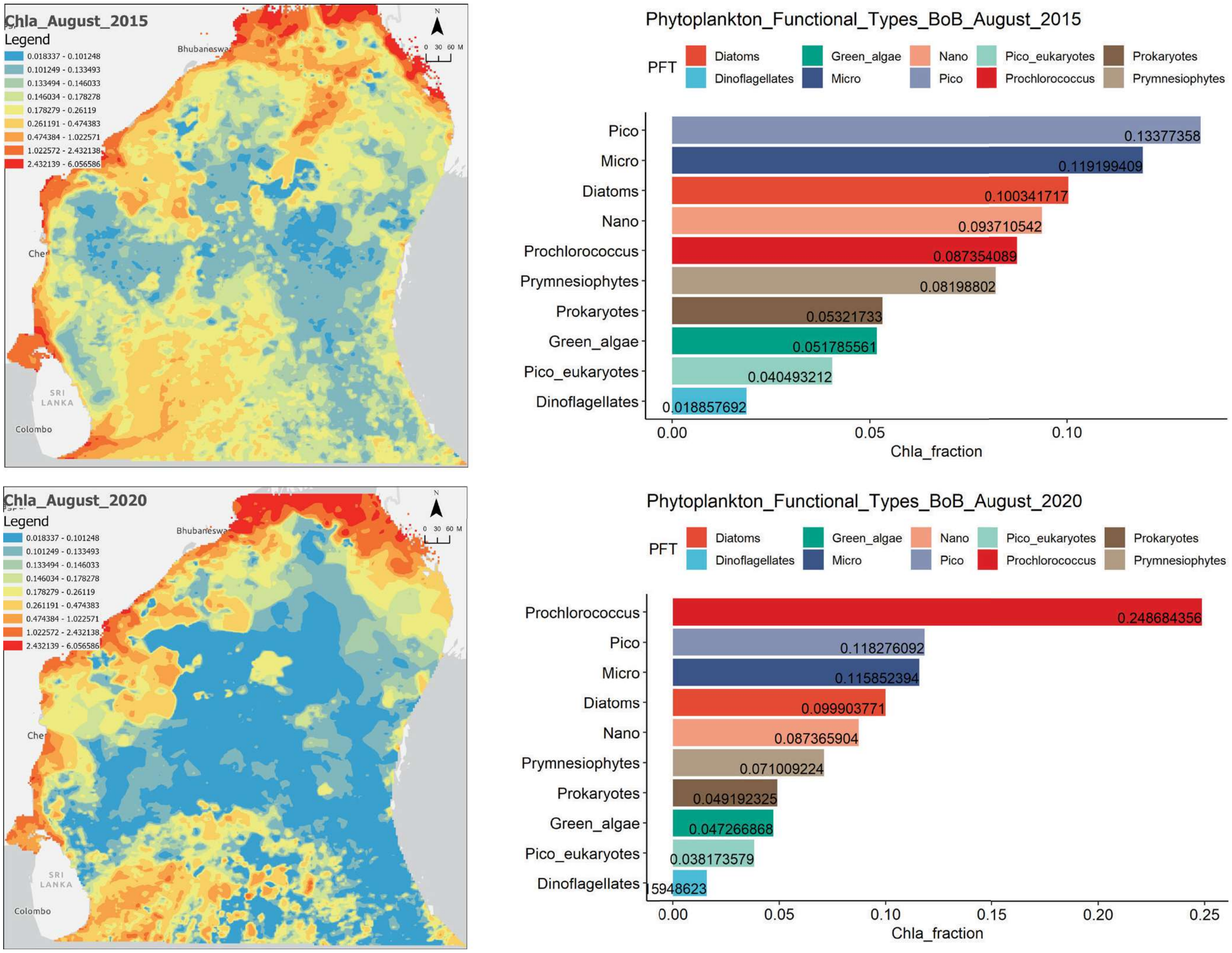


Figure 7b: Variation of Chlorophyll-a (left) and PFTs (right) in August from 2015-2020

In this research, the contribution of PFTs to the chlorophyll-a, CDOM, PAR and SPM over the BoB have been estimated by the abundance-based algorithm of (Hirata et al., 2011) for 2000-2020. Current study shows that Chlorophyll-a as well as the PFTs in the BoB have been declining over time, but the smaller phytoplankton has appeared to be dominant in the open ocean. Average phytoplankton biomass (Chlorophyll-a) in this region was declining at a rate of 0.005 mgm^{-3}/yr. The Prochlorococcus species were clearly overestimated. Several studies also found that the abundance-based model overestimates pico-phytoplankton concentrations usually in ultraoligotrophic (where nutrient concentration is low) and complex waters (Sahay et al., 2017; Sammartino et al., 2015). It has been found that more Chlorophyll-a in the coastal waters where there is enough nutrient from the rivers but less in the open ocean. Compared to the Arabian Sea, which is nearby, it is also less productive. The CDOM has shown a sinusoidal relationship over time. It may have a climatic effect. Some unusual effects from 2015 have been observed, where the SPM has been rapidly increasing, PAR was also increasing but the Chlorophyll-a was decreasing more. The unusual precipitation patterns and the floods from the upstream rivers have been accelerating the SPM (IPCC, 2021). Recently, there have been frequent floods in the GBM deltaic rivers especially in 2015 and 2017, may also lead to high SPM. PAR was more in the summer and less in the winter where it has shown a nearly negative trend from 2000 but positive since 2013 and has been rising.

It was found that Chlorophyll-a was lowest in April (summer) when there were high PAR and low CDOM, and Chlorophyll-a was highest in August (Monsoon) when there was high CDOM. Diatoms are the most dominant microplankton group in the BoB. It is observed that more Prochlorococcus occurred in 2020, but it might have overestimated the values of picoplankton, because the Prochlorococcus was one of the major species in the picoplankton group (prokaryote). Prochlorococcus (unicellular, cyanobacteria) is the most dominant photosynthetic organism on earth adapted to the nutrient poor conditions (Ulloa et al., 2021). (Fan et al., 2023) showed that due of their increased sensitivity to temperature, larger diatoms may perish from warming stress. So, global warming is also affecting the larger plankton groups which are very sensitive to temperature.

Comparing PSC and PTC with the total Chlorophyll-a, CDOM, PAR and SPM, similar patterns with the nano- and pico-plankton concentration are observed. Diatoms have been increasing rapidly with total Chlorophyll-a and other plankton groups were showing a slightly increase, following the abundance-based model that tells that when there is high Chlorophyll-a, the larger planktons will dominate and when there is low Chlorophyll-a, the smaller planktons will dominate. An increase of Chlorophyll-a with the increase of SPM is observed in this study, it might happen as we were comparing the average. In the coastal areas where there is high Chlorophyll-a, increased number of SPM can block the sunlight and decrease the photosynthetic activity. But in the open ocean where there is less Chlorophyll-a, the increased number of SPM will enhance productivity, as it helps to block the harmful UV radiation of sunlight. It may indicate the average Chlorophyll-a is switching from coastal to the open ocean and smaller planktons are taking dominance. PAR was also affecting the photosynthesis production of different PFTs. With the increase of PAR, after a certain limit diatom have shown a rapid decrease, while others were also decreasing, except Prochlorococcus.

Correlation Analysis

Figure 8 showed that there is a significant positive correlation (0.70) between Chlorophyll-a and CDOM whereas PAR shows strong negative correlation with Chlorophyll-a (-0.56) and CDOM (-0.59). This might occur when both Chlorophyll-a and CDOM are sourced from similar organic matter inputs, such as runoff from terrestrial vegetation or organic material produced within the aquatic ecosystem itself. High concentrations of CDOM can reduce the penetration of PAR into the water column, affecting the availability of light for photosynthesis. Consequently, CDOM concentrations and PAR levels frequently show a negative connection. Strong positive relationship was found among the PFTs except the Prokaryotes and Prochlorococcus (Fig. 9). These are the small planktonic groups, hence always found in the oligotrophic waters where there are low nutrients.

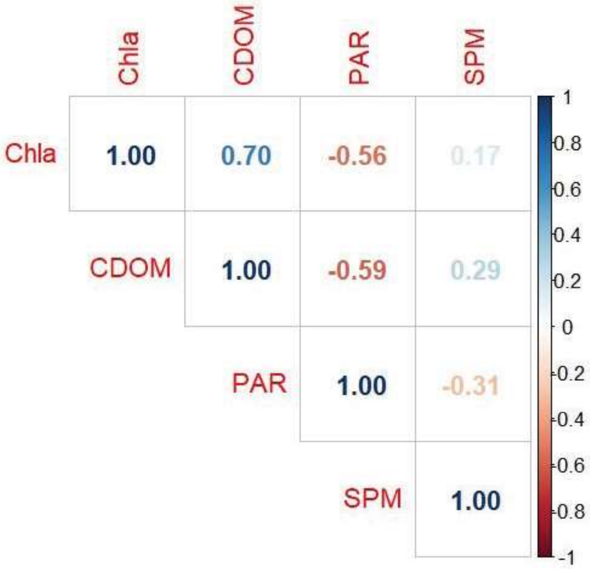
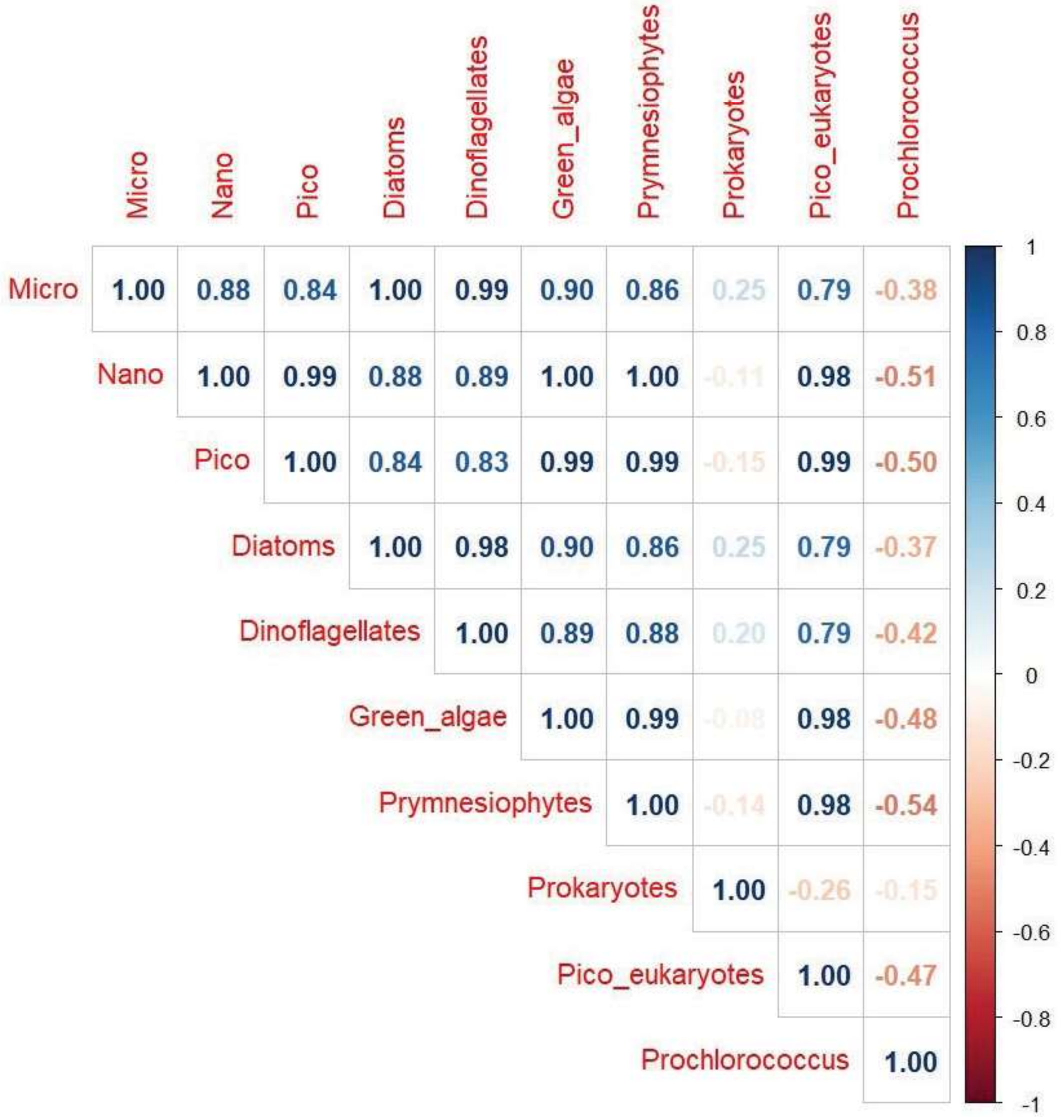


Figure 8: Correlation between Chlorophyll-a, CDOM, PAR, and SPM

DISCUSSION

The observed trends in Chlorophyll-a, PAR/SPM/CDOM highlight the dynamic nature of the BoB, shaped by both seasonal and long-term climatic influences.

Chlorophyll-a showed a decreasing trend over the study period, suggesting a decline in phytoplankton biomass, likely driven by rising sea temperatures and increased global carbon emissions due to climate change, consistent with previous studies (Gittings et al., 2018). Seasonally, Chlorophyll-a peaked during the monsoon, driven by nutrient-rich river runoff (Bandyopadhyay et al., 2017). PAR exhibited a seasonal pattern, lower in winter and higher in summer, reflecting the solar radiation cycle. The post-2014 increase in PAR may indicate atmospheric changes affecting light penetration.



	Micro	Nano	Pico	Diatoms	Dinoflagellates	Green_algae	Prymnesiophytes	Prokaryotes	Pico_eukaryotes	Prochlorococcus
Micro	1.00	0.88	0.84	1.00	0.99	0.90	0.86	0.25	0.79	-0.38
Nano		1.00	0.99	0.88	0.89	1.00	1.00	-0.11	0.98	-0.51
Pico			1.00	0.84	0.83	0.99	0.99	-0.15	0.99	-0.50
Diatoms				1.00	0.98	0.90	0.86	0.25	0.79	-0.37
Dinoflagellates					1.00	0.89	0.88	0.20	0.79	-0.42
Green_algae						1.00	0.99	-0.08	0.98	-0.48
Prymnesiophytes							1.00	-0.14	0.98	-0.54
Prokaryotes								1.00	-0.26	-0.15
Pico_eukaryotes									1.00	-0.47
Prochlorococcus										1.00

Figure 9: Correlation between PFTs

The sinusoidal trend in CDOM aligns with monsoonal river discharge patterns, suggesting that terrestrial inputs primarily drive CDOM levels in the BoB (Das et al., 2017). The complex trend in SPM is increasing from 2013 onwards—suggests shifts in sediment transport, possibly linked to anthropogenic activities or altered monsoonal patterns. Overall, these findings underscore the intricate interplay between climatic factors, riverine inputs, and oceanographic processes in shaping the biogeochemical characteristics of the BoB.

Regarding PFTs, different responses to environmental changes were observed. Microplankton, particularly diatoms, increased exponentially with rising Chlorophyll-a, indicating their dominance in nutrient-rich conditions (Bandyopadhyay et al., 2017). Conversely, Prochlorococcus, a smaller phytoplankton, thrived in oligotrophic (nutrient-poor) conditions, which became more prevalent as Chlorophyll-a decreased.

The relationship between PFTs and PAR highlighted that light availability is crucial for microplankton and diatoms, though excessive light may lead to photoinhibition or nutrient limitations (Das et al., 2017). C

DOM positively influenced diatoms, reflecting their ability to thrive in nutrient-rich conditions brought by riverine input. In contrast, Prochlorococcus showed a negative response to higher CDOM levels, preferring clearer waters (Sahay et al., 2017).

All PFTs generally increased with SPM, suggesting that suspended particles may enhance nutrient availability or provide surfaces for attachment, benefiting diatoms in particular. This trend might indicate a shift in phytoplankton dominance from coastal to open ocean areas, with smaller plankton becoming more prevalent under changing environmental conditions.

Overall, the study reveals that the BoB's phytoplankton community is undergoing significant changes, likely driven by global warming, altered nutrient dynamics, and shifting oceanographic processes (Fan et al., 2023; Ulloa et al., 2021). The region's main productivity and ecosystem dynamics will be significantly impacted by these findings. Further research is needed to explore these interactions and their broader ecological impacts.

It can be said that Phytoplankton biomass in the BoB is declining. Diatoms and Prochlorococcus are the two dominant species of the BoB: diatoms found in coastal waters and Prochlorococcus in open ocean. Microplanktons reduced almost 40% biomass as of 2000, but the Prochlorococcus species were about to rule in the BoB. One of the primary causes of the decline in chlorophyll-a, particularly in coastal waters, may be higher rates of SPM combined with climate impacts. Strong correlation between Chlorophyll-a and CDOM describes that the terrestrial source of CDOM influences the phytoplankton productivity. Smaller planktons like prokaryotes and Prochlorococcus occur in the oligotrophic waters as opposed to larger planktons.

CONCLUSIONS

Current study has given an overview of the total Chlorophyll-a and PFTs with other optical parameters (CDOM, PAR, SPM) in the BoB. Since BoB is one of the least studied areas, there is not enough dataset to validate the model. For the PFT validation, there was NOMAD dataset but only a few stations have been found and some pigments are also missing. Therefore, satellite products and the models are the only option. To achieve better accuracy of PFTs regionally, in the future the in-situ dataset collected from BOB will be used for validation of the abundance-based model.

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