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RESEARCH ARTICLE e-ISSN 2651-5326 ARAŞTIRMA MAKALESİ

Biodiversity and Abundance of Phytoplankton from Auranga Estuary, Valsad District, Gujarat, India

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Abstract: This study describes phytoplankton abundance and diversity from site 1 (downstream) and site 2 (upstream) of Auranga Estuary (20˚63’ N and 72˚82’ E). A Total of 44 species of phytoplankton were recorded, 35 species from downstream and 24 species from upstream. The assessed abundance was 129 cells/mL and 86 cells/mL from the downstream and upstream, respectively. Bacillariophyceae (19) was the dominant group followed by Chlorophyceae (10), Cyanobacteria (07), Dinophyceae (07), and Chrysophyceae (01). *Nitzschia*, *Coscinodiscus* and *Ceratium* were abundant genera at site 1 and *Spirogyra, Microcystis*, *Chlorella* and *Oscillatoria* were abundant at site 2. Nitzschiaceae and Zygnemataceae had highest family contribution at the downstream and upstream, respectively. Members of Bacillariophyceae and Cyanobacteria were present in high numbers throughout the year. The abundance of Chlorophyceae did not fluctuate greatly. Chrysophyceae (*Chromulina pascheri*) was observed during the summer period. Spatially, downstream had higher species diversity and abundance than upstream whereas winter season was favorable for plankton growth compared to summer and monsoon. Species dominance (Site 1: 0.238; Site 2: 0.257) richness (Site 1: 1.13; Site 2: 1.36), evenness (Site 1: 0.88; Site 2: 0.79) and diversity were assessed using alpha biodiversity indices. The Shannon diversity index was 1.417 and 1.268 for downstream and upstream, respectively. It indicates less diversity level in this estuary.

Key words: Phytoplankton, Diversity, Distribution, Seasonal Variations, Diversity Indices

Auranga Halici (Valsad Bölgesi, Gujarat, Hindistan)'nde Fitoplankton Biyoçeşitliliği ve Bolluğu

Özet: Bu çalışma, Auranga Haliç'in (20˚63' N ve 72˚82' E) 1. bölge (akıntı altı) ve 2. bölge (akıntı üstü) alanlarında fitoplankton bolluğu ve çeşitliliğini açıklamaktadır. 35 tür akıntı altından ve 24 tür akıntı üstünden olmak üzere toplam 44 fitoplankton türü kaydedilmiştir. Fitoplankton bolluğu akıntı altı ve akıntı üstünden sırasıyla 129 hücre/mL ve 86 hücre/mL olarak belirlenmiştir. Bacillariophyceae (19) baskın grup olup, onu sırasıyla Chlorophyceae (10), Cyanobacteria (07), Dinophyceae (07) ve Chrysophyceae (01) izlemiştir. *Nitzschia*, *Coscinodiscus* ve *Ceratium*, 1. bölgede ve *Spirogyra*, *Microcystis*, *Chlorella* ve *Oscillatoria*, 2. bölgede bol miktarda bulunmuştur. Nitzschiaceae ve Zygnemataceae, sırasıyla akıntı altı ve akıntı üstü en yüksek familya katkısına sahipti. Bacillariophyceae ve Cyanobacteria üyeleri yıl boyunca çok sayıda mevcuttu. Chlorophyceae'nin bolluğu büyük ölçüde dalgalanma göstermedi. Chrysophyceae (*Chromulina pascheri*) yaz döneminde gözlenmiştir. Mekansal olarak, akıntı altı, akıntı üstünden daha fazla tür çeşitliliğine ve bolluğuna sahipken, kış mevsimi, yaz ve musonla karşılaştırıldığında türlerin büyümesi için elverişliydi. Tür baskınlığı (1. Bölge: 0.238; 2. Bölge: 0.257) zenginlik (1. Bölge: 1.13; 2. Bölge: 1.36), doğruluk (1. Bölge: 0.88; 2. Bölge: 0.79) ve çeşitlilik, alfa biyoçeşitlilik indeksleri kullanılarak değerlendirilmiştir. Shannon çeşitlilik indeksi, akıntı altı ve akıntı üstü için sırasıyla 1.417 ve 1.268 olarak belirlenmiştir. Bu, Haliç'te daha az çeşitlilik seviyesini göstermektedir.

Anahtar kelimeler: Fitoplankton, Çeşitlilik, Dağılım, Mevsimsel Değişimler, Çeşitlilik Indeksleri

Introduction

Since estuaries have been called as the "Nurseries of the Sea", the proper monitoring of diversity and ecology of phytoplanktonic flora in estuaries is a major impetus for marine biological research in order to increase diversity of many species of fishes, benthos and birds that depend on estuaries for foraging and nesting areas. An estuary is a dynamic ecosystem that serves various ecological niches for living beings; it is a productive, nourishing area, a crucial source for biotic and abiotic elements. Unfortunately, in recent years, anthropogenic pressure is declining the biotic diversity reducing the health status of many estuaries in India. The release of enormous quantities of sewage into the estuarine ecosystems has caused considerable ecological imbalance and resulted in large scale disappearance of estuarine flora and fauna (Elliott & Whitfield, 2011). The plankton in estuaries include a great variety of species, even more so than in freshwater (Daborn & Redden, 2016). Phytoplankton include some of the bacteria, some protists and most single-celled as well as high number of multi-cellular microscopic plants in both marine and freshwater habitats. Common groups of phytoplankton are diatoms, blue-green algae, green algae, dinoflagellates and chalk-coated coccolithophores. Their microscopic sizes can be compensated by their enormous abundance and high productivity (Lalli & Parsons, 1997). Phytoplankton are extremely important from the standpoint of monitoring water quality since they are the first group to respond to changes in nutrient conditions in an ecosystem (Santhanam *et al.*, 2019). Thus, some phytoplankton species are widely used to assess the water quality (Thakur *et al.*, 2015). Plankton are the prime indicator species of health and wealth of an aquatic ecosystem (Singh *et al.*, 2013). It is evident that phytoplankton removes carbon more efficiently than terrestrial plants and thereby helps in the control of global warming (Santhanam *et al.*, 2019). The phytoplankton assemblages are highly diverse with the seasonal fluctuations in ecological niches (Nowrouzi & Valavi, 2011). Usually, the diversity of phytoplankton is higher in coastal environments due to the high amount of nutrients. The spatiotemporal pattern has an immense impact on the water quality. The qualitative and quantitative evaluation of phytoplankton highlight the existence and diversity of heterotrophic organisms; in tropical estuaries, the phytoplankton assemblages are strongly influenced by water stratification and meteorological system (Narmada *et al.*, 2015). According to Oseji et. al., (2019), the productivity and structure of an aquatic ecosystem is dependent on the variety of species and abundance of phytoplankton. The variety and relative abundance of species are the components incorporated in diversity (Hosmani, 2010). However, comprehending species diversity based on a single parameter is very difficult; thus ecologists have established several other diversity models and indices to help understand it easier. Specifically, alpha diversity indices are useful tools for monitoring the trophic systems. Diversity indices that are used to assess ecosystems consist richness, abundance, and evenness (Meng *et al.*, 2020).

In earlier studies, Thakur *et. al*., (2015), Sarvankumar *et. al*., (2008), Ram, (1991), Ram *et. al*., (1988), Kardani, (2011), George *et. al*., (2015), and George *et. al.*, (2012) investigated the phytoplanktonic flora in different estuarine systems of Gujarat state. The present study focuses on seasonal and temporal variations of the biodiversity and composition of the phytoplankton community in Auranga Estuary of Gujarat state, which have not been adequately described yet. Auranga Estuary is dissected with creek systems forming extensive mudflats covered with mangroves. Although industrial inputs are limited, Auranga Estuary is subject to anthropogenic pressure due to the biggest dumpsite of Valsad. The Tithal seashore nearby Auranga Estuary is dominated by tourism and is also being promoted for eco-tourism by the state government. The aim of the present study was to investigate phytoplankton species diversity, abundance and its temporal variation in the Auranga Estuary, west coast of India. The sites were selected on the basis of confluence of fresh fluvial water from upper reaches and coastal water from lower reaches as well as earlier screening process.

Materials and Methods

Study Area

Auranga River originates near Bhervi village and flows via Valsad city and finally reaches the Arabian Sea. Geographically, Auranga Estuary is located at 20˚63’ N and 72˚82’ E with an altitude of 614m (Narmada, Water resources, Water supply and Kalpsar Department, Gujarat, 2010). The River is 97 km long with a catchment area of 699 sq/km. It is exposed to high anthropogenic pressure with the biggest dumping site present nearby this Estuary and little industrial pressure. The selected sites for the present study were (1) Downstream- Near Divadandi light house, Kosamba (20˚63’28" N and 72˚89’37' E) and (2) Upstream- Near Lilapore Causeway (20˚62’96” N and 72˚92’30” E) with distance of approximate 3 - 4 km (Figure 1).

Sampling

The phytoplankton samples were collected bimonthly from a depth of 0.5-8 m during the period from January 2019 to December 2019 covering three consecutive seasons: winter, summer and monsoon. The samples were collected from the northern bank to the southern bank of the selected sites of the Auranga Estuary by a boat using plankton net of 20 µ mesh size made up of bolting silk. A total 50 L of sample collected from each site and concentrated to 100 ml through the plankton net (Narmada *et al.*, 2015).

Hydro-chemical parameters including water temperature, pH, and salinity were measured by a thermometer (Bel-Art; Model: B60800-3100), a digital pH meter (pHep®: Hanna instruments) and titration method respectively. In situ dissolved oxygen (DO) was measured by the Winkler method. Nitrate and phosphate levels were measured with a spectrophotometer (Model: 302).

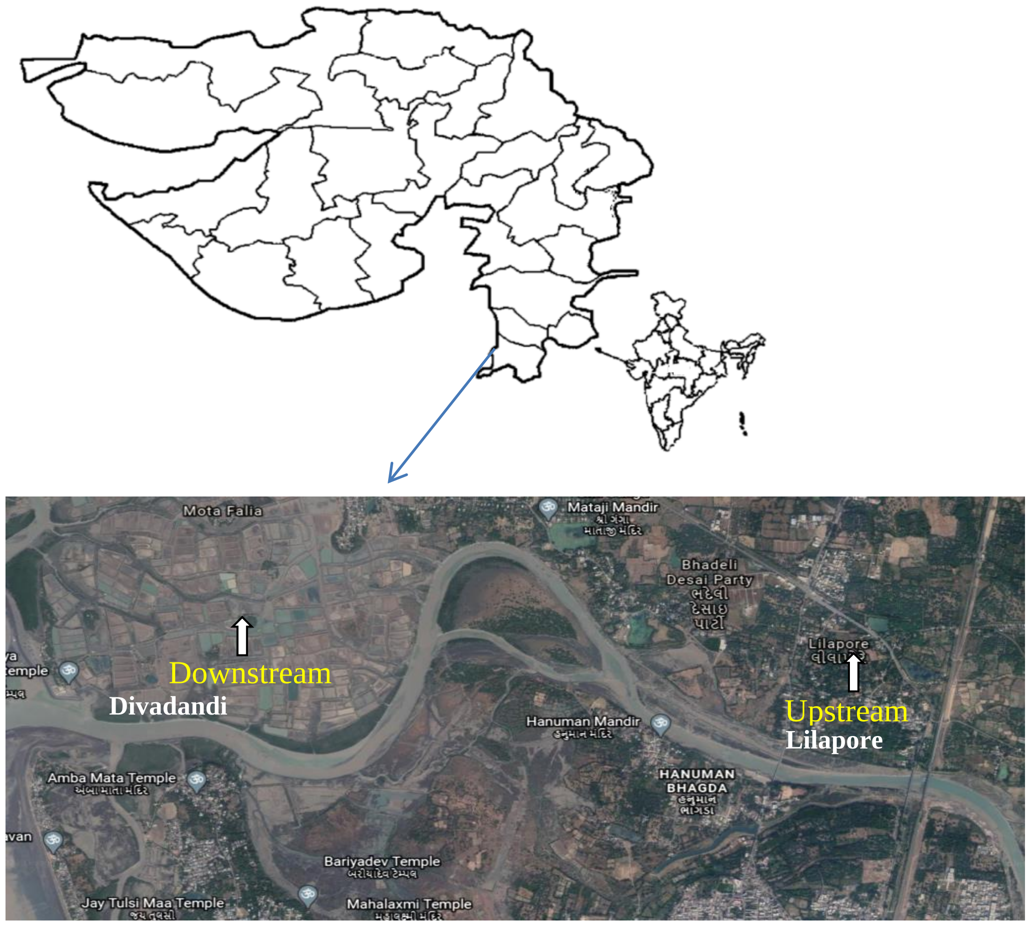


Figure 1. Selected sites from Auranga Estuary, Valsad, Gujarat (Narmada, Water resources, Water supply and Kalpsar Department, Gujarat, 2010).

Samples Analysis

The phytoplankton samples were preserved in 4% formalin and used for future quantitative and qualitative analysis (George *et al.,* 2015). A light microscope (LABOMED STC-HL) was used for qualitative plankton analysis and quantitative analysis were performed by Sedgwick-Rafter chamber. The abundance of phytoplankton is expressed as cell numbers per milliliter (cells/mL) (Baliarsingh *et al.*, 2015). Taxonomic studies of phytoplankton were carried out by using standard references (Joshi *et al.*, 2018; Gopinathan *et al.*, 2007; Hendey, 1957; Bellinger & Sigee, 2010; Taylor *et al.*, 2007). Quantitative analysis like species abundance, relative abundance, percentage composition and diversity indices and qualitative analysis such as species diversity, distribution and family contribution of phytoplankton data were evaluated.

Statistical Analysis

The PAST (Paleontological Statistics; software 3.0 version) was used for statistical analysis such as distribution matrix, statistical summary of spatial and temporal abundance, alpha diversity indices (Simpson Dominance index, Shannon Wiener diversity index, Pielou's evenness index, Margalef richness index). Single factor analysis of variance was used for diversity indices of the collected data.

Result and Discussion

Temporal distribution of phytoplankton species and community structure was dynamic and variable. In the present study, a total of 44 phytoplankton taxa were recorded from both sites of Auranga Estuary, out of which 35 species from St 1 (downstream) and 24 species from St 2 (upstream) were recorded (Table 1). Bacillariophyceae (14) had the highest number of taxa followed by Chlorophyceae (7), Dinophyceae (7), Cyanobacteria (6), and Chrysophyceae (1) at downstream, while at upstream, Bacillariophyceae (9) had more number of organisms followed by Chlorophyceae (8), Cyanobacteria (4), Dinophyceae (2) and Chrysophyceae (1) (Table 1). Similarly, in northern Kuchchh region, Gujarat, a total of 88 species of phytoplankton including pennate diatoms, centric diatoms, dinoflagellates and cyanobacteria were recorded (Kardani, 2011). Also 104 species including diatoms (82), dinoflagellates (16), blue-green algae (3) and green alga (2) were reported from the western mangrove, Kuchchh, (Thakur *et al.*, 2015). Waghmare & Kulkarni (2015) reported 20 genera including diatoms, green algae and blue-green algae from Lendi River, Maharashtra. Genera such as *Nitzschia*, *Coscinodiscus* and *Ceratium* were more abundant at the downstream whereas *Spirogyra*, *Microcystis*, and *Nostoc* were the abundant genera at the upstream represented with higher number of individuals. Commonly, *Nitzschia linearis*, *Coscinodiscus radiatus*, *Chaetoceros sp.*, *Spirogyra porticalis*, *Oscillatoria formosa*, *Chlorella vulgaris* and *Microsystis aeruginosa* habitually occurred at both sites of Auranga Estuary throughout the study period (Table 1).

Table1. List of recorded phytoplankton species

Species Name	St 1	St 2	Species Name	St 1	St 2
Bacillariophyceae			*Coelastrum microporum*	+	+
Family: Nitzschiaceae			Family: Chlorellaceae		
Psuedo-nitzschia australis	-	+	*Chlorella vulgaris*	+	+
Nitzschia sigmoidea	+	-	Family: Cladophoraceae		
Nitzschia fonticola	+	-	*Chaetomorpha ligustica*	-	+
Nitzschia linearis	+	+	Family: Ulotrichaceae		
Nitzschia reversa	+	-	*Ulothrix sp.*	-	+
Family: Naviculaceae			Family: Chlorosarcinaceae		
Navicula salinarum	+	-	*Chlorosarcinopsis variabilis*	+	-
Navicula transitans	-	+	**Cyanobacteria**		
Navicula radiosa	-	+	Family: Nostocaceae		
Family: Leptocylindraceae			*Nostoc commune*	+	+
Leptocylindrus danicus	-	+	*Aphanizomenon flos-aquae*	+	-
Leptocylindrus minimus	+	-	Family: Oscillatoriaceae		
Family: Coscinodiscaceae			*Lyngbya aestuarii*	+	-
Coscinodiscus radiatus	+	+	Family: Microcoleaceae		
Coscinodiscus centralis	+	-	*Kamptonema formosum*	+	+
Family: Pinnulariaceae			*Microcoleus vaginatus*	-	+
Pinnularia subrostrata	+	-	Family: Microcystaceae		
Pinnularia viridis	-	+	*Microcystis viridis*	+	-
Family: Skeletonemaceae			*Microcystis aeruginosa*	+	+
Skeletonema costatum	+	-	**Dinophyceae**		
Family: Melosiraceae			Family: Prorocentraceae		
Melosira varians	+	+	*Prorocentrum emerginatum*	+	-
Family: Cymbellaceae			*Prorocentrum minimum*	+	-
Cymbella mexicana	+	-	Family: Protoperidiniaceae		
Family: Bacillariaceae			*Protoperidinium claudicans*	+	-
Cylindrotheca closterium	+	-	Family: Ceratiaceae		
Family: Chaetocerotaceae			*Ceratium sp.*	+	+
Chaetoceros sp.	+	+	*Ceratium fusus*	+	-
Chlorophyceae			Family: Peridiniaceae		
Family: Zygnemataceae			*Scrippsiella trochoidea*	+	-
Spirogyra porticalis	+	+	Family: Polykikaceae		
Spirogyra tenuissima	+	+	*Polykrikos schwartzii*	+	+
Spirogyra communis	+	+	**Chrysophyceae**		
Spirogyra corrugata	-	+	Family: Chromulinaceae		
Family: Scenedesmaceae			*Chromulina pascheri*	+	+
Scenedesmus serratus	+	-	**Total**	**35**	**24**

(St 1- downstream; St 2- upstream)

Among the phytoplankton, Bacillariophyceae had the highest species composition represented by 40% taxa at the downstream and 37.50% taxa at the upstream. The composition of Bacillariophyceae was almost similar at both sites but the entire phytoplankton community varied with diverse taxa in both sites. Chlorophyceae and Dinophyceae had similar species composition (20%) at the downstream, while Chlorophyceae had the second highest species composition (33.33%) and Dinophyceae had the second lowest species composition (8.33%) at the upstream. The species composition of Cyanobacteria was 17.14% and 16.67% at the downstream and the upstream, respectively. The lowest species composition was represented by Chrysophyceae which was 4.17% and 2.86% at the upstream and downstream, respectively (Figure 2). Among these Bacillariophyceae was the dominant group followed by Chlorophyceae, Cyanobacteria, Dinophyceae and Chrysophyceae. At similar result was reported from the Narmada River near Zadeshwar, Bharuch, as Bacillariophyceae > Chlorophyceae > Cyanobacteria > Euglenophyceae in decreasing order of number of species (George *et al.*, 2015) and from the river of Andhra Pradesh (Venkateswarlu, 1986). In present study, diatoms were the dominant group and were found throughout the year at both sites of Auranga Estuary. This observation agreed with findings by others who reported Bacillariophyceae as the dominant group, i.e., in the Pearl River Estuary, South China (Zhang *et al.*, 2014); in the Cross River Estuary of Nigeria (Ekwu & Sikoki, 2006); in the Muthupettai, South east coast of India (Babu *et al.*, 2013); in the Tapi River, Surat, Gujarat (Sarang & Manoj, 2017); Gulf of Kuchchh (Thakur *et al.*, 2015). The species composition of Chlorophyceae and Cyanobacteria fluctuated in the Auranga Estuary. A similar observation was noted in the Tapi River, Surat, Gujarat (Sarang & Manoj, 2017). Moore (1974) stated that Bacillariophyta are common in epipelic communities.

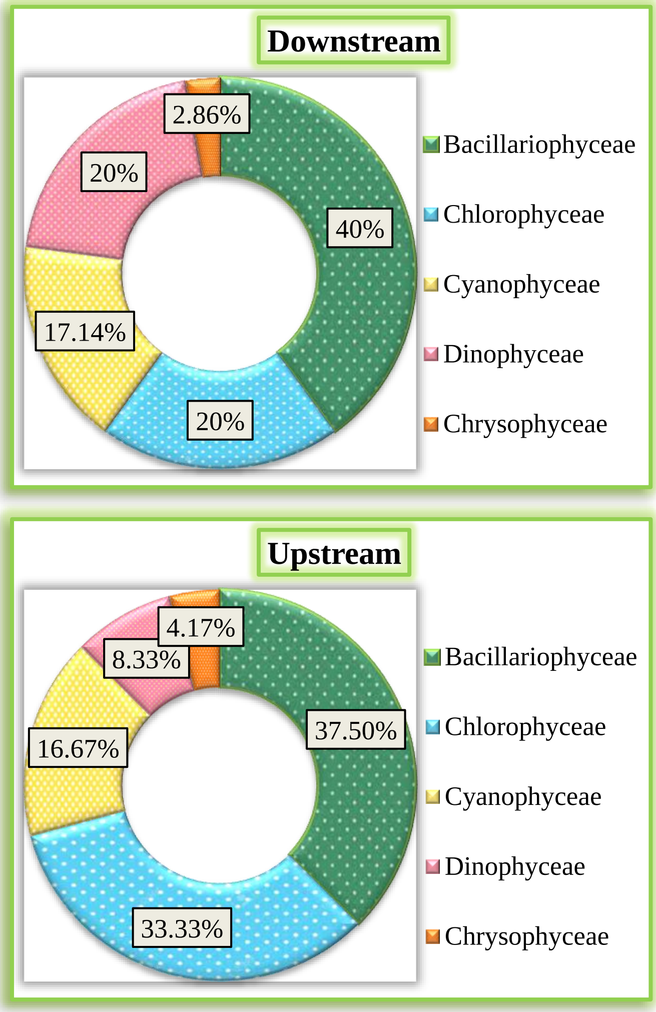


Figure 2. Percentage composition of phytoplankton taxa

The distribution of different phytoplankton is represented by the matrix plot (Figure 3). Chrysophyceae exhibited similar distribution scale in both stations. Dinophyceae and Cyanobacteria were higher in downstream than in upstream. In contrast, Chlorophyceae was in higher proportion at the upstream site while less at the downstream site. Bacillariophyceae were represented by the highest and second highest distribution at the downstream and the upstream station, respectively (Figure 3). Bacillariophyta was found throughout the year in in Dhamra River Estuary of Odisha Coast, Bay of Bengal (Palleyi & Panda, 2011) and in Tapi River, Surat (Sarang & Manoj, 2017). Rajkumar *et al.*, (2009) highlighted the conditions of substratum; temporal as well as geographical factors and distribution of the other companion species influence the percentage species composition and abundance of dominant diatoms. Due to runoff and river flow the estuaries are loaded with a large amount of hydrocarbon and also affected by enormous tidal and fluvial activities. Variations in the species diversity and composition govern the phytoplankton growth rate as well as other limiting factors and photosynthetic responses to irradiance. The ecological phenomena such as competition, predation and succession play key roles in monitoring the biodiversity and changes in these phenomena can change the diversity (Stirling & Wilsey, 2001).

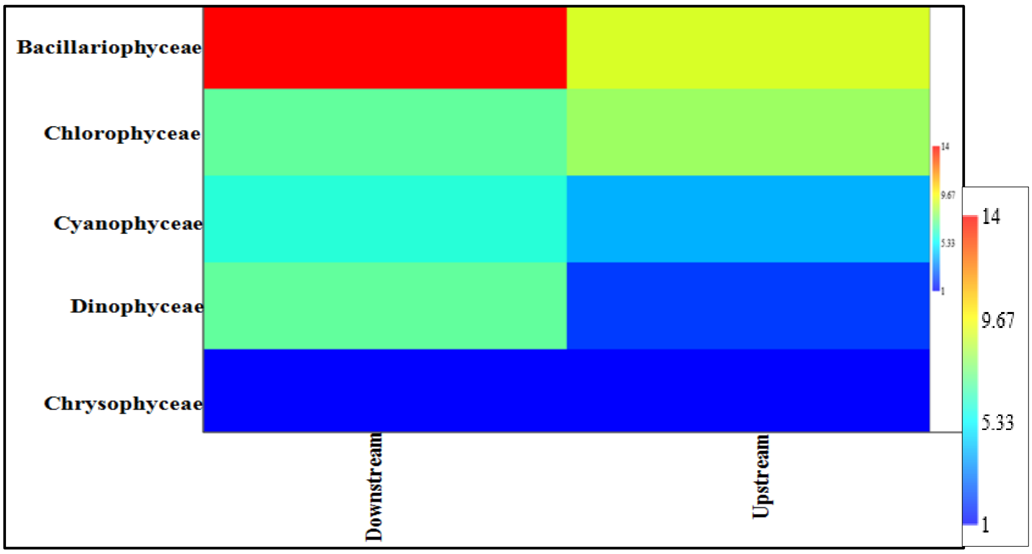


Figure 3. Distribution matrix of phytoplankton

The highest family contribution was by Nitzschiaceae and Zygnemataceae at respective stations of the downstream (Figure 4 A) and the upstream (Figure 4 B). At the upstream station, Oscillatoriaceae and Ulotrichaceae families highly contributed due to higher freshwater influence compared to downstream, while Skeletonemaceae, Cymbellaceae, Bacillariaceae, Chlorosarcinaceae, Prorocentraceae, Protoperidiniaceae and Peridiniaceae were present only in the downstream which may be due to the tidal impact and coastal water influence (Figure 4 A). The tidal flow and marine environmental conditions affected the distribution of these organisms. Majority families of phytoplankton were recorded from the downstream; it might be due to the dynamic environment of estuarine ecosystem, while at the upstream more freshwater flow have impact on the growth and abundance of green and blue-green algae, hence the family contribution of phytoplankton which are associated with Chlorophyceae and Cyanobacteria algae had more contribution at this station. The taxa belonging to Bacillariophyceae and Dinophyceae had higher contribution in the downstream due possibly to sea water influx (Hastuti *et al.*, 2018).

The fluctuations in the proportion of nutrients and the environmental factors influence the phytoplankton biodiversity (George *et al.*, 2015). The pH (mean 7.4 ± 0.67), varied between6.8 -7.7 and maintained buffering capacity which promoted the growth of phytoplankton. In this study, the highest abundance was reported from the downstream (91 ± 22.50 cells/mL) during winter season, while lowest abundance was recorded from the upstream (41 ± 19.55 cells/mL) during monsoon season (Figure 5). The maximum abundance of phytoplankton was found during the winter due to the moderate temperatures (22.5 ± 3.65) ˚C which ranged between 17 ˚C to 31 ˚C throughout the study period relatively higher salinities (11.87 ± 2.71 ppt) due decreased fluvial inflow, anthropogenic sewage and industrial runoff. Spatially, the downstream was characterized by higher phytoplankton abundance (72.00 ± 17.69

cells /mL) than the upstream (65.67 ± 21.57 cells/mL) (Table 2). Seasonal variations in phytoplankton abundance were also observed in both study sites. Seasonal plankton abundance ranked in the downstream as winter (91 ± 22.50 cells/mL) > summer (69 ± 37.54 cells/mL) > monsoon (46 ± 18.19 cells/mL) while at the upstream summer (81 ± 21.57 cells/mL) > winter (75 ± 28.57 cells/mL) > monsoon (41 ± 19.55 cells/mL) (Figure 5; Table 3). Higher abundance in plankton abundance was also shown for creek waters of western mangrove (Thakur *et al.*, 2015) and Muthupettai mangrove region, south east coast of India (Varadharajan & Soundarapandian, 2015). Similar observation was also reported for riverine waters at Narmada River (Sharma & Mankodi, 2011). Higher abundance of phytoplankton during summer and low abundance during monsoon was also reported from mangrove estuaries (Saifullah *et al.*, 2016).

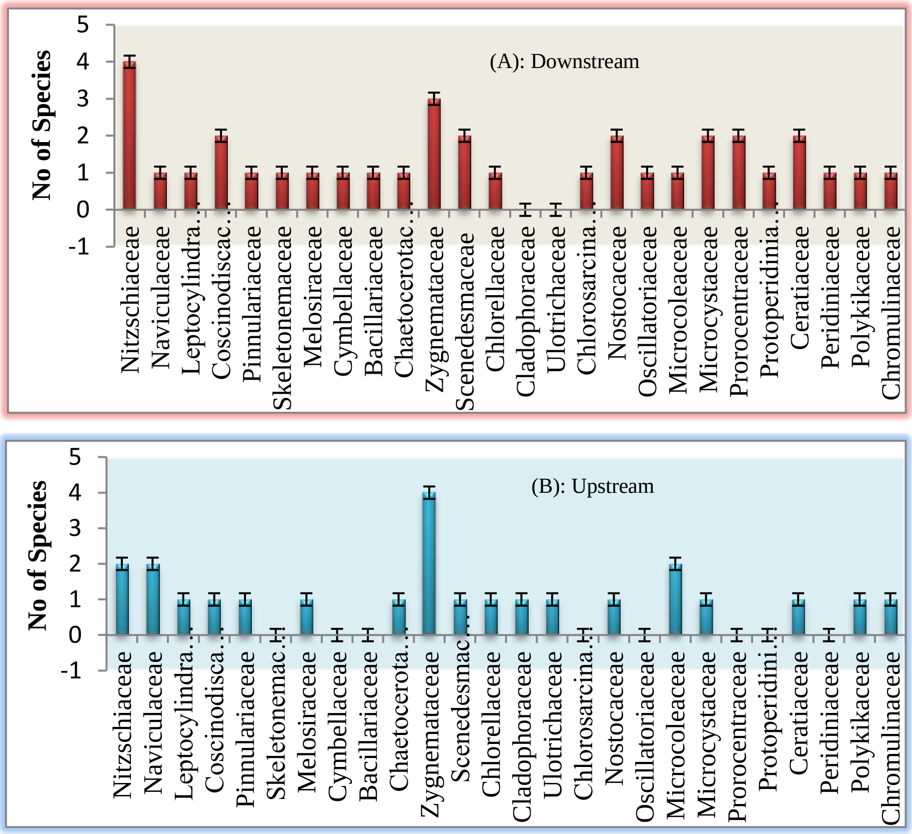


Figure 4. (A) and (B): Phytoplankton family contribution

The maximum number of Bacillariophyceae were found during the winter season in January- February and November-December and minimum during monsoon season in September-October. The maximum and minimum abundances of Dinophyceae were observed during the hot summer (March-April) and monsoon (September-October), respectively. The Chlorophyceae was more abundant during the winter season in January- February and November-December and less abundant during the monsoon months of July-August. The Cyanobacteria were maximum during the summer season in May-June and minimum in September-October. The Chrysophycean species *Chromulina pascheri* was found during the summer season. Ahel *et al.*, (1996) stated that due to the salinity gradient diatoms and dinoflagellates dominated in the estuarine environment. In the present study, higher salinities during the periods of winter (11.87 ± 2.71) and summer (12.43 ± 2.12) as a result of increased evapotation and reduced freshwater inflow and land drainage may have led higher diatoms and dinoflagellate presence. Dissolved oxygen (DO) showed higher concentration at downstream (5.42 ± 1.62) than upstream (3.72 ± 1.84) site of Auranga estuary. Higher DO concentrations (6.46 ± 2.36) recorded during the winter season may be due to the combined effects of higher wind energy and the mixing of heavier rainfall and freshwater. Furthermore, the diversity of aquatic autotropic components and their ability to produce oxygen may also be other important factors that influence the DO concentration. Members of Bacillariophyceae and Cyanobacteria were found normally throughout the study. Chlorophyceae did not show high seasonal variations. However, higher fluctuation was reported in the diversity of Dinophyceae. Temporally, winter (83.0 ± 11.31 cells/mL) season showed highest abundance followed by summer (75.0 ± 8.48 cells/mL) and monsoon (48.5 ± 10.60 cells/mL) (Table 3). During the period of summer, abundance was higher at the upstream (81.0 ± 21.57 cells/mL) than the downstream (69.0 ± 37.54 cells/mL), while during the rest of the two seasons, downstream had more abundance.

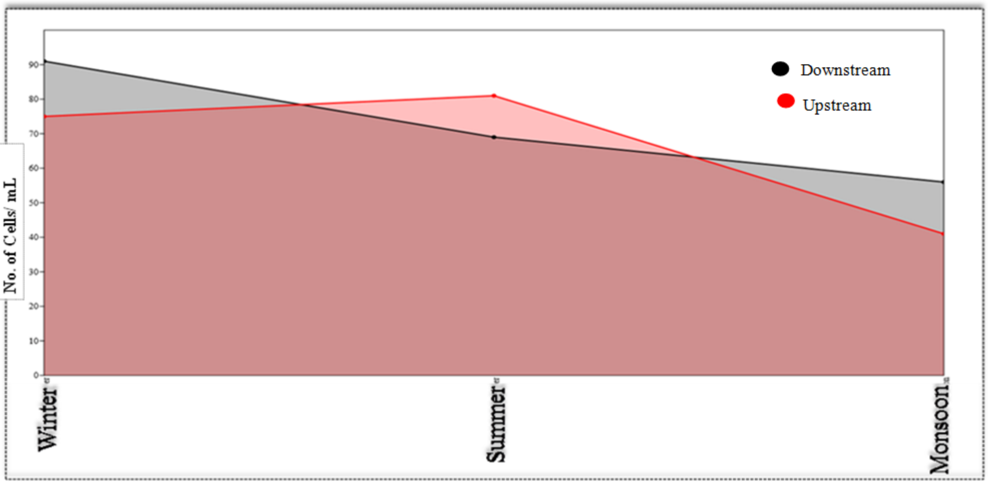


Figure 5. Spatial and temporal abundance of phytoplankton

Table 2. Summary statistics of spatial abundance of phytoplankton

	Mean	SD	Skewness	Kurtosis	Coeff. var	95% CI
Downstream	72	17.69	0.7411	-2.3333	24.572	0.025
Upstream	65.67	21.57	-1.5825	-2.3333	32.850	0.025

Temporal species diversity and species composition were rich during the winter season and poor during monsoon season. Such fluctuations were due to anthropogenic sewage discharges, agricultural fertilizers and fluvial influx from upper reaches that led to excessive inorganic phosphate during winter (0.0279 ± 0.038 mg/L) than summer (0.0212 ± 0.0162 mg/L) and monsoon (0.0168 ± 0.0128 mg/L) in this estuary. The high and low concentrations of nitrate observed during the winter (18.52 ± 5.48 mg/L) and monsoon (13.33 ± 5.28 mg/L) seasons may be due to freshwater and agricultural run offs, and oxidation of ammonia. Both phosphate and nitrate regulate the growth of autotropic microorganisms in this estuary. Similar results were observed in northern Kuchchh region (Kardani, 2011); in Mahakam Delta, east Kalimantan (Effendi *et al.,* 2016); Pichavaram mangrove waters from south-east coast of India (Rajkumar *et al.,* 2009). Rajkumar *et al.*, (2009) reported that the abundance of phytoplankton was minimum during monsoon due to the stratified water column, excess rainfall, low transparency caused by runoffs, decreased salinity, lower temperature and alkalinity, and cloudy skies.

In our study, species diversity and species composition in the summer was higher than that in the monsoon but was lower than that in the winter. During the rainy months (June-July) Matiamuiuri River Estuary in Bangaldesh showed highest phytoplankton densities with peak in July and lowest values in February (Hoque *et al.,* 1999). Because of the large influx of fluvial currents, the plankton composition of Perak Estuary of Malaysia was characteristic to freshwaters and dominated by the diatoms as well as green algae (Nursuhayati *et al.*, 2013). Fluctuations in plankton biomass were also reported from the Gulf of Cariaco, Venezuela (Calvo-Trujillo *et al.*, 2018). The statistical summaries of the spatial and temporal abundance of phytoplankton are given Table 2 and 3. The abundance of phytoplankton skewed to the right with a peak of 0.7411 at the downstream indicate higher abundance whereas negative skewness (-1.5825) at the upstream revealed low abundance. Kurtosis tail's value indicates normally distributed phytoplankton abundance (Table 2). Density without skewness means data are normally distributed (Table 3).

Table 3. Summary statistics of temporal abundance of phytoplankton

	Mean	SD	Skewness	Kurtosis	Coeff. Var.	95% CI
Winter	83.0	11.31	0	-2.75	13.63	0.003
Summer	75.0	08.48	0	-2.75	11.31	0.001
Monsoon	48.5	10.60	0	-2.75	21.87	0.001

Almost all coastal ecosystems are under pressure due to increases in human population and related developmental activities and are very sensitive to pollution, siltation erosion, flooding saltwater obtrusion, storm surges and other activities. Changes in water transparency and turbidity, presence of nutrients and their respective proportions affect the phytoplankton community and species diversity. Alpha diversity indices of Simpson Dominance index, Shannon Wiener Diversity index, Margalef Richness index, and Pielou's evenness index are given in Figure 6. Margalef richness index (1.36) and Simpson Dominance index (0.257) were high in the upstream compared to those in the downstream (1.13; 0.238) (Figure 6). The Shannon Wiener diversity index was 1.417 and 1.268 at the downstream and upstream site respectively and Pielou's Evenness index for the upstream and the downstream were 0.79 and 0.88, respectively (Figure 6). Figure 7 shows the diversity profile of phytoplankton in both stations of the Auranga Estuary and reveales that the diversity of phytoplankton was higher at the downstream station than upstream station. Single factor analysis of variance (ANOVA) for selected diversity indices indicated significant differences (p=0.00214) (Table 4). The abundance of phytoplankton (%) was compared using Lorenz curve with line of perfect equality for both stations (Figure 8). Results showed higher diversity in the upstream compared to downstream. The samples with more equal distribution of organisms were collected from the downstream while some unequal distribution was found in the upstream. The Gini index explains the distribution of phytoplankton among the individual within the ecosystem; the lower value indicate good equality abundance. The Gini index for the downstream was 0.308 and for the upstream was 0.366 which revealed the adequate equality abundance of phytoplankton. Phytoplankton play an identical role in the aquatic environment as herbs and trees do on land; , they transform light and mineral contents to biomass production.. The maximum diversity of phytoplankton showed pivotal level of phytoplankton biomass and massive blooms showed minimum diversity (Effendi *et al.,* 2016).

The phytoplankton biomass and productivity reflect the productivity and health of mangrove ecosystems (Thakur *et al.,* 2015). Phytoplankton primary production is very much associted with fluctuations in water quality and biogeochemical processes including ocean–atmosphere CO_2 exchange Phytoplankton biomass is regulated by crucial factors like turbidity and bio-limiting elements (nutrient) availability (Xia *et al.,* 2014; Palleyi & Panda, 2011).

Table 4. ANOVA- Single factor (Diversity indices)

SUMMARY						
Groups			**Count**	**Sum**	**Average**	**Variance**
Margalef Richness Index			2	2.39	1.195	0.00845
Shannon Wiener Species Diversity Index (H')			2	2.785	1.3925	0.001201
Simpson Dominance Index (D)			2	0.505	0.2525	4.05E-05
Pielou's Evenness Index (J')			2	1.67	0.835	0.00405
ANOVA						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	1.503313	4	0.375828	82.05257	**0.002143**	9.117182
Within Groups	0.013741	3	0.00458			
Total	1.517054	7				

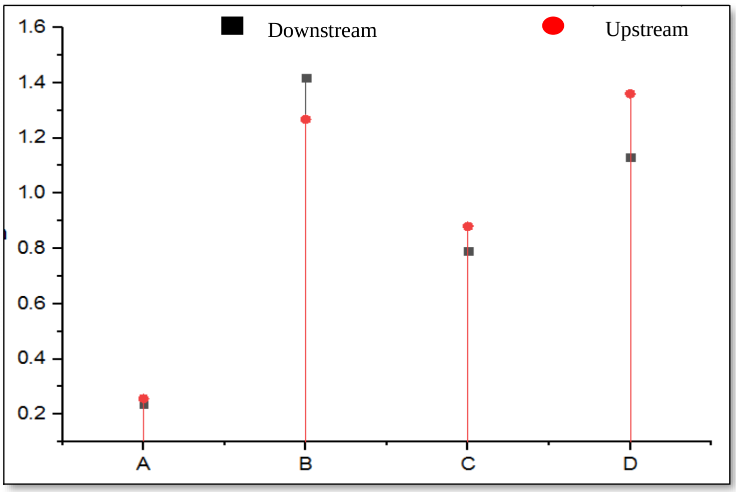


Figure 6. Alpha diversity indices from both stations (A= Simpson Dominance index; B= Shannon Wiener diversity index; C= Pielou's evenness index; D= Margalef richness index)

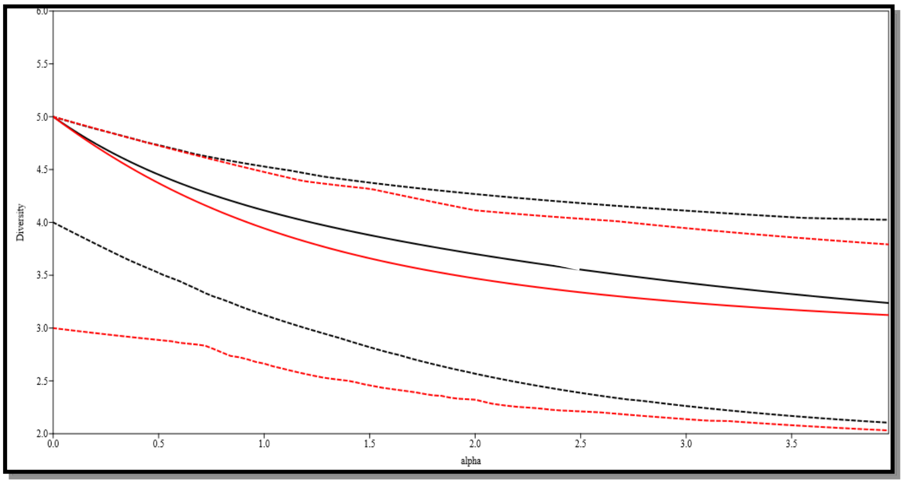
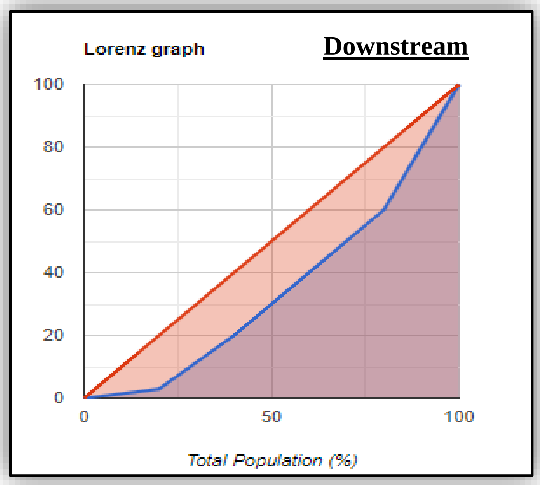


Figure 7. Diversity profile of phytoplankton at the both stations

Phytoplankton are key organisms in monitoring the environmental status of the aquatic ecosystem. They are used as an indicator of ecological conditions and productivity of the ecosystem (Ekwu & Sikoki, 2006; Palleyi & Panda, 2011). Generally, the physical factors such as temperature, pH, dissolved oxygen, presence of nutrients, current velocity water level and chemical factors may influence phytoplankton development (Singh *et al.*, 2013; Nowrouzi & Valavi, 2011; George *et al.*, 2015).



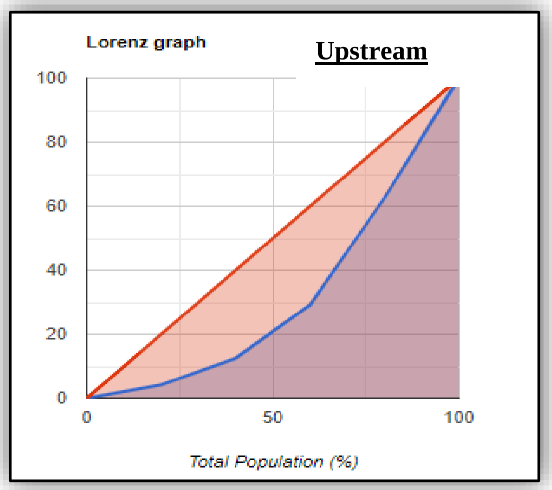


Figure 8. Lorenz curve plots of relative phytoplankton abundance (%) for both stations

Here it can thus be concluded that Bacillariophyceae was the dominant phytoplankton taxa in Auranga Estuary. Bacillariophyta and Dinophyta were abundant in the downstream characterized by estuarine conditions and Chlorophyta and Cyanobacteria were abundant in the upstream characterized by freshwater conditions. Phytoplankton of fluvial and estuarine taxa, abundance and diversity fluctuated temporally as well spatially. Spatially, downstream was more productive than upstream while temporally winter is more productive followed by summer and monsoon. Decreasing freshwater inflow, land field, anthropogenic sewage discharges and industrial runoff together with higher temperatures and salinities increased phytoplankton growth and abundance. Diversity indices revealed less diversity but good abundance of phytoplankton in this estuary. The phytoplankton distribution and abundance will be a useful tool for further assessment and monitoring of estuarine ecosystems. This study establishes an important step towards conducting future research on diversity, ecology, taxonomy and conservation of estuarine phytoplankton in Auranga Estuary and higher trophic level aquatic organisms.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

Author Contributions

All authors contributed to the preparation of the manuscript.

References

Ahel, M., Barlow, R. G., & Mantoura, R. F. C. (1996). Effect of salinity gradients on the distribution of phytoplankton pigments in a stratified Estuary. *Marine ecology progress series*, *143*, 289-295.

Babu, A., Varadharajan, D., Vengadesh, P. N., Thilagavathi, B., Manikandarajan, T., Sampathkumar, P., & Balasubramanian, T. (2013). Diversity of phytoplankton in different stations from Muthupettai, Southeast coast of India. *J. Mar. Sci.: Res. Dev, 3*(3).

Baliarsingh, S. K., Srichandan, S., Pati, S. K., Sahu, K. C., Dash, S. K., Lotliker, A. A., & Kumar, T. S. (2016). Phytoplankton community structure along offshore transects of some Indian estuaries of east coast: An experience with a summer cruise. *Indian Journal of Geo Marine Science, 44*(5), 1-14.

Bellinger, E. G., & Sigee, D. C. (2010). A key to the more frequently occurring freshwater algae. *Freshwater algae*, 137-244.

Calvo-Trujillo, A., Rincones-Reyes, K., Díaz-Ramos, J. R., Márquez-García, B., Subero-Pino, S., Elista-Ramírez, E., & Troccoli-Ghinaglia, L. (2018). Spatial and temporal phytoplankton distribution in the Gulf of Cariaco, Sucre State, Venezuela, February 2014-January 2015. *Boletín de Investigaciones Marinas y Costeras-INVEMAR*, *47*(2), 63-82.

Daborn, G.R., & Redden, A.M. (2016). Estuaries. In: Finlayson C., Milton G., Prentice R., Davidson N. (eds) The Wetland Book. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-6173-5_281-1.

Effendi, H., Kawaroe, M., Lestari, D. F., & Permadi, T. (2016). Distribution of phytoplankton diversity and abundance in Mahakam Delta, East Kalimantan. *Procedia Environmental Sciences*, *33*, 496-504.

Ekwu, A. O., & Sikoki, F. D. (2006). Phytoplankton diversity in the Cross RiverEstuary of Nigeria. *Journal of Applied Sciences and Environmental Management*, *10*(1), 89-95.

Elliott, M., & Whitfield, A. K. (2011). Challenging paradigms in estuarine ecology and management. *Estuarine, Coastal and Shelf Science*, *94*(4), 306-314.

George, B., Nirmal Kumari J. I., & Kumar, R. N. (2015). An evaluation of phytoplankton assemblage in relation to environmental variables of Narmada Estuarine Region of Gulf of Khambhat, Gujarat, India. *Applied Ecology and Environmental Research*, *13*(1), 115-131.

George, B., Kumar, J. N., & Kumar, R. N. (2012). Study on the influence of hydro-chemical parameters on phytoplankton distribution along Tapi estuarine area of Gulf of Khambhat, India. *The Egyptian Journal of Aquatic Research*, *38*(3), 157-170.

Gopinathan, C. P., Rajagopalan, M., Kaladharan, P., & Prema, D. (2007). *Training Manual on Phytoplankton Identidication/Taxonomy*.

Hastuti, A. W., Pancawati, Y., & Surana, I. N. (2018). The abundance and spatial distribution of plankton communities in Perancak Estuary, Bali. In *IOP Conference Series: Earth and Environmental Science, 176*(1), 012-042.

Hendey, N. (1957). III—Marine Diatoms from Some West African Ports. *Journal of the Royal Microscopical Society, 77* (1-2), 28-85.

Hoque, S. A., Zafar, M., & Mahmood, N. (1999). Temporal and spatial distribution of phytoplankton with emphasis on Skeletonema costatum in the Mathamuhuri River–Estuary (Chakaria mangrove ecosystem), Bangladesh. *Pakistan Journal of Marine Sciences*, *8*(1), 29-39.

Hosmani, S. P. (2010). Phytoplankton diversity in lakes of Mysore district, Karnataka state, India. *The Ecoscan*, *4*(1), 53-57.

Narmada, Water resources, Water supply and Kalpsar Department, Gujarat, 2010, (visited on 25th July, 2020).https://gujnwrws.gujarat.gov.in/

Joshi, A., Desai, A.Y., Bhatt, A.J., Kardani, H.K., Yusufzai, S.I., & Khileri, R.A. (2018). *A Guide to the Marine Phytoplankton of Marine National Park, Gujarat*, College of Fisheries Science, Junagadh Agricultural University, India. ISBN: 978-93-5300-352-4.

Kardani, H. K. (2011). Ecological assessment of northern coast of gulf of Kachchh with special reference to planktonic forms, India.

Lalli, C. M., & Parsons, T.R. (1997). Biological *Oceanography an Introduction (2nd eds)*. Elseveir, Oxford, London.

Mani, P. (1994). Phytoplankton in pitcharavarm mangroves, eastcoast of India. *Indian Journal of Marine Science, 23*, 22-26.

Meng, F., Li, Z., Li, L., Lu, F., Liu, Y., Lu, X., & Fan, Y. (2020). Phytoplankton alpha diversity indices response the trophic state variation in hydrologically connected aquatic habitats in the Harbin Section of the Songhua River. *Scientific Reports*, *10*(1), 1-13.https://doi.org/10.1038/s41598-020-78300-7

Moore, J. W. (1974). Benthic algae of Southern Baffin Island: II. The epipelic communities in temporary ponds. *The Journal of Ecology*, *62*(8), 809-819.

Nowrouzi, S., & Valavi, H. (2011). Effects of environmental factors on phytoplankton abundance and diversity in Kaftar Lake. *Journal of Fisheries and Aquatic Science*, *6*(2), 130-140.

Nursuhayati, A. S., Yusoff, F. M., & Shariff, M. (2013). Spatial and temporal distribution of phytoplankton in perak Estuary, Malaysia, during monsoon season. *Journal of Fisheries and Aquatic Science*, *8*(4), 480.

Oseji, O. F., Fan, C., & Chigbu, P. (2019). Composition and dynamics of phytoplankton in the coastal bays of Maryland, USA, revealed by microscopic counts and diagnostic pigments analyses. *Water*, *11*(2), 368.

Palleyi, S., & Panda, C. R. (2011). Influence of water quality on the biodiversity of phytoplankton in Dhamra RiverEstuary of Odisha Coast, Bay of Bengal. *Journal of Applied Sciences and Environmental Management*, *15*(1).

Rajkumar, M., Perumal, P., Ashok Prabu, V., Vengadesh Perumal, N., & Thillai Rajasekar, K. (2009). Phytoplankton diversity in Pichavaram mangrove waters from south-east coast of India. *Journal of Environmental Biology, 30*, 489-498.

Ram, M. J.(1991). Algae and water pollution in Mahi estuary journal of the India fisheries Association.

Ram, M.J., Gajbhiye S.N., & Desai. (1988). Phytoplankton Distribution in The Coastal Waters of Porabandar (Saurashtra). *Journal of the Indian Fisheries Association,18*, 357-367.

Saifullah, A. S. M., Kamal, A. H. M., Idris, M. H., Rajaee, A. H., & Bhuiyan, M. K. A. (2016). Phytoplankton in tropical mangrove estuaries: role and interdependency. *Forest science and technology*, *12*(2), 104-113.

Santhanam, P., Begum, A., & Pachiappan, P. (2019). *Basic and applied phytoplankton biology (eds.)*. Springer, India.

Sarang, T., & Manoj, K. (2017). Phytoplankton population in relation to physic-chemical properties of River Tapi, Surat, Gujarat, India. *Research Journal of Recent Sciences*, *6*(3), 35-37.

Saravanakumar, A., Rajkumar, M., Thivakaran, G. A., & Serebiah, J. S. (2008). Abundance and seasonal variations of phytoplankton in the creek waters of western mangrove of Kachchh-Gujarat. *Journal of environmental biology*, *29*(2), 271.

Sharma, K. N., & Mankodi, P. C. (2011). Study on plankton diversity of Narmada River, Gujarat. *Journal of Current Sci*ence, *16*(1), 111-116.

Singh, U. B., Ahluwalia, A. S., Sharma, C., Jindal, R., & Thakur, R. K. (2013). Planktonic indicators: a promising tool for monitoring water quality (early-warning signals), *Ecology Environment Conservation*, *19*(3), 793-800.

Stirling, G., & Wilsey, B. (2001). Empirical relationships between species richness, evenness, and proportional diversity. *The American Naturalist*, *158*(3), 286-299.

Taylor, J. C., Harding, W. R., & Archibald, C. G. M. (2007). A methods manual for the collection, preparation and analysis of diatom samples. *WRC Report No TT 281/07. Water Research Commission, Pretoria*, 11-23.

Thakur, B., Chavda, C., & Salvi, H. (2015). Phytoplankton diversity at some selected sites of the Gulf of Kuchchh, Gujarat, India. *Bulletin of Environmental and Scientific Research*, *4*(4), 7-12.

Varadharajan, D., & Soundarapandian, P. (2015). Biodiversity and abundance of phytoplankton from Muthupettai mangrove region, southeast coast of India. *Journal of Aquaculture Research and Development*, *6*(12).

Venkateswarlu, V. (1986). Ecological studies on the Rivers of Andhra Pradesh with special reference to water quality and pollution. *Proceedings: Plant Sciences*, *96*(6), 495-508.

Waghmare, B. D., & Kulkarni, A. N. (2015). An assessment of phytoplankton population and seasonal variation in Lendi River, district Nanded, Maharashtra, India. *International Journal of Science and Research*, *4*(12), 936-940.

Zhang, X., Zhang, J., Huang, X., & Huang, L. (2014). Phytoplankton assemblage structure shaped by key environmental variables in the Pearl River Estuary, South China. *Journal of Ocean University of China*, *13*(1), 73-82. doi: 10.1007/s11802-0141972-3