J.Natn.Sci.Foundation Sri Lanka 2023 51 (2): 359 - 372
DOI: http://dx.doi.org/10.4038/jnsfsr.v51i2.10780

RESEARCH ARTICLE

Marine Science

Preliminary study on surface phytoplankton assemblages and physicochemical parameters, off the west and south-west coasts of Sri Lanka

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Submitted: 21 November 2021; Revised: 30 July 2022; Accepted: 26 August 2022

Abstract: This study evaluates the phytoplankton community structure in relation to physicochemical properties in the western and southwestern coastal waters of Sri Lanka. Phytoplankton and water samples were collected from March to April, 2017 at three transect lines towards offshore in Colombo, Beruwala, and Mirissa, each containing 10 sampling sites. The distance between sampling stations on each transect line was approximately 2 km. Phytoplankton samples were collected towing a net (10 μm mesh) by vertical hauls from known depth (2.5 m) and preserved in Lugol's solution. The phytoplankton were identified to the lowest possible taxonomic level and counted under the Sedgwick rafter cell using a light microscope. Water samples were collected at 0.5 m depth using the Ruttner Sampler and analysed for chlorophyll-a, nutrients, and total suspended solids (TSS). This study identified 57 phytoplankton species comprised of diatoms (33 species), dinoflagellates (23 species), and cyanobacteria (1 species). In general, phytoplankton abundance and species diversity decreased towards offshore in the three transects. Total phytoplankton and diatom abundances varied significantly among the three transect lines, and significantly higher abundance was reported at Mirissa and Colombo than at Beruwala (One-way ANOVA; $p < 0.05$). Total phytoplankton abundance significantly correlated with dinoflagellates, toxic species of dinoflagellates, chlorophyll-a, and nitrate-N ($p < 0.01$). Ten toxic species of dinoflagellates were reported in the study. Diatoms dominated (60%) in the study area, followed by cyanobacteria (31%) and dinoflagellates (9%). Diatoms of Cerataulina sp. (31%) and Navicula sp. (50%) were dominant in Colombo and Mirissa respectively, while cyanobacteria of Trichodesmium sp. (85%) dominated in Beruwala, indicating the possibility of blooms of this species at study sites when environmental conditions are favourable.

Keywords: Diatoms, dinoflagellates, physicochemical properties, phytoplankton, Sri Lanka.

INTRODUCTION

Marine phytoplankton represent less than 1% of the Earth's photosynthetic biomass, but are responsible for more than 45% of our planet's annual net primary production and contribute more than 90% of photosynthetic carbon fixation (Field *et al*., 1998). The productivity of marine phytoplankton is influenced by environmental factors, many of which are affected by human activities, so that they undergo massive changes due to global climate change, ozone depletion, and pollution (Behrenfeld *et al*., 2006). Phytoplankton sustain the aquatic food web, drive the marine ecosystem, and constrain the global fish catch. In addition, the phytoplankton absorb solar radiation and control the upper ocean heat flux, thereby influencing climate processes and biogeochemical cycles, particularly the carbon cycle (Roxy *et al*., 2015). Phytoplankton have rapid turn-over times (in the order of days) and are sensitive indicators of environmental stresses (Findlay & Kling, 2001). Due to their high turnover rates and sensitivity to changes in environmental conditions, phytoplankton are useful indicators of changing oceanographic conditions, climate change, and deterioration in water quality (Beaugrand, 2009; Poloczanska *et al*., 2013).

Marine phytoplankton range in size from <1 μm to about 1 mm and include representatives from at least five eukaryotic phyla together with cyanobacteria. This wide size range and phylogenetic diversity present challenges for quantifying and characterizing phytoplankton communities. Marine phytoplankton, especially diatoms and

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dinoflagellates, are considered as major contributors to ecosystem structure and functions (Margalef, 1978; Reynolds, 1997).

Some species of phytoplankton can have harmful effects on organisms at different trophic levels. Blooms of some otherwise harmless species result in massive fish kills by depleting dissolved oxygen content or by clogging the gills of fish. Rapid cell division and population growth in phytoplankton can produce millions of cells per litre of seawater, resulting in visible blooms or 'red tides'. At least 90 of cyst producing species are known to be harmful (Sournia, 1995) and a minimum of 45 species are considered as toxic dinoflagellates (Sournia, 1995; Smayda, 1997; Hallegraeff, 2003). At certain times, the occurrence of a toxin-producing species of phytoplankton may affect wildlife, causing illness or death. Human consumers of certain seafood items (especially bivalve shellfish) are also at risk in the absence of adequate monitoring programmes.

The study of phytoplankton in the east coast of India has indicated the high diversity and low production. A large number of phytoplankton species (193) has been recorded during the monsoon season (Geetha & Kondalarao, 2004). Ecological indices are generally used for describing eutrophication, water quality and community structure. The commonly used indices are Diversity (H'), Evenness (J'), and Dominance (D') (Kumari & Julie, 2003).

The concentrations of N and P usually vary according to regional environmental changes and therefore may affect the physiological and ecological responses of phytoplankton to the anthropogenic stressors, such as ocean acidification and warming of sea surface. Decreased pH and increased temperature are known to interact with UV radiation to influence photosynthesis and/or growth of typical phytoplankton species (Gao *et al*., 2012). The reversal of monsoon currents affects the hydrodynamic features of the coastal area, which in turn affect phytoplankton productivity. In addition, physico-chemical features have been thought to control the phytoplankton community dynamics by determining species composition, species seasonality, species biomass, and productivity biomass (Harris, 1986). Also, rivers are often subjected to increased nutrient concentrations due to run off of fertilizers from adjacent fields, to a point that they must be considered as pollution. This eutrophication deteriorates the water quality and affects consumers higher up in the food web (Hutchins *et al*., 2010).

A few studies on marine phytoplankton have been conducted in Sri Lankan waters such as the Gulf of Mannar and the Palk Strait, and bathing sites (Jayasiri, 2007; Jayasiri & Priyadarshanie, 2007; Weerakoon *et al*., 2017) including a few localised studies off Thalawila in north-west coast, Maruthankerny, off Jaffna, off Colombo, and southern coast (Jayasiri *et al*., 2014, 2016; Ekanayaka *et al*., 2016; Wickramasingha & Jayasiri, 2016). Many studies have been conducted in coastal waters in localised areas on a small scale, and there is no information on phytoplankton community structure in offshore waters and spatially in a large area, which includes three districts for comparison. Phytoplankton assemblages are essential for understanding the quality of primary production in the marine environment

Thus, this study provides valuable information on spatial distribution of phytoplankton community structure in waters off the western and south-western coasts of Sri Lanka.

MATERIALS AND METHODS

Three sampling sites (Colombo, Beruwala, and Mirissa), each containing 10 locations in a transect line towards offshore, were selected for collection of samples. The distance between sampling positions is 2 km with total of 30 sampling positions (Figure 1). Field surveys were carried out from March to April 2017 which comes under the first inter-monsoon. To study the nutrient levels, water samples were collected at the depth of 0.5 m from the surface using the Ruttner Sampler and analysed by standard methods for nitrate, nitrite, phosphate, and silicate (Grasshoff *et al*., 1999). Further, water samples were collected to analyse the chlorophyll-a (Parsons & Strickland, 1963). Phytoplankton sampling was carried out using an open net with a mesh size of 10 μm and diameter of 35 cm of the opening. The plankton hauls were collected by towing the net vertically through the water column from the known depth of 2.5 m to the surface. The phytoplankton samples were preserved in Lugol's solution (0.8 mL to 200 mL sample: Willén, 1976) and they were put into labelled amber coloured glass sampling bottles.

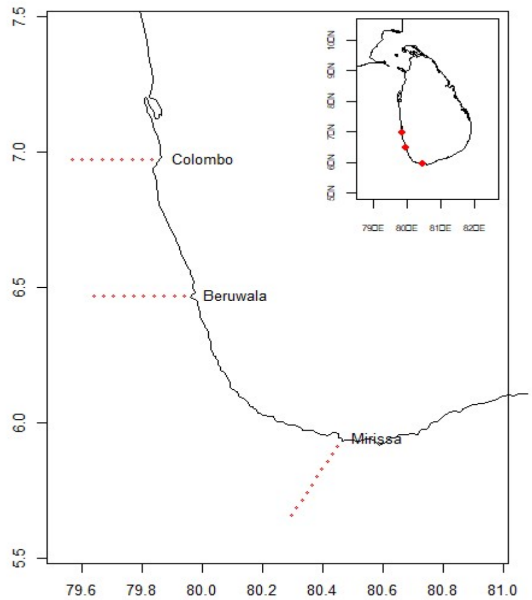

Figure 1: Map of the study area showing sampling transects

Determination of chlorophyll-a content in waters

Chlorophyll-a was determined by filtering 1.00 L of the water sample using GF/F filters (nominal pore size 0.7 μm) under low vacuum. The pigment extraction was done with 10 mL of 90% acetone. The optical density (absorbance) of the extract was determined using a UV Visible spectrophotometer (Optizen 3220uv) (Richards & Thompson, 1952; Parsons & Strickland, 1963). Chlorophyll-a concentrations were calculated using the equations of Parsons *et al.* (1984).

Phytoplankton and chemical analysis

The samples were homogenized and 1 mL of the sample was placed in a Sedgwick rafter cell and the number of phytoplankton was observed and counted under the light microscope (Olympus Bx41). Identification was done using standard keys to the lowest possible taxon (Hasle & Syvesten *et al*., 1997; Hoppenrath *et al*., 2009; Jayasiri, 2009; Phyto'pedia, 2012; Guiry & Guiry, 2013). Phytoplankton abundance, species composition, species richness, and biodiversity indices were calculated using standard formulae.

From each sampling point another 4 L of surface water were collected to analyse chemical parameters including dissolved inorganic nutrients (nitrate, nitrite, phosphate, and silicate) and total suspended solids (TSS). Dissolved inorganic nutrient concentrations were determined colorimetrically with an UV-VIS spectrophotometer according to standard methods for seawater analysis (Grasshoff *et al*., 1999). The gravimetric procedure was used to determine the TSS.

Data analysis

Phytoplankton abundance is calculated as follows;

When a circular net is used, the volume of water filtered can be calculated by the formula given below:

$V = \pi r^2 d$

Where

V = Volume of water filtered (m^3)
r = The radius of the mouth of the net (m)
d = Length of the water column traversed by the net (m)
v = volume of phytoplankton sample (mL)
N = number of organisms in 1mL of the sample
vN = number of organism in volume v

Phytoplankton abundance = $\frac{vN}{V \times 1000}$ number of organisms in unit volume (No. L^{-1}).

Phytoplankton species composition was calculated as per the following formula.

$$C = \frac{p_i}{p_t} \times 100$$

where C is the composition of individual species at a site, p_i is the abundance of individual species and p_t is the total abundance.

Diversity indices were calculated using following formulae
Shannon-Weaver species diversity Index (Shannon & Weaver, 1949)

$$H = -\Sigma\ piX \ln pi$$

Where pi = ni/N, ni = number of individuals of one species and N = total number of organisms.

Evenness Index (Pileou, 1966)

$$J' = H'/\ln(S)$$

Where H = Shannon-Weave Index of general diversity; S = Number of species

Statistical analysis was done by using statistical software SPSS version 23 for Windows. The comparisons of phytoplankton abundance, physicochemical parameters. and diversity indices were made using One-way ANOVA. The Pearson's correlation and principal component analysis were performed in order to evaluate the relationships between phytoplankton abundance (diatoms and dinoflagellates) and physicochemical parameters.

RESULTS AND DISCUSSION

The mean (±SE) abundance of phytoplankton in Colombo, Beruwala and Mirissa (n = 30) was 671 ± 97 No. L^{-1} with a range of 43 – 2030 No. L^{-1}. In general, the phytoplankton abundance decreased towards the offshore. The phytoplankton abundance of this study is consistent with most of the studies conducted in Sri Lankan waters (Table 1). However, higher abundances have been reported in the Palk Strait and Gulf of Mannar than in this study (Table 1). Also, the phytoplankton abundance in the coastal waters of the Arabian Gulf (100 – 1903 No. L^{-1}) is in line with this study (El Gammal *et al.*, 2017). The phytoplankton abundance reported in this study is higher than that of the four commercial harbours of Sri Lanka (Table 1). In contrast to this study, low abundance (15 to 148.5 cells L^{-1}) is reported by Sekadende *et al.*, 2021 in Pemba Channel waters in Tanzania. This study identified a total of 57 phytoplankton species comprised of diatoms (33 taxa), dinoflagellates (23 taxa), and cyanobacteria (1 taxon) (Table 2). Consistent with this study, 61 phytoplankton taxa have been reported in the Palk Strait (Jayasiri, 2007). In contrast to this study, a total of 119 species of phytoplankton were identified belonging to four taxonomic groups, with domination of diatoms (95.93%), in bathing sites of Mt. Lavinia, Unawatuna, and Polhena (Weerakoon *et al.*, 2017). Some 45 species of phytoplankton belonging to 5 groups have been reported in the Arabian Gulf with dominance of diatoms (48% and 23 species; El Gammal *et al.*, 2017). A total of 62 phytoplankton species belonging to the same groups reported in Sri Lanka have been reported in the Uppanar

Estuary, on the southeast coast of India (Saravanakumar *et al*., 2021). A total of 79 species have been identified in the micro-phytoplankton community of the Pemba Channel, Tanzania with 55 diatom species (62.5% of total), followed by 31 dinoflagellate species (35.2%) and 2 cyanobacteria species (2.27%) (Sekadende *et al*., 2021).

Table 1: Phytoplankton abundance in studies carried out in Sri Lankan marine environment

Study area	Abundance		Reference
	Range	Mean ± SE	
Coastal seawater			
Palk Strait	12–1067 × 10^2 No. L^{-1}	-	Jayasiri, 2007
Gulf of Mannar	34–584 × 10^2 No. L^{-1}	-	Jayasiri & Priyadarshani, 2007
Thalawila, Kalpitiya	300–26,320 No. L^{-1}	3273 ± 771 No. L^{-1}	Jayasiri *et al*., 2014
Bathing sites	570–12,250 cells L^{-1}	-	Weerakoon *et al*., 2017
Mulative	279–866 No. L^{-1}	554 ± 201 No. L^{-1}	Jayasiri *et al*., 2016
Colombo	66–11,738 No. L^{-1}	2810 ± 780 No. L^{-1}	Wickramasinghe & Jayasiri, 2016
Southern Bay of Bengal	-	419 ± 72 No. L^{-1}	Kumara, 2016
Southern Coast of Sri Lanka	164–315,640 cells L^{-1}	-	Ekanayaka *et al*., 2016
Southern Coast	-	1729 ± 257 cells L^{-1}	Wijesinghe, 2016
Eastern Coast	-	584 ± 117 cells L^{-1}	Wijesinghe, 2016
Commercial harbours			
Colombo	55–255 No. L^{-1}	142 ± 12 No. L^{-1}	PBBS, 2016
Trincomalee	66–174 No. L^{-1}	102 ± 31 No. L^{-1}	PBBS, 2017
Hambantota	25–289 No. L^{-1}	110 ± 24 No. L^{-1}	PBBS, 2018a
Galle	85–188 No. L^{-1}	128 ± 33 No. L^{-1}	PBBS, 2018b
West and southwest coasts	43–2030 No. L^{-1}	671 ± 97 No. L^{-1}	Present study

One-way ANOVA revealed that abundance of total phytoplankton, diatoms and cyanobacteria varied significantly among the sites ($p < 0.05$; Table 3) while there was no significant difference for dinoflagellates among three transects studied ($p > 0.05$; Table 3). The abundances of total phytoplankton in Mirissa (denoted by the letter b) and Colombo (denoted by the letter B) were significantly higher than that of Beruwala (denoted by letters a and A in Figure 2) and it might be due to the freshwater discharges of the Kelani and Nilwala Rivers which bring an ample amount of inorganic nutrients. Increasing nutrients from anthropogenic discharge stimulates the growth of phytoplankton through photosynthesis, as has been reported (Effendi *et al*., 2016).

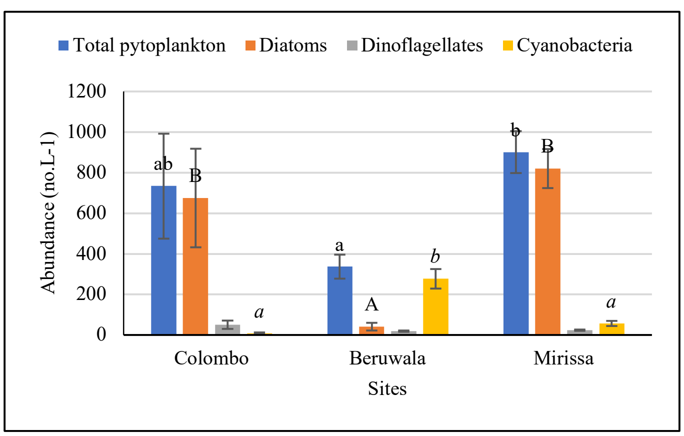

Figure 2: Abundance of total phytoplankton, diatoms, dinoflagellates and cyanobacteria in Colombo, Beruwala and Mirissa. The bars with different letters in lowercase vary significantly among sites for total phytoplankton, uppercase for diatoms and lowercase italic for cyanobacteria ($p < 0.05$).

Table 2: List of phytoplankton species recorded in three transects of Colombo, Beruwala and Mirissa with relative percentage composition of species

Taxonomic group	Species/genus	Relative composition		
		Colombo	Beruwala	Mirissa
Bacillariophyceae (Diatoms)	*Asterionellopsis glacialis*	0.49	-	5.35
	Bacteriastrum sp.	0.50	-	0.01
	Bellerochea malleus	0.25	0.05	13.76
	Cerataulina sp.	30.78	0.26	0.18
	Chaetoceros sp.1	0.21	0.45	0.07
	Chaetoceros danicus	0.00	0.04	0.29
	Chaetoceros lorenzianusns	0.05	0.06	0.01
	Coscinodiscus sp.	0.03	0.56	0.06
	Coscinodiscus granii	0.67	0.26	0.03
	Coscinodiscus stellaris	0.00	-	0.02
	Coscinodiscus concinnus	0.08		0.09
	Coscinodiscus radiatus	1.58	0.08	3.16
	Ditylum sp.1	3.13	-	0.57
	Ditylum brightwellii	1.23	-	0.22
	Eucampia zodiacus	0.04	-	0.37
	Guinardia striata	0.94	1.65	7.30
	Hemidiscus sp.	0.49	0.03	0.54
	Lauderia sp.	0.01	0.18	0.01
	lingulodinium polyedrum	0.55	0.07	0.85
	Meuniera membranacea	0.04	-	0.84
	Nitzschia sp.1	0.00	1.51	0.07
	Nitzschia sigma	3.74	-	0.66
	Navicula sp.	0.59	1.20	49.93
	Pseudo Nitzschia	0.01	0.02	0.14
	Odontella sp. 1	10.80	0.03	1.07
	Odontella mobiliensis	2.94	0.10	0.40
	Odontella sinensis	3.14	0.02	0.47
	Pleurosigma sp.1	0.00	0.14	0.13
	Pleurosigma capense	0.03	-	0.02
	Pleurosigma directrum	0.11	0.16	0.01
	Proboscia sp	0.44	0.01	0.16
	Rhizosolenia sp.	3.30	0.89	3.30
	Thalassionema nitzschioides	0.02	-	0.25
Cyanobacteria	*Trichodesmium sp*	3.79	84.91	0.14
	Trichodesmium (bundle)	0.37	1.02	0.42
Dinophyceae (Dinoflagellates)	*Alexandrium* sp.1	2.23	1.95	0.15
	Alexandrium catenella	0.04	0.13	0.00
	Alexandrium monilatum	1.42	0.31	0.00
	Ceratium furca	2.43	0.37	0.96
	Ceratium tripos	0.53	0.19	0.15
	Ceratium horridum	0.18	0.19	0.03
	Ceratium lineatum	0.48	0.19	0.67
	Ceratium fusus	0.21	0.08	0.02
	Dinophysis sp.	0.18	0.20	0.04
	Diplopelta bomba	0.15	0.02	0.01
	Gyrodinium sp.1	0.07	0.37	0.03
	Gymnodinium sp.1	0.84	0.02	0.01
	Noctiluca scintillans	0.08	-	0.01
	Protoperidinium sp.1	0.34	0.29	0.01
	Protoperidinium diabolum	0.78	-	0.02
	Protoperidinium depressum	0.04	0.04	0.11
	Protoperidinium cerasus	1.16	0.68	0.01
	Protoperidinium curtipes	0.01	-	0.06
	Protoperidinium meuniere	1.24	0.48	0.18
	Protoperidinium Obtusum	0.80	-	0.19
	Prorocentrum sp.1	0.45	0.06	0.01
	Prorocentrum micans	0.80	0.45	0.08
	Prorocentrum redfeildil	0.45	0.28	0.05

- Not reported

Among abiotic interactions, fresh water inflow influences greatly the abundance of planktonic organisms in the marine ecosystem (Cloern, 1996). However, significantly high cyanobacteria were reported in Beruwala due to the presence of Trichodesmium species. The abundance of cyanobacteria in the study area is 114 ± 27 No. L^{-1}. Trichodesmium blooms appear and disappear with suddenness (Qasim, 1972). The mean abundance of dinoflagellates was 31.2 ± 7.2 No. L^{-1} in this study.

Table 3: P values of one-way ANOVA for total phytoplankton, diatoms, dinoflagellates and cyanobacteria for effect of site (df=2)

Categories	P value
Total phytoplankton	0.042
Diatoms	0.003
Dinoflagellates	0.146
Cyanobacteria	0.000

Significant ($p < 0.05$)

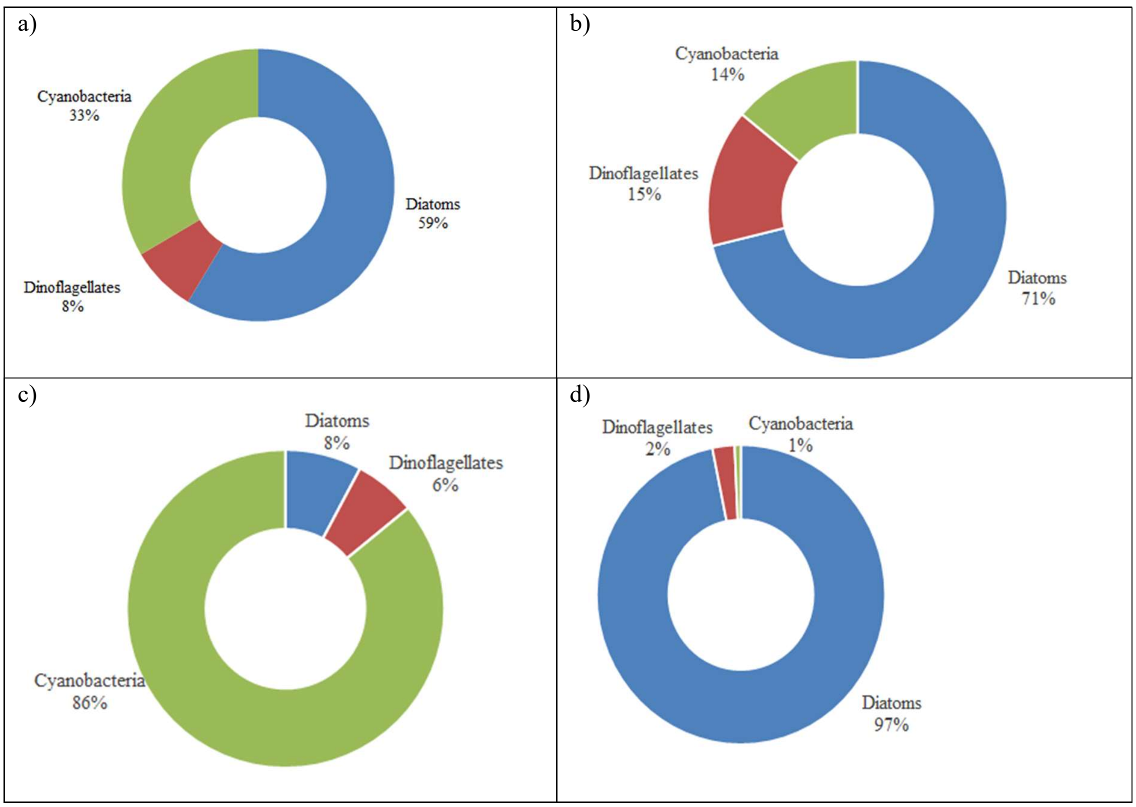

Figure 3: Relative composition of phytoplankton groups in the study area a) Overall; b) Colombo; c) Beruwala; d) Mirissa

Diatoms dominated (60%) in the study area followed by cyanobacteria (31%) and dinoflagellates (9%) (Figure 3a). Diatoms dominated at the three transects of Colombo, Beruwala and Mirissa (78, 60 and 96%) respectively while cyanobacteria were highly abundant in Beruwala (31%) (Figure 3b-3d). The dinoflagellate percentage was higher in Colombo (17%) than in other sites (Figure 3). The dominance of diatoms (83.3%) was also reported by Uttah *et al*., (2013) and these are regarded as the most abundant phytoplankton in turbulent, nutrient-rich waters (Tréguer *et al*., 2018). Further, a higher diatom percentage (91%) was reported in Thalawila, off Kalpitiya (Jayasiri *et al*., 2014) than in this study. Furthermore, the dominance of diatoms has been reported in the Southwestern

Caspian Sea with 58.2% (19 genera, 25 species) followed by dinoflagellates (16.3%) with 7 taxa (Bagheri *et al*., 2012).

Diatoms were dominant (59%) in the study area followed by cyanobacteria (33%) and dinoflagellates (8%) (Figure 3a). Diatoms dominated in the two transects of Colombo and Mirissa (71 and 97 %) respectively while cyanobacteria dominated in Beruwala (86%) (Figure 3b-d). Dinoflagellate percentage was comparatively high in Colombo (15%) than that of other sites (Figure 3). The dominance of diatoms (83.3%) also reported by Uttah *et al*., 2013 and is regarded as the most abundant phytoplankton in turbulent, nutrient-rich waters (Tréguer *et al*., 2018). Further, higher diatom percentage (91%) was reported in Thalawila , off Kalpitiya (Jayasiri *et al*., 2014) than this study. Furthermore, the dominance diatoms has been reported in the Southern Caspian Sea with 58.2% (19 genera, 25 species) followed by dinoflagellates (16.3%) with 7 taxa (Bagheri *et al*., 2012).

There was no observation of any preponderance of harmful phytoplankton species in the study area. The blue green algae were minimal in species richness and abundance except in Beruwala. Only Trichodesmium was present in the forms of bundles and single cells, and it was not in opportunistic proportions. Trichodesmium is known to occur even in the nutrient-poor waters of the warm oceanic gyres (Hegde *et al*., 2008). The eutrophication-indicating species and abundances were not reported in the area during the study. Human activities and physical processes likely influenced diversity and abundance of phytoplankton (Effendi *et al*., 2016).

Table 4: Summary of One-way ANOVA for physicochemical parameters among study sites (df=2)

Parameter	Sum of squares	Mean square	F	p-value
Chlorophyll-a	25.482	12.741	10.383	0.000
TSS	10.346	5.173	2.860	0.050
Nitrite	3.866	1.933	68017.014	0.000
Nitrate	0.004	0.002	4.119	0.027
Phosphate	2.058	1.029	65300.219	0.000
Silicate	2.879	1.439	99.652	0.000

Table 5: Physicochemical parameters in Colombo, Beruwala and Mirissa

Site	Chlorophyll-a (μg/L)	TSS (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Silicate (mg/L)
Colombo	2.38 ± 1.83^{b}	4.94 ± 0.90^{b}	0.770 ± 0.009^{b}	0.034 ± 0.035^{ab}	0.566 ± 0.005^{c}	0.746 ± 0.045^{b}
Beruwala	0.68 ± 0.55^{a}	3.51 ± 0.74^{a}	0.009 ± 0.002^{a}	0.016 ± 0.003^{a}	0.013 ± 0.004^{b}	0.124 ± 0.202^{a}
Mirissa	0.25 ± 0.12^{a}	4.09 ± 2.01^{a}	0.009 ± 0.001^{a}	0.044 ± 0.014^{b}	0.008 ± 0.002^{a}	0.059 ± 0.019^{a}
Mean±SD	1.10 ± 1.42	4.18 ± 1.42	0.263 ± 0.365	0.031 ± 0.024	0.196 ± 0.266	0.310 ± 0.336
Range	0.10–5.51	2.0–7.3	0.01–0.79	0.00–0.08	0.01–0.75	0.04 – 0.81

The different superscript letters in columns indicate significant variation among sites for physicochemical parameters ($p < 0.05$).

Physicochemical parameters

All the physicochemical parameters significantly varied among the study sites of Colombo, Beruwala, and Mirissa (One-way ANOVA; $p < 0.05$; Table 4). The chlorophyll-a level was significantly higher in Colombo than in the other two sites. The TSS level was significantly higher in Colombo than in the other sites, while it was intermediate at Mirissa. Nitrate-N was significantly higher in Colombo and Mirissa than in Beruwala. Phosphate-P was significantly higher in Colombo than in the other sites, while it was intermediate in Beruwala. Silicate-Si was significantly higher in Colombo than in the other sites (Table 5). High nutrient concentrations cause a preferential increase in the biomass and primary production (Chisholm, 1992; Agawin *et al*., 2000). The mean chlorophyll-a concentration in the surface waters off Thalawila was 0.52 ± 0.10 mg m^{-3} with a wide variation of 0.07−2.70 mg m^{-3} (Jayasiri *et al*., 2014), while it is higher in Palk Strait, and chlorophyll-a concentration coincides with a high phytoplankton abundance (Jayasiri, 2007).

Table 6: Summary of one-way ANOVA for diversity indices (df=2)

Index	Sum of squares	Mean square	F	P value
Shannon -Weaver diversity index (H')	7.637	3.818	22.142	0.000
Species richness	313.267	156.633	5.760	0.008
Evenness (J') index	0.688	0.344	25.201	0.000

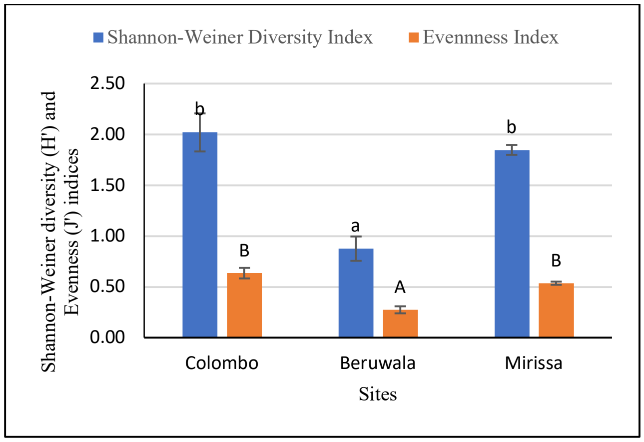

Figure 4: Shannon-Weaver diversity and Pielou's evenness indices at Colombo, Beruwala, and Mirissa. The bars with different letters in lowercase vary significantly among sites for the Shannon-Wiener diversity index and uppercase letters for Pielou's evenness indices ($p < 0.05$).

Diversity indices

Shannon-Weaver and Pielou indices (Magurran, 1996) were used to describe the phytoplankton diversity in the area. According to Bibi and Ali (2013), the values of Shannon-Weaver Index usually fall between 1.5–3.5 and only rarely does it surpass 4.5. In this study, the Shannon-Weaver diversity index and evenness were significantly higher in Colombo (H' = 2.02 ± 0.19) and Mirissa (H' = 1.85 ± 0.40) than in Beruwala (H' = 0.87 ± 0.12). The Shannon-Weaver diversity index and evenness (J) index in the Palk Strait have varied in the range 1.6–2.7 and 0.6–0.9 respectively (Jayasiri, 2007), while in the Gulf of Mannar they are 0.06–2.4 and 0.5–1.0, respectively (Jayasiri & Priyadarshani, 2007).

Ten (10) species of toxic dinoflagellates were reported in the study area. They include: *Alexandrium catenella, Alexandrium monilatum, Gymnodinium sanguineum, Protoperidinium depressum, Protoperidinium curtipes, Prorocentrum micans, Prorocentrum redfeildil, Dinophysis caudate, Noctiluca scintillans,* and *Gymnodinium* sp.

Total phytoplankton abundance significantly correlated with diotoms, dinoflagellates, chlorophyll-a and nitrate-N at p = 0.01. Diatoms significantly correlated with dinoflagellates., chlorophyll-a and nitrate-N at p = 0.01. Dinoflagellates significantly correlated with chlorophyll-a at p = 0.01, and nitrate-N and phosphate-P at p = 0.05 (Table 7). Jayasiri *et al*. (2014) also reported that chlorophyll-a significantly correlated with the phytoplankton density (r = 0.66). Most diatom and dinoflagellate species have been correlated inversely to nutrients in saline pools in the Red Sea (Touliabah *et al*., 2016). Furthermore, Jayasiri (2007) reported a high coefficient of determination ($r^2 = 0.71$) for the relationship between phytoplankton abundance and chlorophyll-a concentration in the surface waters of the Palk Strait.

Table 7: Pearson's bivariate correlations of phytoplankton and physicochemical parameters

Parameter	Diatoms	Dinoflagellates	Cyanobacteria	Chl-a	TSS	NO_2^--N	NO_3^--N	PO_4^{3-}-P	SiO_4^{4-}-Si
Total phytoplankton	0.97[a]	0.78[a]	-0.21	0.60[a]	0.23	0.11	0.78[a]	0.10	0.08
Diatoms		0.74[a]	-0.45	0.58[a]	0.28	0.21	0.81[a]	0.21	0.15
Dinoflagellates			-0.20	0.79[a]	0.19	0.37[b]	0.45[b]	0.37[b]	0.34
Cyanobacteria				-0.19	-0.30	-0.52	-0.32	-0.51	-0.39
Chlorophyll-a					0.34	0.65[a]	0.43[b]	0.66[a]	0.62[a]
TSS						0.38[b]	0.37[b]	0.38[b]	0.33
Nitrite							0.09	1.00[a]	0.94[a]
Nitrate								0.08	0.04
Phosphate									0.93[a]

[a] Correlation is significant at the 0.01 level (2-tailed).
[b] Correlation is significant at the 0.05 level (2-tailed).

The phytoplankton and physicochemical parameters were distributed in different PCA factors. According to the results of the PCA, the original variables could be reduced to three components with eigenvalues greater than 1 (Figure 5), which accounted for 86.5% of the total variance. Chlorophyll-a, NO_2^-, PO_4^{3-}, diatoms and dinoflagellates loaded positively in the component 1 which accounts for 50% of the total variance (Table 8).

Table 8: Significant factor loadings (bold) from phytoplankton and physicochemical properties and percentage of variance explained for the individual component extracted

Parameter	Component		
	1	2	3
Chlorophyll-a	**0.86**	-0.01	0.38
TSS	0.51	-0.09	**-0.50**
NO_2^-	**0.76**	-0.63	0.03
NO_3^-	0.60	0.61	-0.30
PO_4^{3-}	**0.76**	-0.63	0.03
SiO_4^-	0.70	-0.64	0.12
Total phytoplankton	0.70	0.69	0.10
Diatoms	**0.76**	0.60	-0.09
Dinoflagellates	**0.77**	0.33	0.41
Cyanobacteria	-0.55	0.17	0.61
Variance (%)	49.84	25.58	10.62
Total variance (%)	86.05		

The component plot in rotated space for the present study revealed that total phytoplankton and taxonomic groups are affected positively by nitrate (Figure 6). Nitrogen is generally considered as the nutrient with the greatest potential to limit phytoplankton productivity in estuaries and coastal marine waters (Ryther & Dunstan, 1971). Nitrate is the most oxidized form of nitrogen and the end product of the aerobic decomposition of organic nitrogenous matter (Renuka & Rudresh, 2014). The Canonical Correspondence Analysis for the Red Sea has revealed that cyanophyta had a strong positive relationship with water temperature, orthophosphate, ammonia, and reactive silicate while a negative relation has been found between cyanophyta and salinity (Touliabah *et al*., 2016). However, despite the high community diversity, silicate has been found to have a potential role in shaping the community structure (Baraka *et al*., 2021).

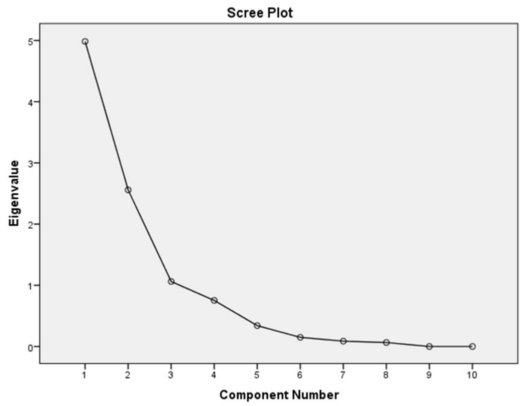

Figure 5: Scree plot for phytoplankton species and physico-chemical parameters

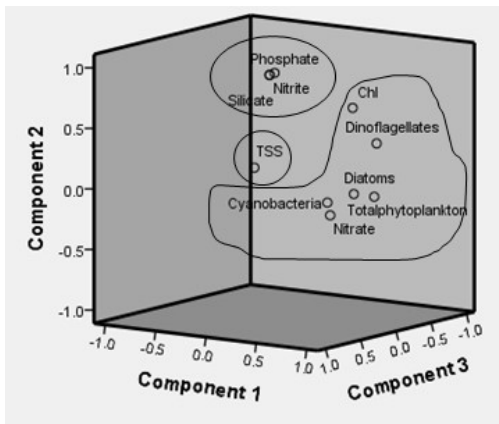

Figure 6: Component plot in rotated space for phytoplankton groups and physicochemical parameters

CONCLUSION

This study documented valuable information on the phytoplankton assemblages in the west and south-west of Sri Lanka in relation to physicochemical parameters. Phytoplankton density is comparatively low in Beruwala compared to Colombo and Mirissa, due to the freshwater discharge of the Kelani and Nilwala Rivers, respectively. High species diversity of phytoplankton was found in Colombo and Mirissa. The study revealed that the contribution of diatoms was higher than those of other taxonomic groups to the total phytoplankton population during the sampling period. Nitrate was found have a potential role in shaping the community structure. There is a possibility of blooming of cyanobacteria in Beruwala when environmental conditions are favourable. However, the low abundance of toxic species of dinoflagellates reported in this study indicates that they would not be a threat to our marine environment. Whilst this study does not record the full community diversity due to the mesh size of the plankton net used and an inability to examine the pico- and nanoplankton, it does demonstrate the low abundance with high diversity pattern of phytoplankton, typical of tropical waters. Diversity and abundance of phytoplankton communities essentially reflects the resource supply into the ecosystem and this information can be used as baseline information for any ocean based disaster or hazard. Thus, regular monitoring of phytoplankton community structure including physicochemical parameters around the seas of Sri Lanka is recommended.

Acknowledgement

The author acknowledges the National Aquatic Resources Research and Development Agency for funding this study and Dr Jagath Rajapaksha for making the location map.

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