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PHYTOPLANKTON COMMUNITY DYNAMICS DURING ASIAN MONSOON SYSTEM PREPONDERATE IN THE COASTAL WATERS OF NORTHERN REGION OF ARABIAN SEA BORDERING PAKISTAN

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Abstract

Seasonal variations in population structure of phytoplankton community with respect to water parameters were investigated from in the coastal and near-shore waters (Manora Island and Mubarak Village stations) bordering Karachi in the northern Arabian Sea. Study was conducted from April 2008 - March 2010 and the data was pooled for: i) Spring inter-monsoon (SIM: March–April), ii) Autumn inter-monsoon (AIM: October–November), iii) Southwest monsoon (SWM: May–September), iv) Northeast monsoon (NEM: December–February). A clear seasonal pattern in phytoplankton population structure and composition was recorded. High phytoplankton productivity was recorded during AIM (MI-1; 126 x 10^3 Cells L^{-l}) and NEM (MI-1; 124x10^3 Cells L^{-l}) periods. Diatoms contribute significantly higher proportion in the phytoplankton community (120x10^3cellsL^{-l}) as oppose to dinoflegellates (54.6x10^3cellsL^{-l}). High phytoplankton taxa counts were recorded at MI stations (200 -208 spp.) during NEM and AIM. High shannon index value 3.5 (SIM) and low 1.14 (SWM) were recorded in near-shore waters at MI and MV, respectively. The Pearson's correlation was calculated and resulted significantly positive correlated among the community and with water parameters. With respect to taxocene structure, MI coatal stations appear to be distinctly different from MI near-shore and MV stations. Influence of reversing monsoonal wind and local effect of Layari outfall on the abundance and distribution is noted.

Key words: Phytoplankton, Monsoon, Northern Arabian Sea, Pakistan.

Introduction

Phytoplankton are the major producers in aquatic food chain, and have a direct or indirect link to the primary consumers (zooplankton, shellfish and finfish) as well as to the organisms at higher trophic levels and hence maintain the flow of energy in an ecosystem (Simčič, 2005; Liyong *et al*., 2005; Sridhar *et al*., 2006; Mathivanan *et al*., 2007; Tas & Gonulol, 2007; Saravanakumar *et al*., 2008). Phytoplankton are good indicator of water quality of a particular area as they are largely controlled by the physicochemical parameter of water, such as, nutrients, temperature and light (Beyruth, 2000; Walsh *et al*., 2001; Liu *et al*., 2004; Atici, 2002; Cetinić *et al*., 2006), together with the circulation pattern of water (Reynolds, 2006). The coastal waters are economically most productive transitional zones for fisheries (Badarudeen *et al*., 1996) and their production is regulated by pelagic autotrophic biodiversity (Kawabata *et al*., 1993). The healthy status of coastal waters depends on the balance of regulating factors (Longhurst *et al*., 1995) and any imbalance may enhance productivity in the area causing bloom conditions which has deleterious impact on fisheries and environmental and human health (Hallegraeff *et al*., 1993).

Arabian Sea is highly influenced by seasonal reversal of winds causing prominent monsoon seasons. The southwest (summer) monsoon caused by land-sea temperature gradient differential effects the physicochemical and biological parameters particularly through upwelling in the western Arabian Sea (Wang *et al*., 2015). The nutrient rich deeper waters are brought to the surface help enhance the primary productivity and ultimately the fisheries yield (Madhupratap *et al*., 2001). The primary production of Arabian Sea is therefore regulated by seasonally upwelled nutrients and light intensity and penetration (Brock *et al*., 1994; Roelke *et al*., 1999) causes seasonality in the biodiversity, composition, abundance, biovolume of phytoplankton and ultimately the efficiency of primary production (Sawant & Madhupratap, 1996). The understanding of planktonic dynamics is important in evaluating an ecosystem. The qualitative, quantitative and seasonal analysis of planktonic organisms may help explain the rate and severity of change in climate which impacts the structure and function of marine communities. Such information from Pakistan waters are generally limited to the taxonomy of phytoplankton (Shameel & Tanaka, 1992; Ghazala *et al*., 2006; Naz *et al*., 2012a, 2012b, 2013a, 2013b) except for some recent studies in the coastal waters which describe seasonal variability in phytoplankton composition distribution (Naz *et al*., 2010; Khokhar *et al*., 2016). Information from the near-shore waters is not available, though some data from off-shore Arabian Sea has been reported (Khokhar *et al*., 2016; 2018). To fill in the gap the present study was carried out to document the seasonal variations in phytoplankton community composition, distribution and abundance, with respect to monsoon seasons, from coastal and near-shore waters along Karachi coast. The importance of regular monitoring of phytoplankton productivity in this very dynamic area is emphasized.

Materials and Methods

The study was carried out at four stations located in the coastal and near-shore waters off of Manora Island (MI) and Mubarak Village (MV) in the northern Arabian Sea (MI-1 coastal water: 24° 44.50 N; 66° 57.50 E; MI-2 near-shore water: 24° 34.00 N; 66° 43.50 E) MV-1 coastal water: 24° 51.50 N; 66° 38.50 E; MV-2 near-shore water: 24° 42.00 N; 66° 27.50 E). Samples were collected monthly and a total of 252 samples were retrieved from four stations during April 2008 - March 2010. Monthly data were pooled as follows to describe monsoonal variations in distribution and abundance of phytoplankton: Spring Inter-Monsoon (SIM; March–April), Autumn Inter-Monsoon (AIM; October–November), Southwest Monsoon (SWM; May–September), Northeast Monsoon (NEM; December–February).

Surface water samples were taken in triplicate from 1m depth at each station using Niskin bottle (1.7 L). Samples were fixed in acidic Lugol's solution and enumerated after settling a known volume (50ml) of samples for 24h in a settling chamber (Hydro-Bios, Germany) as per method described earlier (Utermöhl 1958). The qualitative and quantitative examinations were conducted using inverted microscope (*Olympus*, IX-51, Japan). Species identification was based on morphological characters as described previously (Subrahmanyan, 1946; Wood, 1963, Tomas, 1997; Chaghtai, 2001; Faust & Gulledge, 2002). The phytoplankton nomenclature was updated using information provided in Gómez, (2005; 2012), Guiry & Guiry, (2016), and Index Nominum Algarum (Anon., 2016).

Data was statistically analysed using Pearson Correlation coefficients between the phytoplankton abundance and the water parameters (air and water temperature, salinity, chlorophyll *a*, dissolved oxygen, transparency) (IBM SPSS Statistics version 20). Changes in phytoplankton diversity in different seasons were assessed using Shannon Weiner diversity (H') index and evenness (J) index.

Results

Water parameters: Water parameters were recorded for all the seasons as shown in Table 1. The values of air temperatures (°C) varied between 19.7 ± 0.4 (NEM: MV-1) and 28.9 ± 0.7 (SIM: MV-2) and water temperature between 19.1 ± 3.4 °C (NEM: MV-2) and 28 ± 1.7 °C (AIM: MI-2). The humidity was value lowest (50.4±11%) during AIM and high (77±4.3%) in the SIM periods at MV-2 and MV-1, respectively. Comparing Manora Island (MI-1 and MI-2) and Mubarak Village (MV-1 and MV-2) stations, the high concentration of chlorophyll *a* was recorded at Manora Island stations. Overall three high peaks of chlorophyll *a* were recorded at MI-2 (82 ± 34.2 $\mu g.L^{-1}$: NEM), and MI-1 (71.7 ± 46.5 $\mu g.L^{-1}$; NEM and 64.2 ± 51.3 $\mu g.L^{-1}$: AIM). The Lowest value was recorded during SWM (0.08 ± 1.1 $\mu g.L^{-1}$) at MV-1. Highest dissolve oxygen ($mg.L^{-1}$) concentration was recorded 10 ± 2 $mg.L^{-1}$ during AIM at MV-1 and MV-2 and lowest value 3.4 ± 2.4 $mg.L^{-1}$ was noted during NEM at MV-1.

No significant difference in salinity (PSU) was observed among the stations and seasons, however low (37 ± 0: SIM) and high values (38.3: SWM) were observed at MI-1. The pH values ranged between 7 ± 0 to 7.5 ± 0.25 showed slight variation at all stations; both low and high pH values were recorded at MI-1 and MI-2, respectively. The transparency of water was significantly different; highest transparency was 11.2 ± 2.5 m (MV-1: AIM) low transparency (2.95 ± 0.1m) was recorded during NEM at MI-1 (Table 1).

Phytoplankton abundance: Distinct seasonal pattern phytoplankton abundance was observed in the coastal and near-shore waters of Pakistan. The average abundance of total phytoplankton, diatoms and dinoflegellates are shown in Fig. 1. Result depicts high average abundance of phytoplankton particularly at MI-1 ($126x10^3$ Cells L^{-1}) and MI-2 ($31x10^3$ Cells L^{-1}) during AIM. MI stations also had higher abundance during NEM ($124x10^3$ Cells L^{-1} at MI-1 and $26x10^3$ Cells L^{-1} at MI-2). On the other hand, at MV-1 and MV-2 high values were recorded during AIM only (MV-1: $71x10^3$ Cells L^{-1}; MV-2: $26x10^3$ Cells L^{-1}).

Table 1. Water quality parameters recorded at four stations and monsoonal seasons.

Seasons	Air temperature (°C)				Humidity (%)			
	MI-1	MI-2	MV-1	MV-2	MI-1	MI-2	MV-1	MV-2
SWM (N=10)	25.2 ± 1.2	27 ± 1.2	26.2 ± 2.3	28 ± 0.9	66.7 ± 0.7	72.1 ± 3.5	70 ± 1.2	64 ± 3.8
AIM (N=4)	27 ± 0.5	26.3 ± 0.5	26.5 ± 1.2	27.3 ± 0.4	61 ± 12.5	57 ± 11.3	63 ± 1.1	50.4 ± 11
NEM (N=6)	21.1 ± 0.9	21 ± 0.9	19.7 ± 0.4	20.4 ± 0.9	61.3 ± 4	67 ± 2.9	75 ± 2.1	66 ± 3.9
SIM (N=4)	26.3 ± 0.7	27.4 ± 0.7	28.5 ± 2.3	28.9 ± 0.7	69 ± 0.8	76 ± 1.8	77 ± 4.3	64.5 ± 4.4
	Water temperature (°C)				Salinity (PSU)			
SWM (N=10)	24 ± 1	26 ± 0.5	25 ± 2.1	27 ± 1.2	38.3 ± 1.8	37 ± 0.5	38 ± 0.9	38 ± 0
AIM (N=4)	27 ± 2	28 ± 1.7	26 ± 1.9	26 ± 1.2	37.7 ± 0.9	40 ±1.4	37.5 ± 0.5	37 ± 1.5
NEM (N=6)	21 ± 3	20 ± 0.4	19.2 ± 0.3	19.1 ± 3.4	37.3 ± 0.5	37 ± 0.5	37.5 ± 0.5	37± 0.5
SIM (N=4)	25.5 ± 1	25.4 ± 2	27.4 ± 2.4	26.5 ± 1.6	37 ± 0	38 ± 0.5	38 ± 0.8	38 ± 0.5
	pH				Transparency (m)			
SWM (N=10)	7.4 ± 0.3	7 ± 0.2	7.4 ± 0.2	7 ± 0.2	3.4 ± 0.8	9.1 ± 0.2	10 ± 5	10.3 ± 1.4
AIM (N=4)	7.3 ± 0.2	7.5 ± 0.25	7.5 ± 0	7.5 ± 0	1.8 ± 0.8	8.2 ± 0.3	11 ± 2.5	7.6 ± 1.8
NEM (N=6)	7 ± 0	7 ± 0.2	7 ± 0.2	7 ± 0.2	2.9 ± 0.1	7.3 ± 0.6	9.7 ± 0.4	9.4 ± 0.6
SIM (N=4)	7.2 ± 0.2	7 ± 0.4	7.3 ± 0.25	0 ± 7.5	3.6 ± 0.7	9.1 ± 0.2	9.7 ± 0.3	10.9 ± 1.5
	Dissolved oxygen (mg L^{-1})				Chlorophyll *a* (μgL^{-1})			
SWM (N=10)	7.3 ± 1.5	7.5 ± 1.6	8.9 ± 1.8	8 ± 1.2	8 ± 5.3	6 ± 1.5	0.8 ± 1.1	1.2 ± 2
AIM (N=4)	8.7 ± 1.5	10 ± 1.1	10 ± 2	10 ± 2	64.2 ± 51.3	17 ± 43.1	10.4 ± 49.2	7.9 ± 27
NEM (N=6)	7.8 ± 1.4	7.5 ± 0.7	6.7 ± 2.3	8.5 ± 0.9	71.7 ± 46	82 ± 34.2	8 ± 5.9	14.2 ± 3.4
SIM (N=4)	7.1 ± 2.1	7.1 ± 2	8.17 ± 0.9	7 ± 0.5	27.3 ± 41	3.7 ± 4.2	3.9 ± 1.0	8.14 ± 1.4

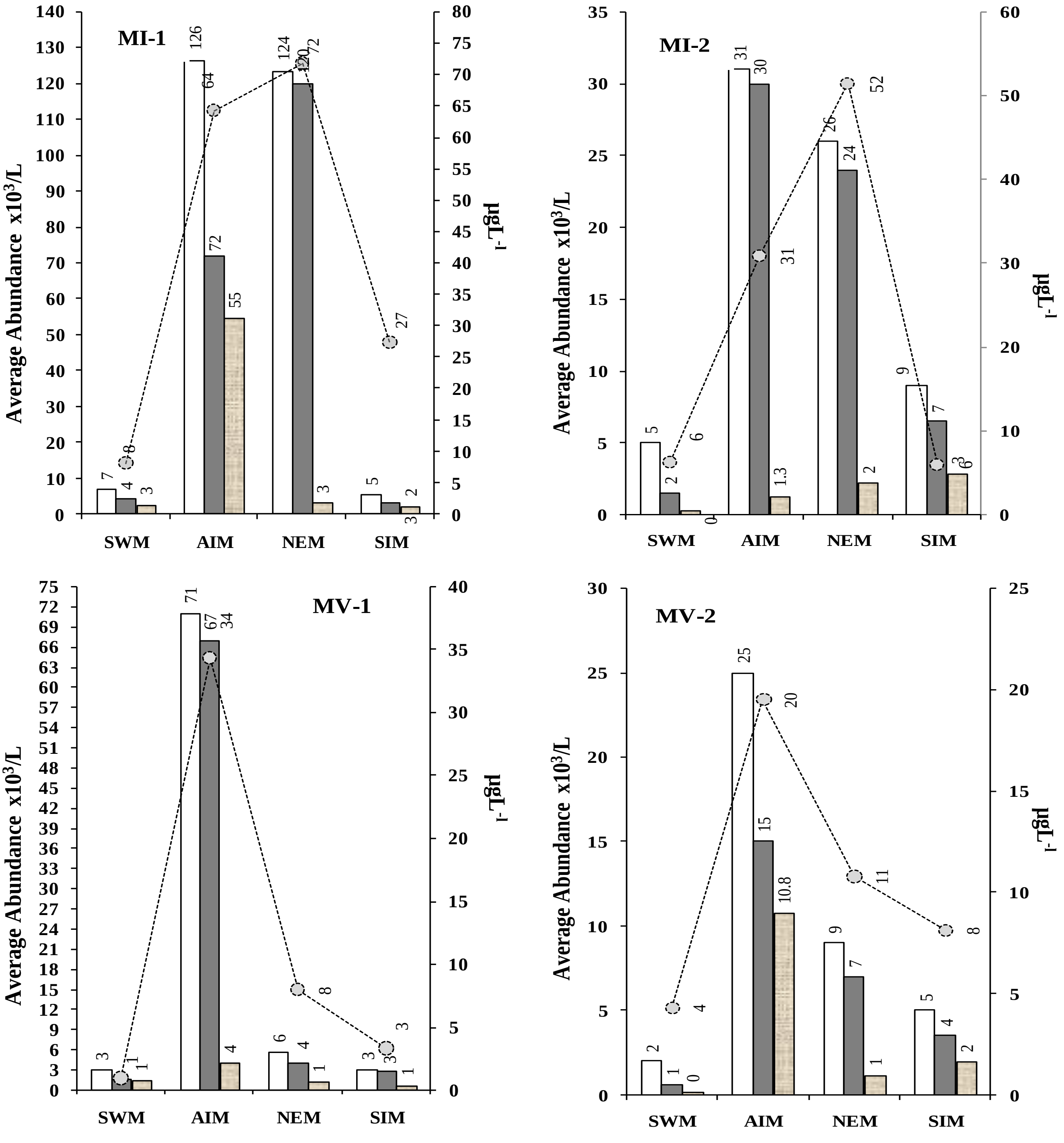

Fig. 1. Phytoplankton, diatoms and dinoflagellates distribution and average abundance during monsoon seasons at coastal (MI-1, MV-1) and near-shore (MV-2, MI-2) stations.

The chlorophyll values followed the phytoplankton abundance pattern at all stations but generally higher values were recorded at MI stations; highest being in NEM period (MI-1: $120x10^3$ cells.L^{-1}; MI-2: $52x10^3$ cells.L^{-1}). At MV stations highest chlorophyll values were recorded during AIM (MV-1: $34x10^3$ mgL^{-1}; MV-2: $20x10^3$ mgL^{-1}). Diatom community constitutes higher proportion in the total phytoplankton abundance compared to dinoflaellates, which were highest during AIM at MV-2 (near-shore; $10.8x10^3$ cells.L^{-1}).

Species diversity: Overall high numbers of phytoplankton species were observed during AIM and NEM periods at MI and MV stations, though the species numbers were comparatively higher in MI waters throughout the year (Fig. 2). Distribution of species recorded during different seasons at MI and MV stations is shown in Table 2. Although the abundance of dinoflagellates was significantly low at all stations, but the number of species were high comparable to diatom species. High species diversity of diatom (43%, SWM; 41%, AIM) and dinoflagellates (52%, NEM: 40%, SIM) were observed at MI-1 and MI-2, respectively. Whereas, at MV-1 and MV-2 the species diversity of diatom (39-40%, NEM) and dinoflagellates (33-37%, NEM) were slightly low (Table 2). On the whole, MI stations had high species diversity compared to MV waters. The estimated diversity indices also show the high value of species diversity (H`) in MI waters (Table 3). High H-index was generally found at all stations ranging between 2.03 (AIM; MI-1) and 3.5 (SIM; MI-2), except for SWM period in the near-shore waters (1.14 (MV-2) to 1.17 (MI-2). The high value of dominance (D) (0.28) and low value (0.2) was recorded during AIM at MI-1 and MV-2, respectively. The equitability (J) index ranged from the lowest value (0.46) during AIM at MI-1 to high values (>0.8) during SIM at MI-1, MI-2 and MV-1 and during NEM at MV-2.

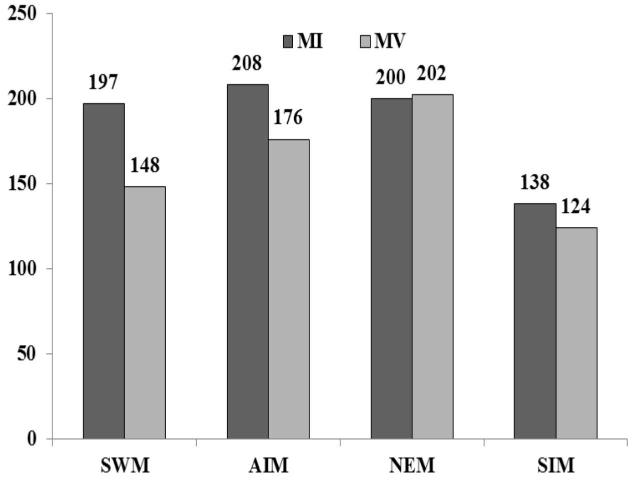

Fig. 2. Phytoplankton taxa counts observed during monsoon seasons at MI and MV stations.

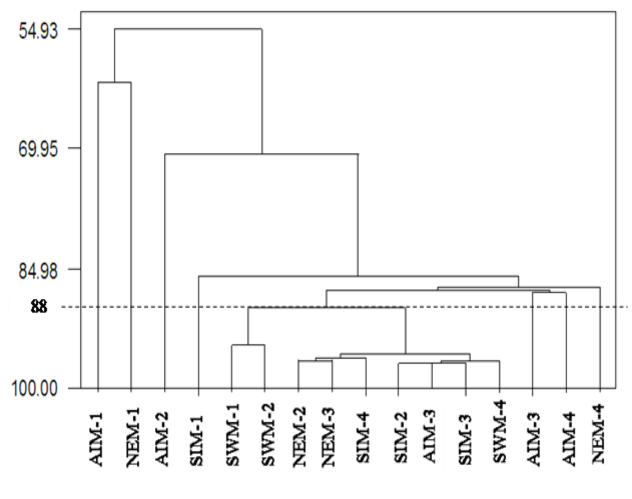

Fig. 3. Cluster analysis of total phytoplankton population abundance and water perametrs correlated with respect to monsoonal periods (AIM, NEM, SIM, SWM) and stations (1= MI-1; 2=MI-2; 3= M-1; 4=M-2).

The data matrix was auto-scaled because of the different magnitudes of the relative compositions of the populations, water parameters correlated on the basis of seasons and stations. The Euclidean distance metric was used to measure the similarity, and k-nearest neighbor clustering was applied to obtain the dendrogram. Overall result showed that high similarities were observed among three stations (MV-1, MV-2 and MI-2), whereas MI coastal waters (MI-1) appear to be distinct from others stations (Fig. 3). MI stations during SWM-1, SWM-2, NEM-2 and SIM-2 appear to be distinct from the rest of the MI stations and are more closely related to MV stations.

Pearson's correlation was used to highlight the relationship between total abundance of phytoplankton, diatoms, dinoflagellates and the environmental parameters (Table 4). Correlation of total phytoplankton abundance had a significant positive correlation with diatom abundance (0.97) and chlorophyll *a* (0.63). Diatom and dinoflagellates also showed positive correlation with chlorophyll *a* (0.61) and (0.26), respectively. A weak correlation was observed between dissolved oxygen with chlorophyll *a*, and pH with water temperature and salinity.

Table 2. Number of diatom and dinoflagellates taxa at Manora (MI-1 and M-2) and Mubarak Village (MV-1 and MV-2) stations.

Season's	MI-1		MI-2	
	Diatom spp.	Dino spp.	Diatom spp.	Dino spp.
SWM	83	86	50	44
AIM	62	86	80	68
NEM	67	93	70	67
SIM	49	63	69	72
Season's	**MV-1**		**MV-2**	
	Diatom spp.	**Dino spp.**	**Diatom spp.**	**Dino spp.**
SWM	56	48	39	55
AIM	74	60	62	51
NEM	78	67	75	60
SIM	22	34	40	63

Table 3. Diversity Indcies calculated for MI and MV coastal and near-shore stations.

Seasons	Dominance (D)	Shannon (H`)	Equitability (J)	Dominance (D)	Shannon (H`)	Equitability (J)
	MI-1			**MI-2**		
SWM	0.09	2.86	0.77	0.04	1.17	0.31
AIM	0.28*	2.03	0.46	0.01*	2.98	0.76
NEM	0.11	2.77	0.70	0.07	3.15	0.81
SIM	0.08	3.28*	0.83*	0.06	3.5*	0.83*
	MV-1			**MV-2**		
SWM	0.16	2.49	0.76	0.03	1.14	0.34
AIM	0.17*	2.33	0.59	0.2*	2.70	0.63
NEM	0.10	2.96*	0.75	0.06	3.3*	0.82*
SIM	0.10	2.81	0.8*	0.10	2.93	0.70

Table 4. Pearson correlations of total abundance of phytoplankton, diatoms and dinoflagellates with the water parameters (Chlorophyll *a*, Water temperature (°C), Salinity (PSU), Dissolved Oxygen µg L^{-1}, pH).

	Phy	Dia	Dino	Chl *a*	W. Temp (°C)	Sali (PSU)	DO (µg l^{-1})
Dia	0.97*						
Dino	0.38	0.14					
Chl *a*	0.63*	0.61*	0.26				
W.Temp (°C)	-0.19	-0.21	0.06	-0.22			
Sali (PSU)	-0.16	-0.15	-0.10	-0.18	0.40		
DO µg l^{-1}	0.05	0.03	0.09	0.29	0.08	0.08	
pH	-0.06	-0.05	-0.05	-0.11	0.34	0.20	-0.08

Phy, Dia, Dino, Chl *a*, W. Temp, Sali, DO, pH. Refer to Phytoplankton, Diatom, Dinoflagellates chlorophyll *a*, Water Temperature, Salinity, Dissolved oxygen and pH. Respectively

* = Significant at probability 0.05

Discussion

Arabian Sea, a semi enclosed sea connected to the Indian Ocean, is known for its unique monsoonal system driven by the seasonal reversal of winds (Sarma, 2003). The consequent variability in the nutrient concentration and other factors in surface waters of the ocean cause remarkable seasonal changes in primary productivity. This physical forcing appears to affect the phytoplankton community dynamics during monsoon seasons along the coast of Pakistan (Northern Arabian Sea). The present study considered four seasons classified on the basis of hydrological parameters; spring inter-monsoon (SIM; March–April), southwest monsoon (SWM; May–September), autumn inter-monsoon (AIM; October–November) and northeast monsoon (NEM; December–February).

Great seasonality in phytoplankton community abundance and distribution in relation with hydrographical parameters is evident in the coastal and near-shore waters of Pakistan. High average abundance of diatom and dinoflagellates during AIM (October–November) and NEM (December–February) is in agreement with similar observation reported from coast of India (central and eastern Arabian Sea) (Subrahmanyan,1960; Sarma, 2013). Previously held information also reflects seasonal distribution of phytoplankton from northern Arabian Sea (Banse, 1987, Saifullah, 1994; Naz *et al*., 2010; Naz *et al*., 2013c, Latif *et al*., 2013; Munir *et al*., 2016), Southeastern Arabian Sea (Jyothibabu *et al*., 2008).

In southwest monsoon the winds intensify and begins to blow in May-June along the central (Oman) western (Somalia) and eastern (Indian coasts) causing the upwelling and brings nutrients rich upwelled waters at the surface accelerates the phytoplankton productivity in the Arabian Sea (Morrison *et al*., 1998). The Arabian Sea is therefore considered as one of the most productive seas (Barber *et al*., 2001) and great seasonality and variability has been reported from central and western parts (Tarran *et al*., 1999). We report on the coastal and near-shore waters along the coast of Pakistan which is a data deficient region. The high cell abundance during AIM and NEM (from October to February) also supports the notion that the upwelled nutrient rich waters along western Arabian Sea (off Oman) are brought to the northern part through up-sloping and causes delayed winter (AIM and NEM periods) blooms.

In earlier studies from western and central regions of the Arabian Sea (Sarma *et al*., 2003, 2013) it was found that great variations exist in grazing rates by microzooplankton in which the primary production always remain higher than grazing. This is mainly because of nutrients gradients among the different stations. These studies have shown the similar results as recorded here. In all four stations significant seasonal variations observed in heterotrophic and autotrophic communities before and after monsoon periods. The coastal station near Manora channel is influenced by the Layari River, carrying sewage and other organic loads, flows out into the coastal waters (MI-1 station) to support primary productivity in the region. Our results not only support that the two localities (MI and MV stations) are different in terms of primary productivity, but particularly suggest that coastal MI station standalone where it respond to the seasonal upwelling in the region and also to the Layari out flux and thus supports the high diversity and abundance in the Manora coastal and near-shore waters.

Although dinoflagellates maintain low abundance compared to diatoms but the number of species were high hence upholds high diversity. High number of diatom and dinoflagellate species have been reported from Manora channel and the coastal waters (Naz *et al*., 2010; Munir *et al*., 2012; Khokhar *et al*., 2016). The composition of diatoms is known to be driven by the availability of nutrients like silicates in the Manora Channel (Naz *et al*., 2010). A stable water column always favors the dinoflagellate species as we found in our observation high species number of dinoflagellates were recorded in NEM period. In general it may be suggested that continuous terrigenous input from Lyari River into the Channel functions to support high primary production. The coastal areas are vulnerable to the loading of anthropogenic nutrients, domestic waste and industrial runoff (Spatharis *et al*., 2007) and thus pose threat to the marine ecosystem where they could alter the species composition and cause massive eutrophication in the region.

High turbidity was observed before and during monsoon period during which high winds causes turbulence in coastal waters and resuspend sediments. Turbid water column restricts the light intensity that negetiely influences the growth of phytoplankton (Chou *et al*., 2012). The dissolved oxygen was also greatly influenced by the monsoonal seasonal variations that cause the influx of terrigenous materials. The high values of dissolved oxygen are the result of upwelling, turbulence, vertical mixing of water, high primary productivity and input of oxygen rich waters that highly affects the metabolism of marine organisms (Thillai, 2010). The chlorophyll concentration has significant positive correlation with phytoplankton abundance. The high values of chlorophyll observed during post monsoon seasons (AIM and NEM) indicate high productivity of photosynthetic community. At times diatom and dinoflagellate cell abundance is low but the chlorophyll values remain high, for example, during AIM at MI-1 and NEM at MI-2 and MV-2. This may suggest considerable contribution of other photosynthetic organisms, such as, cyanobacteria, to the chlorophyll values.

However, low chlorophyll values during SWM and SIM may be attributed to the the influx the turbid conditions caused by high energy winds and low transparency. Similar observations were reported by Panda *et al*., (2012) from Bay of Bengal and Satpathy *et al.*, (2010) from east coast of India.

In summary, the area is evidently influenced by the wind reversal and monsoon periods that control the oceanic processes and coastal upwelling. The relatively high diversity observed at coastal station near Manora channel mouth as compare to other three stations is supported by the effluent flux through Layari River. Dinoflagellates maintain high diversity in the near-shore waters, yet the environmental conditions are not conducive for their growth. The data provided is useful to understand dynamics of phytoplankton in relation to the environmental variables in local waters and can act as baseline for further assessment and monitoring.

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