Pak. J. Bot., 48(2): 799-811, 2016.

DISTRIBUTION AND ABUNDANCE OF DIATOM SPECIES FROM COASTAL WATERS OF KARACHI, PAKISTAN

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Abstract

This is the first comprehensive study on the distribution and abundance of diatom species from the coastal and near-shore waters of Karachi, Pakistan, bordering northern Arabian Sea. A total of 20 genera are recorded in high abundance (*Cerataulina, Chaetoceros, Coscinodiscus, Cylindrotheca, Eucampia, Guinardia, Haslea, Hemiaulus, Lauderia, Lennoxia, Leptocylindrus, Navicula, Nitzschia, Trieres, Planktoniella, Pleurosigma, Pseudo-nitzschia, Rhizosolenia, Thalassionema* and *Thalassiosira*). The most abundant genera were observed *Guinardia*, *Chaetoceros*, *Leptocylindrus*, *Nitzschia* and *Lennoxia* at all stations. Manora coastal station (MI-1) had high abundance corresponding with high Chlorophyll *a* (130µgL^{-1}) values. Minimum abundance and low chlorophyll *a* value (0.05µgL^{-1}) were observed at Mubarak Village coastal station (MV-1). Diatom abundance showed significant correlation with Chlorophyll *a*. In present study 12 centric and 8 pennate forms were recorded and similarly high diversity of centric taxa was observed compared to pennate forms. A total of 134 species are recorded of which 40 species were observed at four stations, 31species at three stations, 23 at two stations and 40 species only at one station. The total phytoplankton and diatom peak abundance was observed during NE monsoon (winter season) associated with nutrient loading through up-sloping of nutrient rich water upwelled off of Oman during South West monsoon. Overall higher diversity was observed at Manora coastal and nearshore stations (MI-1, MI-2) indicating the influence of organic pollution loading from Layari and Malir rivers.

Key words: Diatom species, Diversity, Abundance, Coastal waters, Northern Arabian Sea, Pakistan.

Introduction

In marine ecosystem diatoms are considered as the most successful group among other autotrophic eukaryotes (phytoplankton) population (Dorgham *et al.,* 1987; Dorgham & Moftah, 1989; Jacob & Al-Muzaini, 1990; Subba Rao & Al yamani, 1998; Thompson, 1998). They are dominantly found in diverse range of habitats (fresh, marine, warm, cold, acidic, basic waters and moist places) and across the continents (Muruganantham *et al.,* 2012). Their role as bioindicator of ecological health is well known (Laskar & Gupta, 2009). Diatoms have high species diversity 10,000 to 100,000 taxa (Werner, 1977; Gordon & Drum 1994; Norton *et al*., 1996) and considered as suitable group for biodiversity assessments (Admiraal & Harry, 1980; Mann, 1999; Stevenson & Smol, 2003). Physico-chemical conditions, including nutrient levels, hydrographic conditions, spatial and temporal variations, precipitation, freshwater flux, tidal incursion, winds pattern, currents and biological processes (e.g. grazing, growth) generally regulate the distribution and abundance of diatom species (Patrick & Reimer, 1966; Dugdale, 1967; Kinne, 1970; Ryther & Dunstan, 1971; Smayda, 1980; Kristiansen, 1996; Raibole & Singhi, 2011; Amarnath *et al*., 2013; Naz *et al*., 2010; Mariani *et al.,* 2013). Seasonal reversal of monsoons in the Arabian Sea is most pronounced and maximum seasonal variability is observed in this oceanic basin (Dietrich, 1973; Banse, 1987). Arabian Sea is the only ocean to reverse its circulation completely on a semi-annual basis. The phenomenon results in intense upwelling causing nutrient rich surface waters (Qasim, 1977; Banse, 1987). Summer (SW monsoon; May to Sep) and winter (NE monsoon; Oct to Apr) reversal of winds impact the water circulation which causes upwelling of nutrient rich waters and enhance primary productivity in the northern Arabian Sea (Parab *et al.,* 2006). Variations in environmental condition determine the distribution, abundance and diversity of diatoms and dinoflagellates, and diatoms become abundant in spring and dinoflagellates in summer (Mariani, 2013).

A few reports on phytoplankton blooms and chlorophyll *a* distribution with respect to seasons in northern Arabian Sea are available (Banse & McClain, 1986; Banse, 1987; Brock *et al*., 1991). However, there is a paucity of data regarding seasonal abundance and distribution of diatoms in Pakistani waters (10 m and 50 m contour line). Most studies carried out on diatoms from coastal and near-shore waters were on taxonomic assessment (Chaghtai & Saifullah, 1992; Tabassum & Saifullah, 2010, 2011; Naz *et al.,* 2012a, 2012b) and some on their distribution (Saifullah & Moazzam, 1978; Chaghtai & Saifullah, 1992; Shameel & Tanaka, 1992; Saifullah, 1994; Ghazala *et al.,* 2006; Naz *et al.,* 2010, 2012b, 2013a, 2013b; Tabassum & Saifullah, 2011, 2012; Latif *et al*., 2013). The present work was therefore, designed to investigate and compare seasonal variations in composition, distribution and abundance of diatoms in relation to water parameters from the coastal and near-shore waters of Karachi.

Study area: Four stations were selected along the Karachi coast (Fig. 1): Station 1 (MI-1; 24°45'4.75"N, 66°59'9.29"E), 10m depth, off Manora Island (MI); Station 2 (MV-1; 24°52'6.18"N, 66°37'21.86"E), 10m depth, off Mubarak Village (MV); Station 3 (MV-2; 24°45'39.12"N, 66°26'13.38"E), 50m depth, off MV; Station 4 (MI-2; 24°35'5.91"N, 66°46'26.34"E), 50m depth, off MI (Fig. 1). MI-1 & MV-1 are referred as coastal waters and MV-2 and MI-2 as near-shore waters.

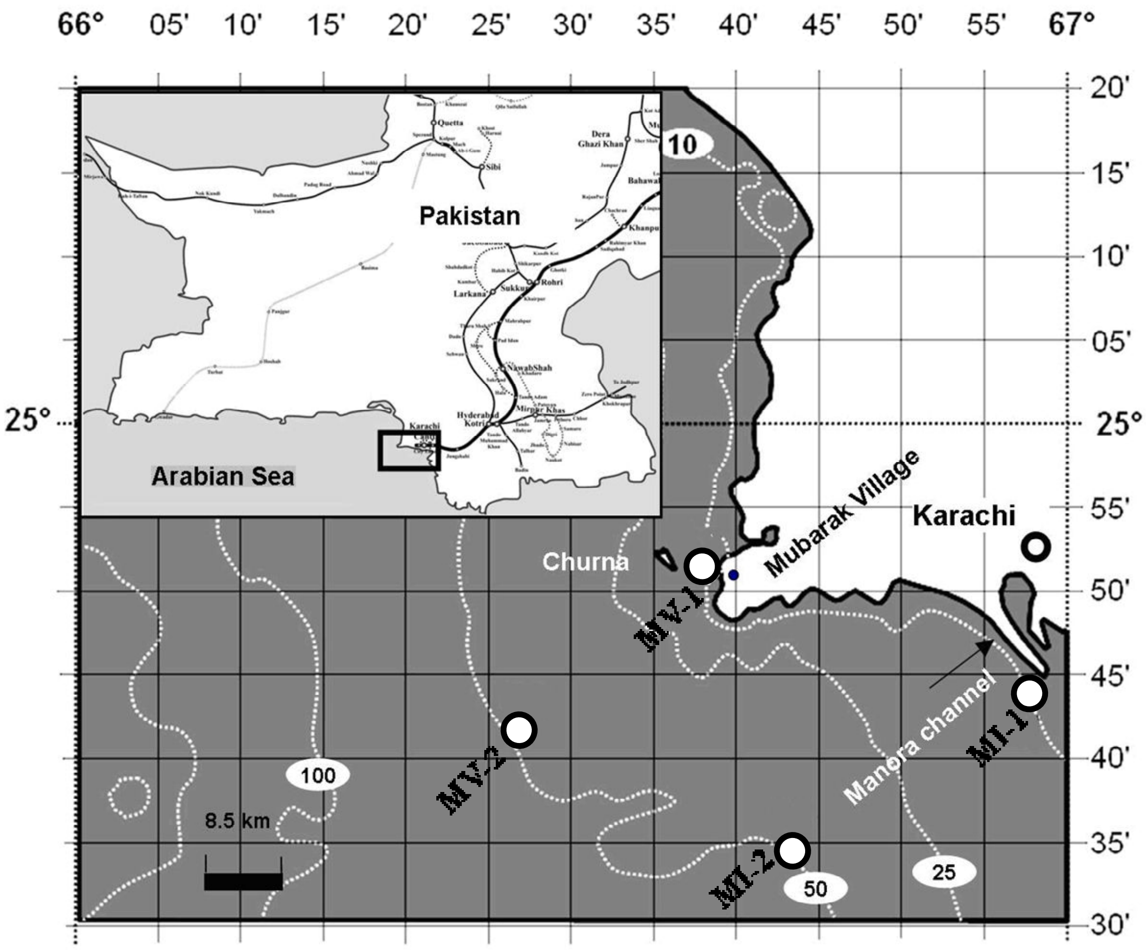

Fig. 1. Map of Karachi coast showing location in the coastal and near-shore waters off of Manora Island (MI-1; 10m contour line and MI-2; 50m contour line) and Mubarak Village (MV-1; 10m contour line and MV-2; 50m contour line).

Materials and Method

Water samples were collected every month from each station in triplicate from 1 m below surface using Niskin bottle (1.7 Liter) during day time, samples were fixed in 1% acid Lugol's solution and stored in brown bottles at 4°C. Cell density was analyzed using previously described settling method (Utermohl, 1958). Samples were allowed to settle for 24 hours in settling chamber (50 ml; Hydro-Bios, Germany). Cells were counted using an inverted microscope (*Olympus,* IX-51, Japan). Identification of species was based on morphological characteristics (Subrahmanyan, 1946; Wood, 1963; Tomas, 1997). Current names of species were checked from three data bases including World Register of Marine Species (Anon., 2014) [http://marinespecies.org], Algae Base (Guiry & Guiry, 2014) [http://algaebase.org;] and Index Nominum Algarum (Anon., 2014) [http://ucjeps. berkeley.edu/ina/img].

For the measurement of chlorophyll (Chl *a*), 250-1000 ml of samples were filtered through GF/F (0.7 µm; Whatman), extracted with 90% acetone and absorbance was recorded (Shimadzu UV-visible spectrophotometer) in accordance with Strickland & Parsons (1972). Water and air temperatures (mercury thermometer), salinity (Refractometer), transparency (Secchi disc), dissolve oxygen (DO; HANNA-C100) and pH (Hanna, HI-9023) were also recorded. Humidity data was obtained from National Weather Forecasting Centre, Meteorological Department Pakistan (Anon., 2014; [http://www.pmd.gov.pk]). Statistical parameters (Pearson correlation) were calculated using computer software Minitab (Version 5).

Results

Seasonal abundance: Phytoplankton cell abundance showed fluctuating data ranging from a minimum value of 1.1 x 10^3cells L^{-1} (MV-1) to a maximum value of 656.17 x10^3cells L^{-1} (MI-1). Generally higher values were recorded during Oct to Jan (Fig. 3) with some yearly differences. It is interesting to note that coastal stations (MI-1, 56 x 10^3 L^{-1}; MV-1, 14.9 x 10^3 L^{-1}) exhibit higher cell abundance as compared to corresponding near-shore stations (MV-2, 10.06 x 10^3 L^{-1}, MI-2, 18.4 x 10^3 L^{-1}).

Diatom abundance (Fig. 3) data also reflect high abundance during winter season (NE Monsoon). Percent contribution of diatom in the total phytoplankton population (Fig. 3) evidently reflects that diatoms generally share more than 50% of phytoplankton abundance except for a few instances. With respect to stations there is no clear pattern of diatom proportions in phytoplankton abundance. Stations MI-1 (80%; coastal waters MI) and MV-2 (67%; near-shore off MV) showed lower average contribution of diatom compared to stations MV-1 (89%; coastal waters) and MI-2 (91%; near-shore; Fig. 3).

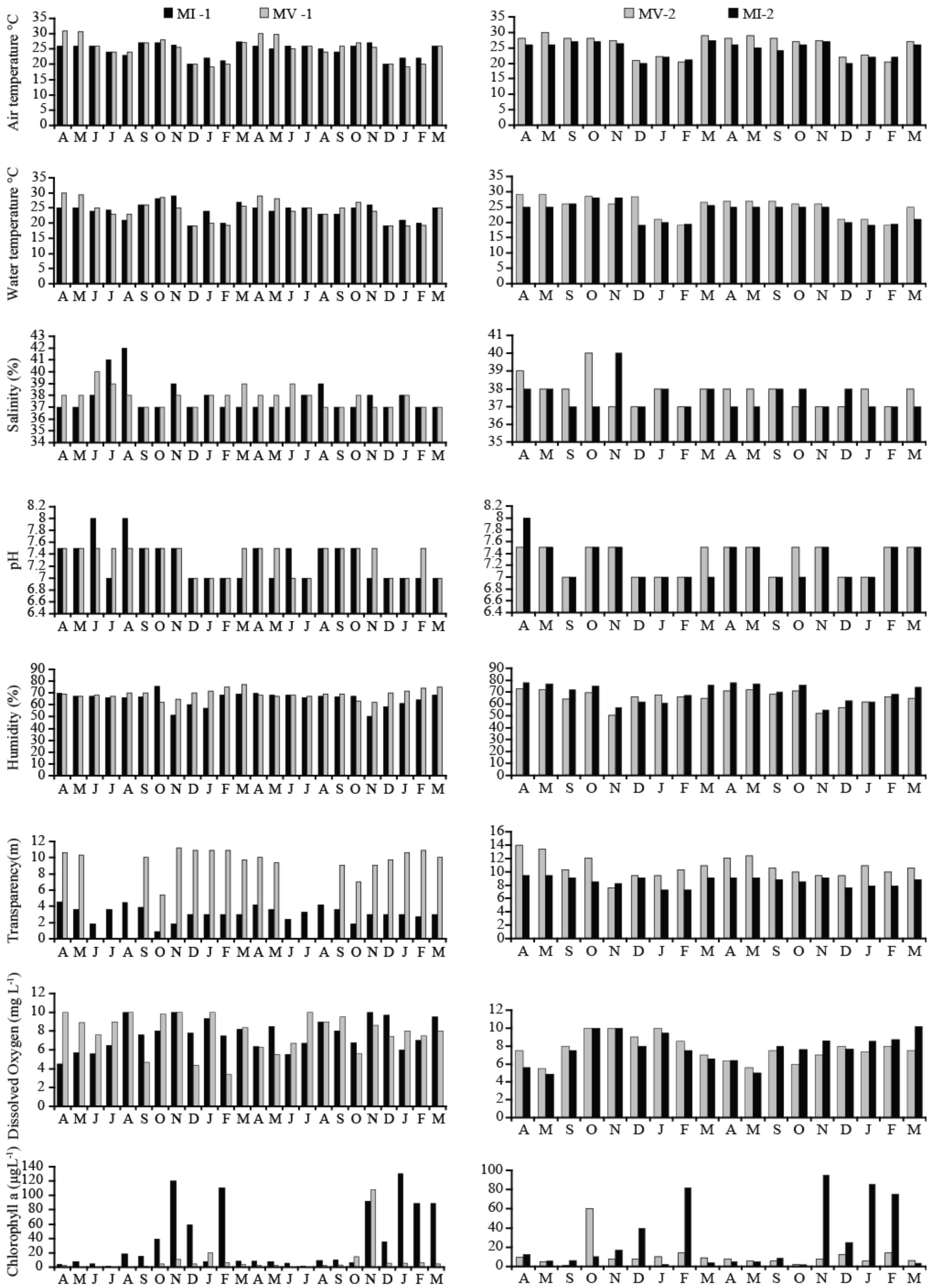

Fig. 2. Seasonal variations in water parameters (air and water temperature (ºC), salinity (PSU), pH, humidity (%), transparency (m), dissolved oxygen (mgL^{-1}) & chlorophyll *a* (µgL^{-1}) concentrations observed in the coastal (Ml-1& MV-1) and near-shore (MV-1 & MV-2) waters.

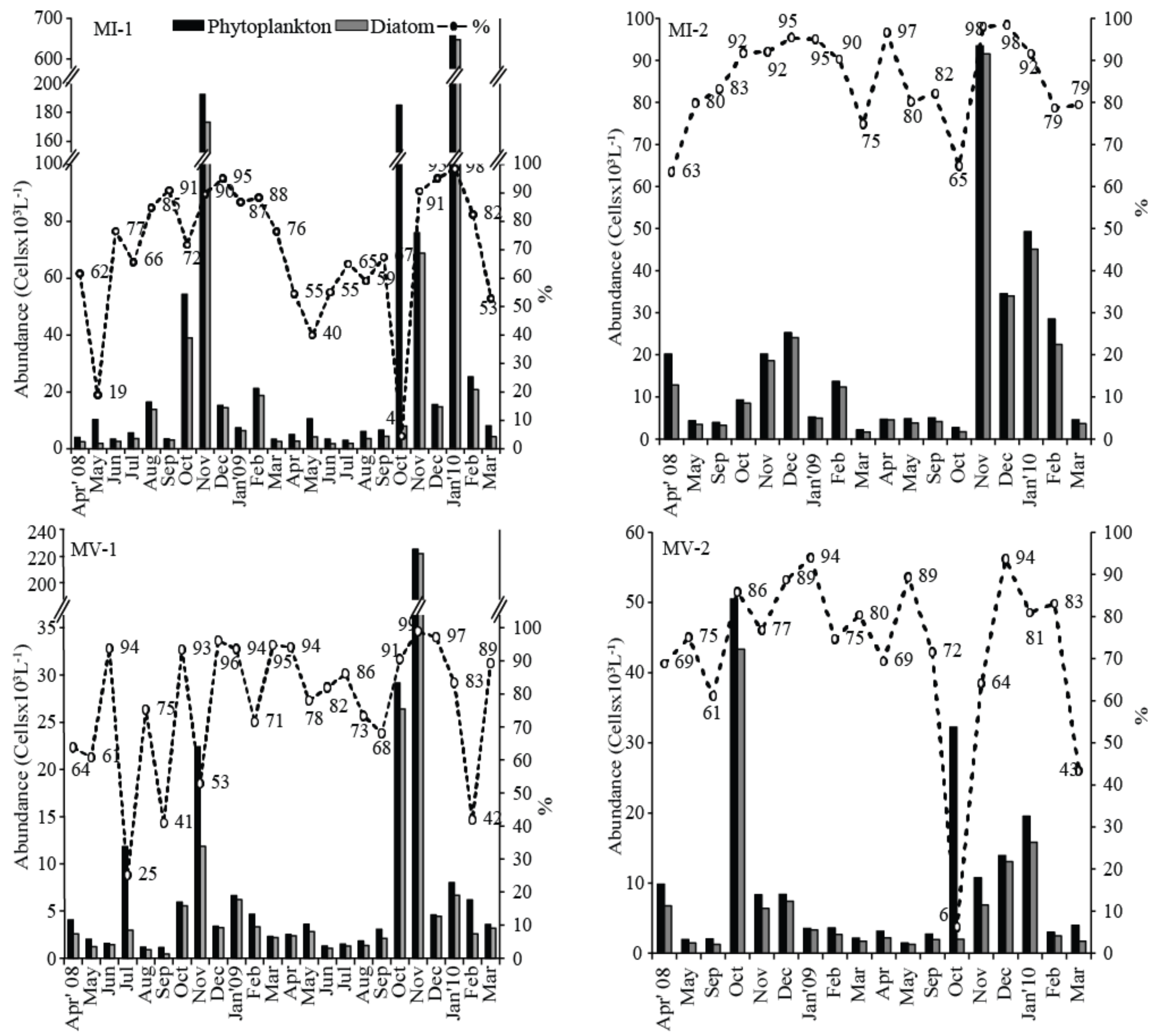

Fig. 3. Seasonal variations in the total abundance (Cells x10^3 L^{-1}) of phytoplankton and diatom and percent contribution of diatom in the total phytoplankton population recorded from the coastal (MI-1 & MV-1) and near-shore (MV-2 & MI-2) waters.

Abundance and distribution: genera: A total of 20 dominant genera were recorded (12 centric and 8 pennate forms) in samples from all stations (Table 1). The data reveals again that stations MI-1 and MI-2 had diverse and abundant population of diatoms compared to stations MV-1 and MV-2. Total abundance of 20 dominant genera at MI-1 and MI-2 was higher (4.6 x$10^3$$L^{-1}$ and 2.1x$10^3$$L^{-1}$, respectively) compared to MV-1 and MV-2 (1.79 x$10^3$$L^{-1}$ and 0.88 x$10^3$$L^{-1}$, respectively). Six genera were recorded in abundance from MI-1 including *Leptocylindrus* (Jan 2010, 68 x$10^3$$L^{-1}$), *Nitzschia* (Jan 2010, 67 x10^3 L^{-1}), *Guinardia* (Nov 2008; 26 x$10^3$$L^{-1}$), *Trieres* (Nov 2008; 12.3 x$10^3$$L^{-1}$), *Thalassionema* (Jan 2010, 18 x 10^3 L^{-1}), and *Coscinodiscus* (Nov 2009, 11.19 x10^3 L^{-1}). Table 1.

Three genera were found abundant at MV-1, namely, *Chaetoceros* (Nov 2009, 156 x10^3 L^{-1}), *Leptocylindrus* (Nov 2009, 34x10^3 L^{-1}), and *Pseudo-nitzschia* (Nov 2009, 16x10^3 L^{-1}), while only one genus *Guinardia* (Oct 2008, 35x$10^3$$L^{-1}$) was dominant at MV-2. Five genera including *Chaetoceros* (Nov 2009, 25x$10^3$$L^{-1}$) *Guinardia* (Nov 2009, 21 x 10^3 L^{-1}), *Navicula* (Nov 2009, 17 x 10^3 L^{-1}), *Nitzschia* (Feb 2010, 12 x 10^3 L^{-1}), and *Pseudo-nitzschia* (Nov 2009, 16.21 x 10^3 L^{-1}) were dominant at MI-2. Minimum cell abundance was recorded for genus *Navicula* from station MI-1 (Feb 2009 and 2010 0.35 x 10^3 L^{-1}), and genus *Planktoniella* at the stations MV-1, MV-2, MI-2 (Feb 2009, 0.07 x 10^3 L^{-1}; Jan 2010, 0.16 x 10^3 L^{-1}; Feb 2009, 0.09 x 10^3 L^{-1} respectively; Table 1, Fig. 4). Maximum percent contribution of each dominant genus, shown in (Fig. 4) was 54% for *Chaetoceros* spp.; MV-1), followed by *Guinardia* spp. (40%; MI-1), *Leptocylindrus* spp. (16%; MV-1), *Eucampia* spp., *Navicula* spp. (6%; MV-2 and MI-2 respectively), *Pseudo-nitzschia* spp. (14%; MI-2 and 6-10%; MI-1 and MI-2), *Nitzschia* spp. & *Lennoxia* sp. (9%; MI-1), *Thalassionema* spp. (6%; MI-2 and 4%; MV-2, respectively), *Haslea* spp. (5%; MI-1). *Coscinodiscus, Cerataulina, Trieres, Rhizosolenia Hemiaulus, Cylindrotheca, Lauderia*, *Planktoniella* and *Thalassiosira* had variable low percent contribution at all stations (Fig. 4).

Table 1. Maximum mean abundance (Cells x10^3 L^{-1}) of diatom genera distributed in the coastal (MI-1 & MV-1) and near-shore (MV-2 & MI-2) waters. Month of occurrence, temperature & salinity are given in the parenthesis.

Genera	Stations			
	MI-1	MI-2	MV-1	MV-2
Cerataulina	5.15 (Jan 2010, 21 °C, 38PSU)	2.80 (Nov 2009, 25°C,37PSU)	0.367 (Jan 2009, 20°C,38PSU)	0.813 (Jan 2010, 21°C,38PSU)
Chaetoceros	5.47 (Feb 2010, 20°C,37PSU)	24.84 (Nov 2009, 25°C,37PSU)	156.45 (Nov 2009, 24°C,37PSU)	3.89 (Jan 2010, 21°C,38PSU)
Coscinodiscus	11.19 (Nov2009, 26°C,38PSU)	0.44 (Apr 2008, 25°C,38PSU)	0.34 (July 2009, 19°C,38PSU)	0.48 (Nov 2008, 26°C,37PSU)
Cylindrotheca	1.56 (Dec2009, 19°C,37PSU)	4.58 (Nov 2009, 25°C,37PSU)	0.337 (July 2009, 23°C,39PSU)	0.65 (Dec 2008, 28.3°C,37PSU)
Eucampia	5.45 (Nov2009, 26°C,38PSU)	2.00 (Nov 2008, 28°C,40PSU)	0.913 (May 2009, 28°C,38PSU)	4.51 (Jan 2010, 21°C,38PSU)
Guinardia	26.27 (Nov2008, 29°C,39PSU)	20.83 (Nov 2009, 25°C, 37PSU)	4.614 (Nov 2009, 24°C,37PSU)	34.86 (Oct 2008, 28.5°C,40PSU)
Haslea	0.36 (Feb 2009-10, 20°C, 37PSU)	0.31 (Dec 2008, 19°C,37PSU)	0.313 (Dec 2008, 19°C,37PSU)	0.581 (Oct 2009, 26°C,37PSU)
Hemiaulus	3.95 (Jan 2010, 21°C,38PSU)	3.43 (Nov 2009, 25°C,37PSU)	1.953(Dec 2008, 19°C,37PSU)	0.64 (Dec 2009, 21°C,37PSU)
Lauderia	0.89 (Aug 2008, 21°C,42PSU)	1.06 (Apr 2008, 25°C,38PSU)	0.547 (Dec 2009, 19°C,37PSU)	0.31 (Sep 2009, 27°C,38PSU)
Lennoxia	42.19 (Jan 2010, 21°C, 38PSU)	5.47 (Jan 2010, 19°C,37PSU)	0.513 (Oct 2008, 19°C,37PSU)	1.74 (Oct 2008, 28.5°C,40PSU)
Leptocylindrus	67.7 (Jan 2010, 21°C,38PSU)	3.3 (Nov 2009, 25°C,37PSU)	33.98 (Nov 2009, 24°C,37PSU)	1.6 (Oct 2008, 28.5°C, 40PSU)
Navicula	0.35 (Feb 2009-10, 20°C,37 PSU)	16.78 (Nov 2009, 25°C, 37PSU)	0.17 (Aug 2008, 21°C,38PSU)	0.42 (Oct 2008, 28.5°C,40PSU)
Nitzschia	66.78 (Jan 2010, 21°C,38PSU)	11.95 (Feb 2010, 19.3°C, 37PSU)	5.333 (Nov 2008, 25°C,38PSU)	1.52 (Nov 2009, 26°C,37PSU)
Trieres	12.3 (Nov 2008, 29°C,39PSU)	6.59 (Dec 2009, 20°C,38PSU)	0.52 (Mar 2010, 23°C,39PSU)	0.5 (Dec 2008, 28.3°C, 37PSU)
Planktoniella	0.66 (Jan 2010, 21°C,38PSU)	0.09 (Feb 2009, 19.3°C, 37PSU)	0.073 (Feb 2009, 19.2°C,38PSU)	0.16 (Jan 2010, 21°C,38PSU)
Pleurosigma	1.5 (Dec 2009, 19°C,37PSU)	0.14 (Apr 2009, 25°C, 37PSU)	0.147 (Dec 2009, 19°C,37PSU)	0.49 (Nov 2009, 26°C, 37PSU)
Pseudo-nitzschia	0.52 (Apr 2009, 25°C,37PSU)	16.21 (Nov 2009, 25°C, 37PSU)	16.21 (Nov 2009, 24°C,37PSU)	2.97 (Oct 2009, 26°C, 37PSU)
Rhizosolenia	0.98 (Nov 2009, 26°C,38PSU)	1 (Nov 2008, 28°C, 40PSU)	0.434 (Nov 2008, 25°C,38PSU)	1.167 (Apr 2008, 29°C,39PSU)
Thalassionema	18.1(Jan 2010, 21°C,38PSU)	4.38 (Dec 2008, 19°C,37PSU)	4.387 (Dec 2008, 19°C,37PSU)	1.10 (Nov 2009, 26°C,37PSU)
Thalassiosira	0.69 (Feb 2010, 20°C,37PSU)	1.07 (Apr 2008, 25°C,38PSU)	0.126 (Nov 2008, 25°C,38PSU)	0.181 (Nov 2008, 26°C,37PSU)

Abundance and distribution: species: Stations MI-1 and MI-2 appear to have high species diversity exhibiting 91 and 94 species, respectively. On the other hand, MV-1 (84 spp.) and MV-2 (76 spp.) showed comparatively low diversity (Table. 2). Species diversity in each genus was more or less similar at all four stations. However, genus *Chaetoceros* showed high diversity at all stations (17-22 spp.) followed by genera having 6-10 species (*Pleurosigma*, *Rhizosolenia* and *Thalassiosira*) and those having 4-6 species (*Coscinodiscus, Nitzschia*). Remaining 14 genera had 1-5 species (Table 2).

In the selected 20 dominant genera a total 134 species were recorded. On the basis of their occurrence 40 species were considered as dominant (recorded from all four stations), 31species were abundant (observed at three stations), 23 species were common (occurring at two stations) and 40 species were rare (found at only at one station). It may be noted that occurrence and abundance of species vary with respect to station (Table 2). With respect to cell abundance a total of 3 species were dominant (>75x10^3 cells L^{-1}) recorded only at MI-1 (*Guinardia delicatula*, *Leptocylindrus minimus* and *Pseudonitzschia fraudulenta*), whereas, abundantly occurring species (25-75x10^3 cells L^{-1}) were 6 (MI-1), 2 (MI-2) and 1 (MV-1 and MV-2), respectively. Large number of species were common (1-25x10^3 cells L^{-1}) at station MI-1 (39), MI-2 (33), MV-1 (27) and MV-2 (21). Similarly, a large number of rare species (1-1x10^3 cells L^{-1}) were recorded from MI-1 (43), MI-2 (59), MV-1 (62) and MV-2 (54) (Table 2).

Environmental conditions & diatom abundance: The seasonal data of water quality parameters determined at the time of collection is depicted in Fig. 2. The air and water temperature fluctuated between a minimum of 19.0 °C (Dec. 2008, Jan 2009, 2010) and a maximum of 30°C - 31 °C (Apr-2008). Salinity values varied with a narrow range between 37 - 42 PSU at all four stations. High salinity (42 PSU) was recorded at MI-1 in Aug. At MV-1, MV-2 and MI-2 salinity peaks appeared in Jun, Oct and Nov, respectively. Values for pH varied between 7.0 and 8.0 and percent humidity values ranged from 50% - 78% during study period. Transparency (Secchi depth) ranged between 0.9 – 14m (Fig. 2). It may be noted that stations off of Manora Island had low transparency (0.9 - 4.57m MI-1 and 7.3-9.4m MI-2) compared to other two corresponding station (5.4-11.27m MV-1 and 7.62-14.0m MV-2, respectively). Overall dissolved oxygen values ranged at all stations were 3.4 mg L^{-1} to 10 mg L^{-1}. It appears that generally high DO (>5.0 mg L^{-1}) concentration prevails at the study sites and only at four instances low DO values were recorded (3.4 mg L^{-}1, MV-1, Feb.; 4.4 mg L^{-1}, MV-1, Dec.; 4.5 mg L^{-1}, MI-1, Apr. and 4.9 mg L^{-1}, MI-2, May). Chlorophyll *a* content in water, indicating primary production had values ranged from 0.05–130 μgL-^{1}; highest value (Jan 2010) being at MI-1 and the lowest (Jul 2009) at MV-1 (Fig. 2).

Pearson correlation was applied to investigate relationship between total abundance of diatom species and water parameters (Table 3). Total abundance of diatom species showed significant positive relationship with Chlorophyll *a* at all stations. Total abundance has week positive correlation with salinity (MI-1, MV-2), DO (MV-1, MV-2, MI-2), transparency (MV-1, MV-2), pH (MV-1, MV-2, MI-2) and temperature (MV-2).

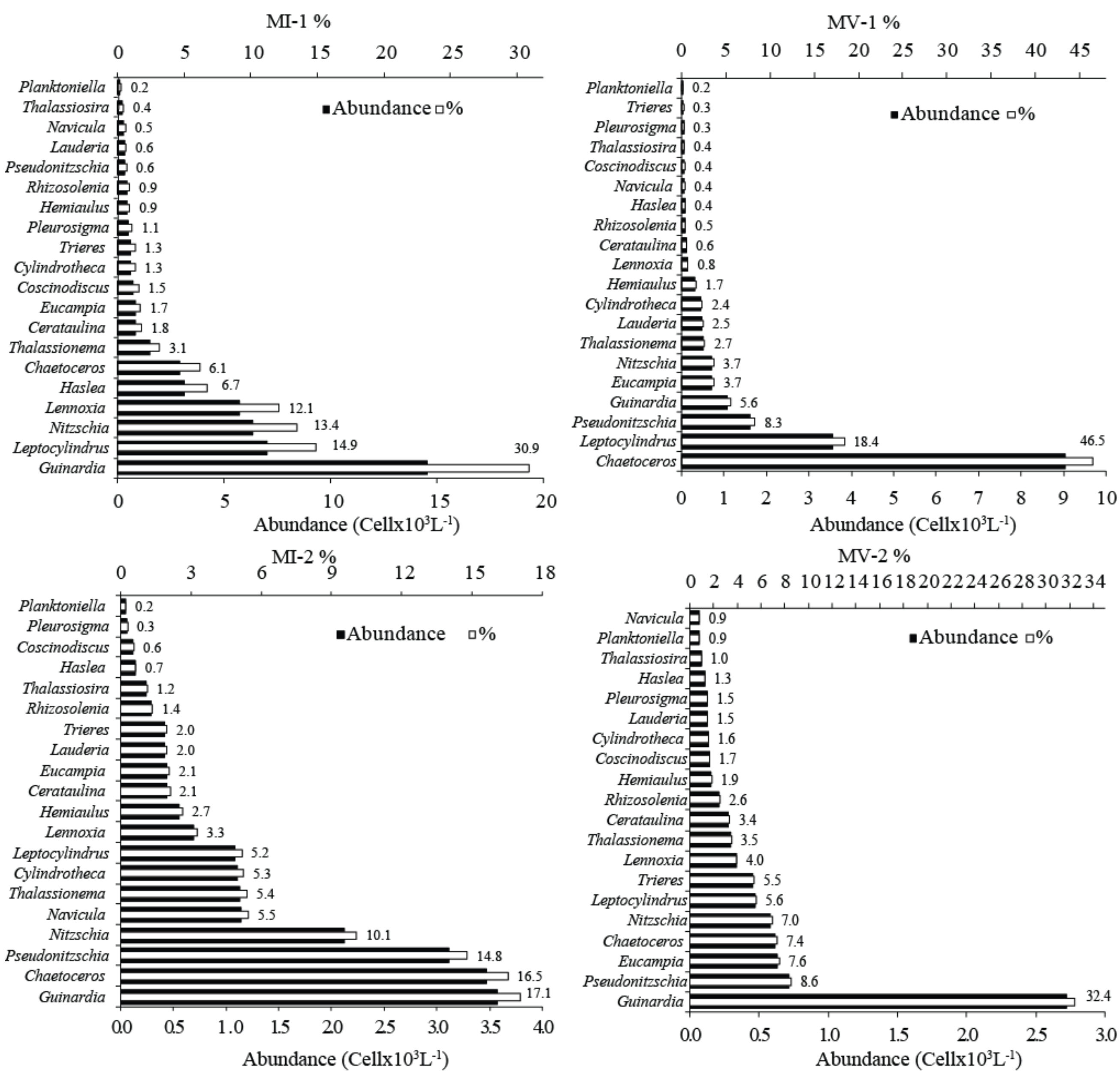

Fig. 4. Abundance and percentage contribution of twenty dominant diatom genera in the coastal (MI-1 & MV-1) and near-shore (MV-2 & MI-2) waters.

Table 2. List of diatom species identified from coastal (MI-1 & MV-1) and near-shore (MV-2 & MI-2) waters (Apr 2008 - Mar 2010) showing distribution and abundance (cells L^{-1}) for recorded species (Rare:1-1000 = +, Common: 1001-25000 = ++, Abundant: 25001 - 75,000 = +++ and Dominant: >75,001 = ++++).

Dominant genera	Species	Stations			
		MI1	MI2	MV1	MV2
Cerataulina	*Cerataulina* sp.1	+	+	-	-
(4 spp.)	*Cerataulina* sp.2	-	+	+	++
	Cerataulina dentata Hasle 1980	+	+	-	-
	Cerataulina pelagica (Cleve) Hendey, 1937	++	++	++	++
		3	**4**	**2**	**2**
Chaetoceros	*Chaetoceros* sp.1	++	++	++	+
(30 spp.)	*Chaetoceros* sp.2	-	++	-	+
	Chaetoceros sp.3	++	++	++	++
	Chaetoceros affinis Lauder, 1864	+	-	-	-
	Chaetoceros anastomosans Grunow, 1882	++	+++	++	+
	Chaetoceros atlanticus Cleve, 1873	++	++	-	+
	Chaetoceros atlanticus var. *neapolitanus* (Schroeder) Hustedt, 1930	++	+	++	-
	Chaetoceros borealis Bailey, 1854	-	-	+	-
	Chaetoceros brevis F. Schütt, 1895	++	+	++	-
	Chaetoceros coarctatus Lauder, 1864	++	+	++	++
	Chaetoceros castracanei Karsten, 1905	++	++	++	++
	Chaetoceros compressus Lauder, 1864	++	++	++	++
	Chaetoceros convolutus Castracane, 1886	++	-	-	+
	Chaetoceros costatus Pavillard, 1911	+	+	++	-
	Chaetoceros curvisetus Cleve, 1889	++	++	++	+
	Chaetoceros danicus Cleve, 1889	++	+	-	+
	Chaetoceros decipiens Cleve, 1873	++	++	-	+
	Chaetoceros densus (Cleve) Cleve, 1899	+	+	+	-
	Chaetoceros diversus Cleve, 1873	+	++	+	+
	Chaetoceros eibenii Grunow, 1882	-	-	+	-
	Chaetoceros granii (Cleve) Nomen, 1899	-	-	+	-
	Chaetoceros laciniosus F. Schütt, 1895	-	+	+	+
	Chaetoceros lauderi Ralfs, 1864	-	-	-	+
	Chaetoceros lorenzianus Grunow, 1863	+	++	+++	+
	Chaetoceros neglectus Karsten, 1905	-	-	+	-
	Chaetoceros peruvianus Brightwell, 1856	-	+	-	-
	Chaetoceros pseudocurvisetus Mangin, 1910	+	++	+	-
	Chaetoceros radicans F. Schütt, 1895	++	-	-	+
	Chaetoceros socialis H.S.Lauder, 1864	+	++	++	-
	Chaetoceros teres Cleve, 1896	-	+	-	-
		21	**22**	**20**	**17**
Coscinodiscus	*Coscinodiscus* sp.1	++	+	+	+
(10 spp.)	*Coscinodiscus argus* Ehrenberg, 1839	-	-	+	-
	Coscinodiscus asteromphalus Ehrenberg, 1844	-	-	+	-
	Coscinodiscus centralis Ehrenberg, 1844	+	+	+	-
	Coscinodiscus concinnus W. Smith, 1856	+	-	-	-
	Coscinodiscus granii Gough, 1905	-	+	+	+
	Coscinodiscus marginatus Ehrenberg, 1844	++	+	-	+
	Coscinodiscus oculus-iridis (Ehrenberg) Ehrenberg, 1840	-	+	+	-
	Coscinodiscus radiatus Ehrenberg, 1840	-	+	-	+
	Coscinodiscus wailesii Gran & Angst, 1931	-	-	-	+
		4	**6**	**6**	**5**
Cylindrotheca	*Cylindrotheca* sp.1	+	+	+	+
(3 spp.)	*Cylindrotheca* sp.2	+++	++	++	++
	Cylindrotheca fusiformis Reimann & J.C. Lewin, 1964	-	-	-	+
		2	**2**	**2**	**3**

Table 2. (Cont'd.)

Dominant genera	Species	Stations			
		MI1	**MI2**	**MV1**	**MV2**
Eucampia	*Eucampia* sp.1	+	+	-	+
(3 spp.)	*Eucampia cornuta* (Cleve) Grunow, 1883	++	++	+	-
	Eucampia zodiacus Ehrenberg, 1839	++	++	++	++
		3	**3**	**2**	**2**
Guinardia	*Guinardia delicatula* (Cleve) Hasle, 1997	++++	+++	++	++
(3 spp.)	*Guinardia flaccida* (Castracane) H. Peragallo, 1892	+++	++	++	++
	Guinardia striata (Stolterfoth) Hasle, 1996	++	++	++	+++
		3	**3**	**3**	**3**
Haslea	*Haslea* sp.1	-	+	-	-
(5 spp.)	*Haslea* sp.2	+++	+	+	+
	Haslea sp.3	++	+	-	+
	Haslea trompii (Cleve) Simonsen, 1974	+	-	+	+
	Haslea wawrikae (Husedt) Simonsen, 1974	++	++	+	+
		4	**4**	**3**	**4**
Hemiaulus	*Hemiaulus* sp.1	-	+	-	+
(4 spp.)	*Hemiaulus hauckii* Grunow ex Van Heurck, 1882	++	-	-	-
	Hemiaulus membranaceus Cleve 1873	++	++	++	++
	Hemiaulus sinensis Greville,1865	++	++	+	+
		3	**3**	**2**	**3**
Lauderia	*Lauderia annulata* Cleve, 1873	++	++	++	++
(2 spp.)	*Lauderia borealis* Gran, 1900	++	-	+	-
		2	**1**	**2**	**1**
Lennoxia	*Lennoxia faveolata* H.A. Thomsen & K.R. Buck, 1993	+++	++	++	++
(1 spp.)		1	1	1	1
Leptocylindrus	*Leptocylindrus danicus* Cleve, 1889	++	++	++	++
(3 spp.)	*Leptocylindrus mediterraneus* (H. Peragallo) Hasle, 1975	+	+	++	+
	Leptocylindrus minimus Gran, 1915	++++	++	+++	++
		3	**3**	**3**	**3**
	Navicula sp.1	++	+	+	+
Navicula	*Navicula directa* (W. Smith) Ralfs, 1861	++	+	+	+
(5 spp.)	*Navicula distans* (W. Smith) Ralfs, 1861	+	+	+	-
	Stauroneis granii E. Jorgensen, 1905	-	+	+	-
	Navicula transitans Cleve, 1883	-	+	-	-
		3	**5**	**4**	**2**
Nitzschia	*Nitzschia* sp.1	+++	++	++	++
(6 spp.)	*Nitzschia* sp.2	+++	++	++	+
	Nitzschia cf.*sigma* (Kützing) W. Smith, 1853	+	-	-	-
	Nitzschia longissima (Brébisson) Ralfs, 1861	+	++	+	+
	Nitzschia lorenziana Grunow, 1879	+	+	+	+
	Nitzschia robusta Hustedt, 1949	+	+	-	-
		6	**5**	**4**	**4**
Trieres	*Trieres mobiliensis* (J.W. Bailey) M.P. Ashworth & E.C. Theriot, 2013	+	+	+	+
(3 spp.)	*Trieres regia* (M. Schultze) M.P. Ashworth & E.C. Theriot, 2013	+	+	-	-
	Trieres sinensis (Greville) M.P. Ashworth & E.C. Theriot, 2013	++	++	+	+
		3	**3**	**2**	**2**
Planktoniella	*Planktoniella sol* (C.G. Wallich) Schütt, 1892	++	+	+	+
(1 spp.)		1	1	1	1
Pleurosigma	*Pleurosigma* sp.1	+	+	+	+
(11 spp.)	*Pleurosigma* sp.2	+	+	+	-
	Pleurosigma sp.3	+	-	-	+
	Pleurosigma acutum Norman ex Ralfs, 1861	+	+	-	-
	Pleurosigma elongatum W. Smith, 1852	+	+	+	+

Table 2. (Cont'd.)

Dominant genera	**Species**	**Stations**			
		MI1	**MI2**	**MV1**	**MV2**
	Pleurosigma strigosum W. Smith, 1852	+	+	+	-
	Pleurosigma directum Grunow, 1880	-	-	-	+
	Pleurosigma elongatum W. Smith, 1852	++	+	+	-
	Pleurosigma formosum W. Smith, 1852	++	-	+	+
	Pleurosigma macrum W. Smith, 1853	-	-	+	-
	Pleurosigma normanii Ralfs, 1861	+	+	+	+
		9	**7**	**8**	**6**
Pseudonitzschia (4 spp.)	*Pseudonitzschia* sp.1	++	++	++	++
	Pseudo-nitzschia fraudulenta (Cleve) Hasle, 1993	++++	-	-	-
	Pseudo-nitzschia seriata (Cleve) H. Peragallo, 1899	+	+	++	++
	Pseudo-nitzschia subcurvata (G.R. Hasle) G.A. Fryxell, 1993	-	-	+	-
		3	**2**	**3**	**2**
Rhizosolenia (18 spp.)	*Rhizosolenia* sp.1	-	+	-	+
	Rhizosolenia sp.2	+	+	+	++
	Rhizosolenia sp.3	-	+	-	+
	Rhizosolenia sp.4	+	-	+	+
	Rhizosolenia sp.5	-	+	-	-
	Rhizosolenia sp.6	-	-	-	+
	Rhizosolenia sp.7	-	+	-	-
	Rhizosolenia hebetata Bailey, 1856	-	+	+	+
	Rhizosolenia acuminata (H. Peragallo) H. Peragallo, 1907	+	-	-	-
	Rhizosolenia bergonii H.Peragallo, 1892	+	-	-	+
	Rhizosolenia clevei var. communis Sundström, 1984	+	-	-	-
	Rhizosolenia hyalina Ostenfeld, 1901	+	-	-	-
	Rhizosolenia imbricata Brightwell, 1858	+	+	+	-
	Rhizosolenia longiseta O. Zacharias 1893	-	+	-	-
	Rhizosolenia setigera Brightwell, 1858	++	-	+	-
	Rhizosolenia simplex Karsten, 1905	-	+	+	-
	Rhizosolenia striata Greville, 1864	-	++	-	-
	Rhizosolenia styliformis T. Brightwell, 1858	+	-	+	-
		9	**10**	**7**	**7**
Thalassionema (2 spp.)	*Thalassionema frauenfeldii* (Grunow) Tempère & Peragallo, 1910	++	++	+	++
	Thalassionema nitzschioides (Grunow) Mereschkowsky, 1902	++	++	++	++
		2	**2**	**2**	**2**
Thalassiosira (16 spp.)	*Thalassiosira* sp.1	+	+	+	-
	Thalassiosira sp.2	+	+	-	+
	Thalassiosira sp.3	+	+	-	-
	Thalassiosira anguste-lineata (A. Schmidt) G. Fryxell & Hasle, 1977	++	-	-	-
	Thalassiosira delicatula Ostenfeld, 1908	-	+	+	+
	Thalassiosira eccentrica (Ehrenberg) Cleve, 1904	+	-	-	-
	Thalassiosira gracilis (Karsten) Hustedt, 1958	-	-	+	-
	Thalassiosira hyalina (Grunow) Gran, 1897	-	+	-	-
	Thalassiosira leptopus (Grunow ex Van Heurck) Hasle & G.Fryxell, 1977	-	-	-	+
	Thalassiosira lineata Jousé, 1968	-	+	-	-
	Thalassiosira mediterranea (Schröder) Hasle, 1972	-	+	-	-
	Thalassiosira minima Gaarder, 1951	+	-	+	-
	Thalassiosira oestrupii (Ostenfeld) Hasle, 1972	-	-	+	+
	Thalassiosira pacifica Gran & Angst, 1931	-	-	+	-
	Thalassiosira punctigera (Castracane) Hasle, 1983	-	-	-	+
	Thalassiosira gravida Cleve, 1896	-	-	+	+
		6	7	7	6
Genera: 20	**Species: 134**	**91**	**94**	**84**	**76**

Table 3. Pearson correlation between diatom abundance and water parameters recorded at coastal (MI-1 and MV-1) and near-shore (MI-2 and MV-2) stations.

MI-1	**Abundance**	**Chl *a***	**DO**	**Temp**	**Salinity**	**Trans**
Chl *a*	0.603*					
DO	-0.091	0.296				
Temp.	-0.12	-0.193	-0.012			
Salinity	0.089	-0.051	0.279	-0.042		
Trans	-0.134	-0.304	-0.037	-0.276	0.262	
pH	-0.174	-0.372	-0.187	0.235	0.276	0.007
MI-2	**Abundance**	**Chl *a***	**DO**	**Temp.**	**Salinity**	**Trans**
Chl *a*	0.770*					
DO	0.234	0.208				
Temp.	-0.196	-0.503	-0.159			
Salinity	-0.163	-0.358	0.09	0.379		
Trans	-0.087	-0.365	-0.503	0.566	-0.103	
pH	0.065	-0.079	-0.172	0.389	0.054	0.44
MV-1	**Abundance**	**Chl *a***	**DO**	**Temp.**	**Salinity**	**Trans**
Chl *a*	0.986*					
DO	0.068	0.078				
Temp.	-0.006	-0.076	0.202			
Salinity	-0.217	-0.248	0.048	0.165		
Trans	0.155	0.096	0.221	0.601	0.074	
pH	0.104	0.184	-0.274	-0.061	-0.428	-0.089
MV-2	**Abundance**	**Chl *a***	**DO**	**Temp**	**Salinity**	**Trans**
Chl *a*	0.899*					
DO	0.467	0.498				
Temp.	0.11	0.078	-0.264			
Salinity	0.021	0.6	0.096	0.0457		
Trans	0.155	0.16	-0.367	0.44	0.21	
pH	0.113	0.168	-0.522	0.457	0.689	0.345

Chl *a*= chlorophyll a; DO = dissolved oxygen; Temp = Temperature; Trans = Transparency.
*= Significant correlation (p>0.05)

Discussion

The present study provides data on the distribution and abundance of major diatom genera in relation to the environmental parameters from the coastal waters of Karachi. The phytoplankton abundance appears to vary with seasons showing a unimodal distribution peak between October and February (northeast monsoon). This may be due to the prevalence of strong upwelling in the central and northern Arabian Sea which enhance primary productivity and control distribution pattern and abundance of phytoplankton in the region (Brock *et al*., 1991; Marra & Barber, 2005; Tegen & Fung, 1995; Tarran *et al*., 1999; Levy *et al*., 2007). Although the upwelling is not known along the coast of Pakistan but the wind induced convective mixing and up-sloping of nutrient rich water are responsible for high productivity in the northern Arabian Sea during northeast (winter) monsoon period (Banse, 1968, 1986; Kuzmenko, 1975; Saifullah, 1979; Sournia *et al*., 1987; Del Amo *et al*., 1997; Rousseau *et al*., 2002; Dey & Sing, 2003; Banzon *et al*., 2004; Marra & Barber, 2005; Schapira *et al*., 2008; Tabassum *et al*., 2010; Naz *et al*., 2013a, 2013b). The present data also shows that high chl *a* concentration during northeast monsoon in coastal and near-shore waters corresponds significantly to high diatom abundance data. High values of chl *a* were also reported earlier during northeast monsoon (Dey *et al*., 2003). The rest of the water parameters had no significant correlation with diatom abundance. This allows us to generally assume that nutrient distribution in the area regulates phytoplankton abundance.

Coastal waters are also influenced by the influx of dissolved nutrient through rivers in terms of high primary productivity (Cebrián & Valiela, 1999). The study area along the coastal belt receives discharges from Lyari and Malir rivers (drains in Manora channel and Korangi Creek, respectively) carrying high loads of domestic, agricultural and industrial effluents (Beg *et al*., 1984,1992) which particularly seems to influence stations (MI-1 & MI-2) located off of Karachi. These stations showed high cell abundance compared to the corresponding coastal and near-shore stations off of Mubarak village (MV-1 & MV-2, respectively) towards Baluchistan coast away from the above mentioned two rivers. High nutrient availability at two stations off of

Karachi also supports higher species diversity. In the coastal and near-shore waters, diatoms share higher proportion in the total phytoplankton abundance throughout the year except for a few instances. This is in agreement with many previous studies showing that diatoms form an abundant group in different waters (Wang *et al*., 2006; Harnstrom *et al.,* 2009; Schiebel *et al*., 2001, 2004; Karthik *et al*., 2012).

In the present study, some 20 genera of diatom were observed which showed regular seasonal occurrence and high abundance in coastal and near-shore waters. Among them *Chaetoceros, Coscinodiscus, Guinardia, Lennoxia, Leptocylindrus, Nitzschia, Pseudo-nitzschia* and *Thalassionema* appeared in blooming conditions during northeast monsoon period. Occurrence and high abundance of dominant genera have also been reported earlier in the same region and time (Tabassum & Saifullah, 2010; Tabassum & Saifullah, 2012). Thomas *et al*., 2013 also reported the diatom species (*Thalassiosira, Thalassionema*, *Pseudo-nitzschia*, *Leptocylindrus* and *Lauderia*) from up welled coastal waters of south eastern Arabian Sea. Similar diatom species had been reported from Omani waters (Al-Hashmi *et al*., 2014), the coastal waters of Port Blair (South Andaman Island) and from Japanese and African waters (Estrada & Blasco 1985; Shevchenko & Orlova, 2010), respectively. The present study also depicts high diversity of centric diatoms (52-65 spp.) compared to pennate forms (25-32 spp.) at all stations; higher diversity being at MI-1 and MI-2 (off of Manora channels)**.** Verlecar *et al*., 2006 linked the higher number of centric species to organic pollution and nutrient enrichment. Being coastal and near-shore stations, these waters appear to have high loads of organic effluents. MI-1 and MI-2 particularly receives high organic pollution from Lyari and Malir rivers (Baig, 1975; Beg *et al*., 1992, 1984; Anon., 2008; Qadri *et al*., 2011; Nergis *et al.,* 2012; Jilani & Khan, 2013) and may be the reason for high diversity of centric diatoms in coastal and near shore waters.

Arabian Sea appears to be highly influenced by global warming and Sea level rise, which affects seasonality, strengthen the monsoon periods, and increases productivity (Goes *et al*., 2005). In the perspective of global warming, sea level is generally rising and as a consequence many physical parameters, such as, precipitation, inland runoff (volume of fresh water), climatic seasonality, sea surface temperature, acidification, etc., are effected to influence vertical water column parameters (Riebesell, 2004; Moore *et al*., 2008). These consequences, coupled with certain natural and anthropogenic factors, bring unpredictable change in composition and growth of phytoplankton. To understand enigmatic variations in distribution pattern of phytoplankton, long term multidisciplinary investigations are required at various geographical locations (Moore *et al*., 2008). The two year data on the spatio-temporal distribution of diatoms in the coastal waters of Pakistan reported here indicates seasonal variability in abundance and distribution of diatoms and requires further studies to monitor effect of rapidly changing climatic influences which promote growth of bloom forming planktonic species in the Arabian Sea.

Acknowledgements

Authors wish to acknowledge financial support (Senior Research Fellowship) to FN from the Center of Excellence in Marine Biology, University of Karachi and research grant to PJAS from DFID, UK, DelPHE project. We are grateful to Dr. Y. V. B. Sarma, King Abdullah University of Science and Technology, Jeddah, Saudi Arabia, for his help and valuable suggestions for the improvement of the manuscript.

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(Received for publication 8 April 2015)