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DISTRIBUTION AND DIVERSITY OF PHYTOPLANKTON FROM THE COASTAL WATERS OF MANORA, KARACHI, PAKISTAN

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ABSTRACT

Twelve commonly occurring genera of marine phytoplankton *i.e.*, *Biddulphia* Gray SF, *Coscinodiscus* Ehrenberg, *Chaetoceros* Ehrenberg, *Eucampia* Ehrenberg, *Hemidiscus* Wallich, *Rhizosolenia* Ehrenberg, *Stephanopyxis* Ehrenberg (Ehrenberg), *Gyrosigma* Hassall, *Nitzschia* Hassall, *Pleurosigma* W Smith, *Thalassionema* Grunow*ex* Mereschkowsky, *Thalassiothrix* Cleve & Grunow have been collected from Manora Channel Karachi, Pakistan. The diatoms members of the Bacillariophycota were the dominating group among the studied populations of the phytoplankton during the period of investigation (October to December 2013). These diatoms belong to 1 kingdom, 1 phylum, 1 class and 2 orders have been identified taxonomically. Allthe investigated genera are taxonomically known species. During this study *Hemidiscus* has been reported for the first time from Manora Channel. A variety of diatom genera belong to the order Biddulfiales (centric diatom) and another order Bacillariales (pennate diatoms) have been found from Manora Channel Karachi, Pakistan. The 2 centric and 2 pennate diatoms were present in all the collected samples this tendency was exhibited by *Chaetoceros, Coscinodiscus, Nitzschia* and *Pleurosigma*. Whereas *Biddulphia, Eucampia, Gyrosigma* & *Thalassiothrix* were found in the months of November and December. The low occurrence demonstrated by three genera *i.e. Hemidiscu, Stephanopyxis, Rhizosolenia* and *Thalassionema*.

KEYWORDS: Phytoplankton, Manora, Diversity, Diatoms.

INTRODUCTION

The coastline of Pakistan is about 885 km long (Shameel and Tanaka, 1992) has most productive neritic province. It comprises a variety of oceanic creatures *i.e.* viruses, bacteria, fungi, algae, and large and small marine animals. According to the Kennish, (1997) the over exploitation of coastal resources by human beings has now turned into a serious environmental issue all over the world. Among pollution creating countries in the world Pakistan ranks 135, as concerning the environmental impacts it has 28th position among most affected countries. A number of research works have been carried out on the effects of unprocessed domestic as well as industrial effluent on the marine environment *e.g.* hazardous to the habitats, harmful for marine life, declining of ecotourism and limited access to coastal areas (Swedmark *et al*., 1971; Anon., 1972; Rabalais and Nixon, 2002). Karachi is the major city of Pakistan located on the coastal area. It has two seaports Karachi port and Bin Qasim collectively handle more than 90 percent of all external trade of Pakistan. It has five major industrial areas, including chemical, textile,

pharmaceutical, metal industries, automobile, oil refineries, tanneries additionally Pakistan steel mills, KE Bin Qasim power plant situated on the fringes of the main city (Amjad *et al*., 2007; http://www.dawn.com http://www.dawn.com/2009/01/28/local6.htm 2009) and 80% automotive industry of Pakistan located at Port Qasim.

The Karachi coast, particularly Manora channel, is seriously polluted. The main stream of industrial and domestic waste comes through Lyari River (now turned into a sewer) flows across the Karachi city and discharges its untreated effluent into the Karachi harbor. The other is the Malir River discharges into Korangi Creek (Beg, 1995). Industrial pollution includes all types of heavy metals about 170 tanneries in Korangi, continuously adding large amount of Chromium into the creeks and steel mill is source of Iron pollution. Agriculture is also a source of pollutants (World Bank Reports, 1991; Zaigham, 2004). The leakage during the transportation of oil from coast to the different cities and continuous dredging of the waterway also increases degradation of coastal waters (IAEA-MEL 1987; Rizvi*et al*., 1995; Qureshi *et al*., 1997; Saleem and Kazi, 1998; Akram*et al*., 2007).

Phytoplankton are the fundamental unit of marine ecosystems and provide food for many animals in marine environment ranging from zooplankton to large mammals (Waniek and Holliday, 2006; Malone *et al*., 2016). They are the primary source of energy in marine systems and contributed 95% of organic material in terms of primary production (Lewis, 1974).

A number of researchers investigated the flora of Northern Arabian Sea regarding the taxonomic status of phytoplankton (Hassan and Saifullah, 1971; Chaghtai and Saifullah, 1988; Shameel and Tanaka, 1992; Gul and Saifullah, 2007; Tabassum and Saifullah, 2010). Some workers examined the distribution, seasonal variation, and ecology and diversity of phytoplankton (Salim and Iqbal, 1964; Gul and Saifullah, 2010; Tabassum and Saifullah, 2012). Hence, there is a need to study variation in phytoplankton populations with respect to the influence of pollution.

The Manora Channel is an important and major contributor of fisheries in Karachi. The present study was conducted to investigate the distribution of phytoplankton communities, especially diatoms with reference to hydrographic parameters of the sampling site.

MATERIALS AND METHODS

Study area: The sampling was carried out from Manora Channel (24° 47’38.6” N 66° 58’36.1” E). It is about 8 km long and 850-100 m wide, which surrounds by Keamari Fish Harbor, Karachi Shipyard, several Islands including backwater mangrove area (Qureshi *et al*., 2001). The Manora Channel connected to the Baba Channel near the Baba & Bhitt Islands at the southern end and then to the northern Arabian Sea (Khatoon *et al*., 2014). According to the Qureshi *et al*. (2001). The untreated domestic and industrial wastewater of about 400 million gallons per day generates from Karachi. This waste with the addition of oil discharge from ships and oil tankers dump into this channel because of the mentioned causes it becomes a severely polluted marine area of Karachi coast. The marine life *e.g.*, marine food chain, most important the primary producers, fisheries and mangrove forests are threatened.

Sampling of phytoplankton: The sampling was carried out from the Manora Channel during the months of October-December 2013. Samples were collected by using a net of phytoplankton, having 20 µm mesh size with a diameter of 36 cm. The net was operated horizontally from the boat for five minutes during mid tides (Anon., 1994).

Preservation of phytoplankton for qualitative analysis: The collected samples were shifted to the plastic bottles (1 L), and preserved simultaneously in 4% formaldehyde solution. Samples were brought to the laboratory and stored with great care.

Identification of phytoplankton: The phytoplankton sample in 100 mL of 4% formaldehyde solution was gently mixed and 1 mL of each was taken from the collected sample to identify count the different species of phytoplankton in the samples. The phytoplanktons were identified from (Subramanyan, 1946; Santhanam *et al*., 1987; Tabassum and Saifullah, 2010; Tabassum and Saifullah, 2012).

Physical parameters: The salinity, temperature and pH of seawater were measured simultaneously at the time of collection. The temperature was measured with a thermometer and salinity with a handheld mobile refractometer (ATAGO S/Mill-E), while pH was measured by the Jenway pH meter.

Chemical parameter: Approximately 1 L of seawater samples collected in amber glass bottles for the estimation of 'chlorophyll – a' was brought to the laboratory in an ice cooler. The analysis of 'chlorophyll – a' of seawater sample was done by Strickland and Parsons (1968; 1972) methods. Samples were filtered through Whatman GF/F filter (45 µm pore size & 47 mm diameter) with Millipore filtration assembly. The chlorophyll-a was extracted from the concentrate of phytoplankton in 90 % of aqueous acetone and placed it in dark refrigerator. The extract was centrifuged for 5-10 minutes at 3000 rpm. The concentration of chlorophyll –a was determined with a spectrophotometer.

RESULTS

The present study revealed the presence of different species of diatoms collected from the offshore waters of the Manora Channel during the period of October to December 2013 (Table 1). The collected specimens showed the occurrence of 12 genera, belonging to five different genera of the order Bacillariales and seven genera of the order Biddulfiales, class Bacillariophyceae, phylum Bacillariophycota (*fide* Shameel, 2001, 2008, 2012). The samples showed total six, nine and 10 species in the months of October, November and December respectively. They have identified and all are taxonomically known species.

Distribution of diatoms in Manora Channel: Three samples each were collected from the Manora Channel and all investigated species are found to be the taxonomically known (Table 1). Two genera of the order Biddulfiales; *Biddulphia*, *Eucampia* and *Gyrosigma* and *Thalassiothrix* belongs to the order Bacillariales found in the months of November and December while were not present in the month of October. However, *Stephanopyxis* was observed only in the month of October and *Rhizosolenia* in November. *Hemidiscus* was recorded only in the month of December. *Thalassionema* was observed in October and December. This is the only species which was found in these two months (Table 1). But *Chaetoceros*, *Coscinodiscus*, *Nitzschia* and *Pleurosigma* appeared to be the most highly distributed species during the study period (Table 1).

Table 1. Occurrence of different genera of diatoms collected from Manora Channel during October to December 2013.

S. No.	Name of genera	Collection Period		
		October	November	December
1.	*Biddulphia*	-	+	+
2.	*Coscinodiscus*	+	+	+
3.	*Chaetoceros*	+	+	+
4.	*Eucampia*	-	+	+
5.	*Gyrosigma*	-	+	+
6.	*Hemidiscus*	-	-	+
7.	*Nitzschia*	+	+	+
8.	*Pleurosigma*	+	+	+
9.	*Rhizosolenia*	-	+	-
10.	*Stephanopyxis*	+	-	-
11.	*Thalassionema*	+	-	+
12.	*Thalassiothrix*	-	+	+
Total		**6**	**9**	**10**

(+) = Present, (-) = Absent

Physical parameters: Physical parameters were determined during the investigated period from October to December 2013. The temperature ranged from 29^{o}C in October to 24^{o}C in December. The salinity values ranged between 33 to 40 ‰. The pH ranged from 8.0 to 8.5 and was more or less constant.

Chemical parameter: The concentration of chlorophyll-a was 19 µg / L in the month of October at the Manora Channel. Due to the insufficient samples no further studies were made to investigate the chlorophyll-a content.

DISCUSSION

This study was conducted from October to December, 2013. The diatoms are considered as a major taxonomic group of phytoplankton and construct a view about organization, vitality and tendency of oceanic environment. The occurrence of diatoms and primary production coupled with upwelling (Garrison *et al*., 2000). While large growth of phytoplankton is linked to carbon cycle during the months of October to December in Arabian Sea (Garrison *et al*., 2000).

The distribution of diatoms has been reported from the polluted waters of the Manora Channel (Saifullah and Moazzam, 1978) while, fast growing industries and increased population in Karachi causing domestic and industrial wastewater pollution in Manora Channel which effects on diatoms composition and their primary production reported by Haq, (1976).

Present work focused on the distribution of diatom communities to reveal the indirect effects of abiotic factors and pollution stress at Manora Channel during the months of October and December 2013. Twelve genera of planktonic diatoms, belonging to one phylum (Bacillariophycota), one class (Bacillariophyceae) and two orders (Bacillariales & Biddulfiales) have been collected and identified.

Table 1 lists the various genera of diatoms investigated during the study period. Two centric (*Biddulphia* & *Eucampia*) and two pennate (*Gyrosigma* & *Thalassiothrix*)

diatoms were observed in the months of November and December. *Biddulphia* is a neritic and very commonly occurring genus. It has been reported from the Karachi harbor by Saifullah & Moazzam (1978) and descried from coastal waters of the Indian Ocean as well by (Subramanyan, 1958). *Biddulphia* furthermore, reported by Saima *et al*. (2013) in a survey conducted to investigate the phytoplankton communities of Miani Hor and neighboring sea waters. Saifullah & Moazzam (1978) observed genus *Eucampia* during the investigation of species composition and seasonal occurrence of centric diatoms in a polluted marine environment at Karachi coast. It is widely distributed genus and has also been reported from the west coast of India, Bay of Bengal and coast of Madras (Hustedt, 1930, Subramanyan, 1958; SubbaRao, 1976).

Gyrosigma & *Thalassiothrix* were also found in the month of November and December has previously reported by Salim, (1963); Salim and Iqbal (1964); Moazzam, (1973); Saifullah and Chaghtai, (2005) and *T frauenfeidii* found as pollution indicator from the industrially polluted waters in Uppanar estuary, from the southeast coast of India (Periyanayagi *et al*., 2007).

Thalassionema was the only genus observed during the month of October and December. It has been studied in detailed for the first time from the coastal water of Karachi by (Saifullah and Chaghtai, 2005) and moreover reported from Balochistan sea waters by Saima *et al*. (2013). Additionally, it has been found at Madras coast and west coast of India (Hustedt, 1931; 1932; Subramanyan, 1958).

Chaetoceros, *Coscinodiscus*, *Nitzschia* and *Pleurosigma* were found throughout the study period from Manora Channel. Several studies have been made on the occurrence, distribution, abundance and seasonal succession of *Chaetoceros* from different parts of the world (Hustedt, 1930, Salim, 1954; 1963; Salim and Iqbal, 1964; Subramanyan 1958; Saifullah and Steve, 1973; SubbaRao, 1976; Tabassum and Saifullah, 2010). Twenty-three species of this genus from Karachi Harbor has reported by Saifullah and Moazzam (1978). A study from the Western Pacific Ocean (Australia) in the coastal Magnetic Island lagoon revealed the presence of the genus *Chaetoceros* (Stanca*et al*., 2013).

Coscinodiscus exhibited the wide range of distribution from the North Arabian Sea, coastal waters of India, Australia, Canada and various other regions of the world (Hustedt, 1931; Subramanyan, 1958; Salim, 1963; Salim and Iqbal, 1964; Saifullah and Steve, 1973; SubbaRao, 1976; Saima *et al*., 2013; Stanca *et al*., 2013).

The two genera of the order Bacillariales *Nitzschia* & *Pleurosigma* revealed their presence in the autumn inter-monsoon and early north-east monsoon seasons in Manora channel and also showed the capacity to survive in highly polluted waters of the Channel. As earlier studies have been reported, their occurrence in the mangrove area of Sandspit near Karachi in winter season (Salim, 1963; Chaghtai and Saifullah, 1992).

It is an interesting observation that three genera of the order Biddulfiales *i.e.*, *Stephanopyxis* was found in the month of October, *Rhizosolenia* was in November and *Hemidiscus* in December respectively; *Rhizosolenia* was found in colonial or individual cells were also seen. Moazzam in (1973) and Saifullah and Moazzam (1978) have studied the occurrence, species composition, seasonal variation and taxonomy of several centric diatoms from the polluted environment of the Manora Channel (Salim, 1963; Saeed *et al*., 1995; Tabassum and Saifullah, 2011). The centric diatom *Stephanopyxis* was reported by Saifullah (1973) during the survey of the standing crop of seaweeds from Karachi coast. While no taxonomic record could be found on the occurrence of the genus *Hemidiscus* from the coastal water of Karachi except Saima *et al*. (2013) who reported it from MianiHor lagoon.

Several studies (Battarbee *et al*., 1997; Kelly *et al*., 1998) suggested that diatoms are being used as the pollution indicators because they are abundantly found in freshwater as well as marine environment and sensitive to water quality changes. According Birks (1994); Moser *et al.* (1996) they have ability to tolerant against the Diatoms exhibit high resistance to the shift of water quality.

The concentration of chlorophyll-a was 19 µg/L in the coastal water of Manora Channel. A number of studies have been made from Pakistan on the abundance, diversity and chlorophyll content of dinoflagellates (Saifullah, 1979) and seasonal and spatial distribution of chlorophyll-a in the north Arabian Sea is bordered Pakistan (Saifullah, 1994). The values decreased in offshore waters, whereas from the Makran shelf very high values were recorded over deep water (Saifullah, 1994). The values of chlorophyll-a ranged from 0.5 to 40 µg/L in the intertidal and nearshore waters of the Karachi coast this study was conducted by Saeed *et al.* (1995). Another study in MianiHor lagoons and adjacent open sea waters revealed the concentration of chlorophyll-a from 0.64 to 13.35 µg/L in the lagoon. The distribution and diversity of investigated members of Bacillariophycota varied from month to month and no generalization may be made. There was no significant difference between the distribution of phytoplankton and physical and chemical parameters (*i.e*., temperature, salinity, pH and chlorophyll a contents. Therefore, no comparative conclusion about different genera of diatoms may be drawn in the cases of physical and chemical parameters as the data obtained too small and inadequate.

REFERENCES

Akram, M., R.M. Qureshi, N. Ahmad and T.J. Solaija. (2007). Determination of gamma emitting radionuclides in the inter-tidal sediments off Balochistan (Pakistan) Coast, Arabian Sea. *Radiat. Prot. Dosim.*, 123(2): 268-273.

Amjad, A. Shah, I. Kasawani and J. Kamaruzaman. (2007). Degradation of Indus Delta mangroves in Pakistan. *Inter. J. Geol.*, 1(3): 27-34.

Anonymous. (1972).A report of the committee on water quality criteria. National Academy of Sciences.US Govt. Pri Off, Washington DC.

Anonymous. (1994). Standard operating procedure for phytoplankton sample collection and preservation. Grace Analytical Lab, 536 South Clark Street, Chicago.

Battarbee, R.W., R.J. Flower, S. Juggins, S.T. Patrick and A.C. Stevenson. (1997). The relationship between diatoms and surface water quality in the Hoylandet area of North–Trondelag, Norway. *Hydrobiol.*, 348(1-3): 69-80.

Beg, M.A.A. (1995). "Environmental Degradation" *Pak. & Gulf. Eco.*, 11-17 February, 1995.

Birks, H.J.B. (1994). The importance of pollen and diatom taxonomic precision in quantitative palaeo environmental reconstructions. *Rev. Palaeobot. Palynol.*, 83(1-3): 107-117.

Chaghtai, F. and S.M. Saifullah. (1988). An illustrated account of species of *Ceratium* Schrank found in North Arabian Sea bordering Pakistan. *Cent. Excel. Mar. Biol. Univ. Kar. Public*., 5: 1-50.

Chaghtai, F. and S.M. Saifullah. (1992). First recorded bloom of *Navicula*Bory in a mangrove habitat of Karachi.*Pak. J. Mar. Sci*., 1: 139-140.

Garrison, D.L., M.M. Gowing, M.P. Hughes, L. Campbell, D.A. Caron, M.R. Dennett, A. Shalapyonok, R.J. Olson, M.R. Landry, S.L. Brown, H.B. Liu, F. Azam, G.F. Steward, H.W. Ducklow and D.C. Smith. (2000). Microbial food web structure in the Arabian Sea: a US JGOFS study. *Deep-Sea Research II*, 47(7): 1387-1422.

Gul, S. and S.M. Saifullah. (2007). Genus *Amphisolenia* Stein from north-west Arabian Sea shelf of Pakistan. *Pak. J. Bot*., 39(2): 561-576.

Gul, S. and S.M. Saifullah. (2010). Taxonomic and ecological studies on three marine genera of Dinophysiales from Arabian Sea shelf of Pakistan. *Pak. J. Bot.*, 42(4): 2647-2660.

Hassan, D. and S.M. Saifullah. (1971). Somethecate Dinophyceae from inshore water of Karachi. *Pak J. Bot*., 3(1&2): 61-70.

Haq, S.M. (1976). Overview on pollution in the coastal environment of Pakistan and its possible implication for the marine ecosystem. In: *Proceeding of the International Symp. On Marine Pollution Research.* (Ed.): Meyers, S.P., Louisiana State Uni. pp. 33-53.

Hustedt, F. (1930). Die Kieselalgen Deutschlands, Österreichs und der Schweizunter Berücksichtigung der übrigen Länder Europassowie der angrenzenden Meeresge-biete. In: (Ed.): Rabenhorst, L. *Kryptogamen-Flora von Deutschlands, Österreich und der Schweiz*. Akademische Verlagsgesellschaft m. b. h., Leipzig, p. 1-920.

Hustedt, F. (1931-32). Die Kiselalgen. In*: Rabenhorst'sKryptogamen flora von Deutschland, Oster- reich und der Schweiz*. 7: 1-4.

Htpp://www.dawn.com Internet edition (2009). "NA discusses depletion of mangrove forests" Dawn.com January 21.

http://www.dawn.comInternet edition (2009)."KARACHI: Industrial estates in need of combined treatment plants"Dawn.com January 28.

http://www.npr.org/templates/story/story.php?storyId=91009748.NPR. June 2, 2008.

IAEA-MEL. (1987). Marine pollution baseline.Survey in the Korangi.Phitti Creek, Pakistan. Final Report. ILMR, IAEA, Monaco 27.

Kelly, M.G., A. Cazaubon, E. Coring, A. Dell' Uomo, L. Ector, B. Goldsmith, H. Guasch, Hürlimann J., A. Jarlman, B. Kawecka, J. Kwabfrans, R. Laugaste, E-A. LindØm, M. Leitao, O. Marvan, J. Padisák, E. Pippe, J. Prygiel, E. Rott, S. Sabater, H. van Dam and J. Vizinet. (1998). Recommendations for the routine sampling of diatoms for water quality assessment in Europe. *J. Appl. Phycol.*, 10(2): 215-224.

Kennish, M.J. (1997).Practical handbook of estuarine and marine pollution.*CRC PressMar. Sci. Ser. USA*.

Khatoon, Z., R. Paperno and S.M. Hussain. (2014). Length–weight relationships of five fish species collected from Manora Channel and associated backwaters of the northern Arabian Sea. *J. Appl. Ichthyol.*, 30(1): 235-238.

Lewis, W.M. Jr. (1947). Primary production in the plankton community of a tropical lake. *Ecol. Monog*., 44(4): 377-409.

Malone, T., M. Azzaro, A. Bode, E. Brown, R. Duce, D. Kamykowski, S.H. Kang, Y. Kedong, M. Thorndyke, J. Wang, C. Park, H. Calumpong and P. Eghtesadi. (2016). Primary production, cycling of nutrients, surface layer and plankton. In: *The first global integrated marine assessment world ocean Oceans and Law of the Sea*. United Nations.

Moazzam, M. (1973). Taxonomic and seasonal studies of planktonic centric diatoms from Manora channel (Lower Harbor) Karachi. M. Sc. (Thesis) Dept. Mar. Biol., Karachi University. Pp. 1-350.

Moser, K.A., G.M. MacDonald and J.P. Smol. (1996). Applications of freshwater diatoms to geographical research. *Prog. Physicl. Geography*, 20(1): 21-52.

Periyanayagi, R., V. Sasikala, R. Venkatesan, R. Karthikayen and T. Balasubramanian. (2007). Phytoplankton in relation to pollution in Uppanar estuary southeast coast of India. *Res. J. Environ. Toxicol.*, 1(3): 153-157.

Qureshi, R.M., A. Mashiatullah, S.H.N. Rizvi, S.H. Khan, T. Javed and M.A. Tasneem. (2001). Marine pollution studies in Pakistan by nuclear techniques. *The Nucleus*, 38(1): 41-51.

Qureshi, R.M., M.I. Sajjad, A. Mashiatullah, F. Waqar, S. Jan, M. Akram, S.H. Khan and S.A. Siddiqui. (1997). Isotopic investigations of pollution transport in shallow marine environments off the Karachi Coast, Pakistan. *Proceedings of the International Symposium on Isotope Techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and the Atmosphere*, 14-18 April, 1997, Vienna, Austria. Pp. 353-365.

Rabalais, N.N. and S.W. Nixon. (2002). Nutrient over-enrichment of the coastal zone. *Estuaries*, 24B: 639-644.

Rizvi, S.H.N., T. Masood, S. Khan, M. Ali and J. Baquer. (1995). Circulation pattern in the Karachi coastal waters in relation to the outfall. In: *The Arabian Sea – Living Marine Resources and the Environment.* (Eds.): Thompson, M.F. and N.M. Tirmizi. pp. 641-652.

Saeed, H., N. Khan and S.H.N. Rizvi. (1995). Distribution of Chlorophyll "a" and phytoplankton along the Karachi coast. In: *The Arabian Sea – Living Marine Resources and the Environment.* (Eds.): Thompson, M.F. and N.M. Trimzi. Vanguard Books Ltd. Lahore. pp. 509-517.

Saifullah, S.M. (1973). A preliminary survey of the standing crop of seaweeds from Karachi Coast. *Bot. Mar*., 16(3): 139-144.

Saifullah, S.M. (1979). Occurrence of dianoflagellates and distribution of chlorophyll – a on Pakistan shelf. In: *Toxic Dinoflagellates Blooms*. (Eds.): Taylor, D.L. and H.H. Seliger. Elsevier/ North Holland, pp. 203-208.

Saifullah, S.M. (1994). Seasonal and spatial distribution of chlorophyll a in the north Arabian Sea bordering Pakistan.*Pak. J. Mar. Sci.,* 3(1): 25-30.

Saifullah, S.M. and F. Chaghtai. (2005). Effect of 'Tasman Spirit' oil spill on marine plants in the coastal area of Karachi. *Int. J. Biol. Biotec*., 2(2): 299-306.

Saifullah, S.M. and M. Moazzam. (1978). Species composition and seasonal occurrence of centric diatoms in a polluted marine environment. *Pak. J. Bot.,* 10(1): 53-64.

Saifullah, S.M. and D.M. Steve. (1973). Seasonal succession of certain species of phytoplankton from St. Margaret's Bay, N.S. *Pak. J. Bot.,* 5: 11-18.

Saima, L., A. Zarrien and G. Siddiqui. (2013). Seasonal variability of phytoplankton in a coastal lagoon and adjacent open sea in Pakistan. *Turk. J. Bot*., 37(2): 398-410.

Salim, K.M. (1954). Some plankton diatoms from the Karachi Coast. *Pak. J. Sci*., 6: 5-10.

Salim, K.M. (1963). A systematic account of some marine diatoms from the Karachi Coast. *Pesh. Univ. J.,* 8(1): 19-52.

Salim, K.M. and M.M. Iqbal. (1964). Distribution of diatoms in the intertidal pools at the rocky ledge Manora, Karachi. *Pak. J. Sci.,* 16: 125-139.

Saleem, M. and G.H. Kazi. (1998). Concentration and distribution of heavy metals (Pb, Cd, Cr, Cu, Ni and Zn) in Karachi shore and offshore sediments. *Pak. J. Mar. Sci.,* 7(1): 71-79.

Santhanam R., N. Ramanathan, K. Venkataramanujam and G. Jegatheesan. (1987). Phytoplankton of the Indian seas: An Aspect of Marine Botany. Daya Pub. House, Delhi, India. pp. 134.

SubbaRao, D.V. (1976). Marine plankton diatoms as indicators of ocean circulation in the Bay of Bengal. *Bot. Mar*., 19(3): 183-187.

Subrahmanyan, R. (1946). A systematic account of the marine plankton diatoms of the Madras coast. *Proc. Indian Acad. Sci.,* 24B(4): 85-197.

Subrahmanyan, R. (1958). Ecological studies on the marine phytoplankton on the west coast of India. *Mem. Ind. Bot. Soc.,* 1: U5-\5l.

Shameel, M. (2001). An approach to the classification of algae in the new millennium. *Pak. J. Mar. Biol.,* 7(1&2): 233-250.

Shameel, M. (2008).Change of divisional nomenclature in the Shameelian classification of algae. *Int. J. Phycol. Phycochem.,* 4: 225-232.

Shameel, M. (2012). Nomenclatural changes in the shameelian classification of algae. *Int. J. Phycol. Phycochem.,* 8(1): 7-22.

Shameel, M. and J. Tanaka. (1992). A preliminary check-list of marine algae from the coast and inshore waters of Pakistan. In: *Cryptogamic Flora of Pakistan*. (Eds.): Nakaike, T. and S. Malik. Vol. 1 Nat. Sci. Mus., Tokyo pp. 75-85.

Stanca, E., L. Roselli, M. Cellamare and A. Basset (2013).Phytoplankton composition in the coastal magnetic Island lagoon, Western Pacific Ocean (Australia).*Transit Waters Bull.,* 7(2): 145 – 158.

Strickland, J.D.H. and T.R. Parsons. (1968). A practical handbook of seawater analysis. *Bull Fish Res. Bd. Can.,* 167: 1-311.

Strickland, J.D.H. and T.R. Parsons. (1972). A practical handbook of seawater analysis. *Bull Fish Res. Bd. Can.,* 167.

Swedmark, M., B. Broanten, E. Emanuellsson and A. Grammo. (1971). Biological effects of surface active agents on marine animals. *Mar. Biol.*, 9(3): 183-201.

Tabassum, A. and S.M. Saifullah.(2010). The Planktonic diatoms of the genus *Chaetoceros* Ehrenberg from northwestern Arabian Sea bordering Pakistan. *Pak. J. Bot.*, 42(2): 1137-1151.

Tabassum, A. and S.M. Saifullah. (2012). Centric diatoms from north Arabian Sea shelf of Pakistan. LAP Lambert Academic Publishing, pp. 1-136.

Waniek, J.J. and N.P. Holliday. (2006). Large – scale physical control on phytoplankton growth in the Irminger Sea, Part II: Model study of the physical and meteorological preconditioning. *J. Mar. Sys*., 59(3): 219-237.

World Bank. 1991: "Karachi Port Modernization" staff appraisal report #LN 3335-PAK. 13 May, 1999. Pp. 26 -27.

Zaigham, N.A. (2004). Unauthorized squatter settlements are one of major sources for polluting surface and subsurface waters in Karachi. Proceedings of the WSSD workshop on human settlement and environment (Pakistan's Response to its Obligations under the WSSD Plan of Implementation), Islamabad, December 14-15, p 100-112.

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