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Diatom Species Composition and Seasonal Abundance in a Polluted and Non-polluted Environment from Coast of Pakistan

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Abstract: Diatoms species composition and their seasonal abundance was analyzed at two stations (St. A, 24°49.77′N 66°57.85′E and St. B, 24°47.93′N 66°58.87′E) of Manora Channel, coastal waters of Karachi, northern Arabian Sea bordering Pakistan. Samples were collected bimonthly from May 2002 to July 2003 and examined using inverted microscope. There was no significant variation observed between species composition at both A and B stations. Distribution pattern and seasonal variations in cell abundance of dominant, abundant, frequent and rare species were observed in which seven dominant species were recorded from station B and six dominant species from station A. Among both centric and pennate diatoms, the genera *Chaetocerose affine, Pleurosigma* sp 1, *Thalassiosira* sp, *Navicula directa* and *Nitzschia longissima*, *Rhizosolenia setigera*, *Thalassionema nitzschiodes* remain dominated all year although seasonal variations in their cell abundance were observed for these species. Statistical analysis showed that most of the dominant species were positively correlated with the salinity and temperature at both stations A and B. It suggests that temperature and salinity are the most significant factors that give shape to the diatom community and control the community changes. Dominance of pennate species over centric types with high abundance of these pennate species showed that they have better tolerance against pollution and other environmental variables.

Key words: Diatom, species composition, seasonal abundance, coastal waters.

Introduction

Diatoms are the main primary producers in the ocean (Smayda, 1978) and the number of species estimated is from 10,000 to 100,000 so is considered as the most suitable group for the study of biodiversity and ecology of the ecosystem. The pattern of distribution of diatom species can be determined by two important phenomena: one is the seasonal variability and other is eutrophication in the area (Stoermer and Smol, 1999; Admiraal and Harry, 1980; Qasim, 2003). Geography of an area also is considered as a main factor that plays an important role in distribution of diatom species. It is the ability of a species that can help them to survive in an environment, where mixing of different hydrographical factors is taking place consistently (Stevenson, 1997). According to Kociolek and Spaulding (2000), ratio of species which are confining to certain geographical areas are much higher than earlier thought.

Seasonality has great impact on species composition and diversity (Kristiansen, 1996; Patrick and Reimer, 1966; Stevenson et al., 1996; Potapova et al., 2002). The Arabian Sea is well known for its unique hydrographical conditions which are controlled by the Indian Ocean. The

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biological activity including distribution of diatoms is related with the monsoon driven wind forces which as a result cause the upwelling in the region (Currie et al., 1973; Qasim, 1977; Ivanova et al., 2003). SWM (South west monsoon) from June to September and NEM (North east monsoon) from November to February results in elevated primary production in the northern part of Arabian Sea (Parab et al., 2006). Strong upwelling and fluxes enhance the concentration of silicate which support the growth of diatom species and greatly affect the composition of different species in the community (Haake et al., 1993a; Haake et al., 1993b).

The role of diatom composition is very important in an ecosystem which is still unexplored from this side. The purpose of this research work is to contribute the knowledge about distribution and abundance of diatom species from the coastal waters of Karachi (bordering northern part of Arabian Sea) and assess the relative importance of hydrographical factors affecting their composition.

Material and Method

Samples were collected bimonthly using 1.7 litre Niskin bottle over a period of May 2002 to July 2003 at the Manora Channel located on the estuary of Lyari river. Samples were taken at two stations established for regular sampling. 1. Station A (24°49.77′N 66°57.85′E) Manora Channel (inside) a polluted area with impact from Layari river and mangrove ecosystem. 2. Station B (24°47.93′N 66°58.87′E) Outside Manora Channel in the open water, a non-polluted station with more oceanic ecosystem influence. Samples were fixed in Lugols solution. Diatom species cell numbers were counted according to the procedure described earlier by Utermohl (1958). Triplicate samples were settled for 24 hours in a settling chamber (50 ml). The settled samples were observed using inverted microscope. Identification of diatom species was done using available identification keys (Thomas, 1997). Water parameters like salinity measured by refractometer and temperature by mercury thermometer. Species composition and their abundance was compared at both stations A and B and correlated with water parameters like salinity and temperature.

Result

There was no significant variation observed between species composition at both A and B stations. Distribution pattern and seasonal variations in cell abundance of dominant species were observed in which seven dominant species were recorded from station B and six dominant species from station A. Among both centric and pennate diatoms, the genera *Chaetocerose affine, Pleurosigma* sp 1, *Thalassiosira* sp, *Navicula directa* and *Nitzschia longissima*, *Rhizosolenia setigera, Thalassionema nitzschiodes* remain dominated all year round although seasonal variations in abundance were observed for these genera. Nine species were abundant at both stations and ten species were found frequently at stations A and seven species at station B (Table 1). In pennate types *Asterionella Formosa, Navicula transitranse, Navicula* sp, *Pleurosigma* sp 2, *Synedra* sp, *Pinnularia* sp, *Thalassionema nitzschiodes* and in centric types *Guinardia flaccida, Eucampia zodiac* were found abundant at station A. At station B *Amphora* sp, *Asterionella Formosa, Navicula* sp 6, *Pleurosigma* sp 2 in pennate types and *Guinardia flaccida, Eucampia zodiac, Odontella sienensis, Odontella mobileinsis* were observed as abundant species. The species found frequently at station A *Amphora* sp, *Asterionellopsis glacialis, Gyrosigma* sp, *Pseudonitzschia* sp belong to pennate types and *Odontella sienensis, Odontella mobileinsis*, *Odontella aurita*, *Planktoniella sol* and *Rhizosolenia imbricata* belong to the centric types. The species found frequently at station B *Navicula transitranse* and *Synedra* sp belong to pennate types and *Odontella aurita, Plantoniella sol, Chaetocerose decipience* and *Rhizosolenia imbricata* belong to the centric types.

Fourteen species at station B and eleven species at station A were found rare. *Licmophora paradoxa, Nitzschia clostrium, Navicula f delicatula, Pleurosigma directum, Pleurosigma normani, Pleurosigma macrum, Coscinodiscus radiatus, Corthrone criopilum, Chaetocerose decipiense, Ditylum brightwilli* and *Guinardia striata* were found rare at station A and *Asterionellopsis glacialis, Cylindrotheca clostrium, Gyrosigms* sp, *Pseudonitzschia* sp, *Pleurosigma directum, Pleurosigma normani, Coscinodiscus radiatus, Corthrone criopilum, Ditylum brightwilli, Guinardia striata, Rhizosolenia styliformis, Rhizosolenia bergonii, Skeletonema* sp and *Triceracium* sp were found rare at station B. The species were selected according to the average cell abundance and their presence throughout the period of this study. LM and SEM (Light and Scanning electron micrographs) of some diatom species are presented in Plates 1 and 2.

Table 1: Diatom species identified from stations A and B. Species selected according to total abundance ($\times 10^3$ cell/litre) of all data

Diatom species	*St A*	*St B*
Pennate taxa		
Amphora sp	**	***
Asterionellopsis glacialis	**	**
Asterionella formosa	***	***
Cylindrotheca clostrium	A	***
Gyrosigms sp	***	**
Licmophora paradoxa	*	A
Nitzschia clostrium	**	A
Nitzschia longissima	****	****
Navicula directa	****	****
Navicula transitranse	***	A
Navicula f delicatula	***	A
Navicula sp 6	***	***
Pseudonitzschia sp	**	*
Pleurosigma sp 1	****	****
Pleurosigma sp 2	***	**
Pleurosigma directum	*	*
Pleurosigma normani	**	*
Pinnularia sp	**	**
Pleurosigma macrum	*	A
Synedra sp	***	**
Thalassionema nitzschiodes	****	****
Centric taxa		
Coscinodiscus radiatus	**	*
Corthrone criopilum	*	*
Chaetocerose danicus	A	**
Chaetocerose decipience	**	**
Chaetocerose affine	****	****
Ditylum brightwilli	***	*
Guinardia flaccida	**	***
Guinardia striata	*	*
Eucampia zodiac	***	***
Odontella sienensis	**	***
Odontella aurita	***	***
Odontella mobileinsis	**	**
Planktoneilla sol	**	**
Rhizosolenia setigera	****	****
Rhizosolenia imbricata	***	**
Rhizosolenia styliformis	A	*
Rhizosolenia bergonii	A	*
Skeletonema sp	A	*
Thalassiosira sp	****	****
Triceracium sp	A	*

Dominant****, Abundant***, Frequent**, Rare*.

Seasonal Abundance of Dominant Species

In centric type ***Thalassiosira*** sp are cosmopolitan and have great diversity. Approximately 100 species are reported from various areas. This species was dominant and present throughout the year except in May-1-2003, June, July, 2002, Feb-1 and Mar-1-2003 from station B and from station A present throughout the year except in the months of May-1, Sep-2, December, 2002, and Mar, 2003. It constitutes 1.5% in the months of September, 2002 and April, 2003 of the total diatoms at station A and 4.41% in the month of January, 2003 at station B (Table 2). Distribution pattern of *Thalassiosira* sp shows seasonal variation in the cell abundance. This species has high abundance at station B as compared to station A. This species has a high peak in the month of May-1, 2002 at 0.19×10^3 cell/litre when salinity was 37‰ and temperature was 29.1ºC. Second highest cell abundance was recorded in the second half of the month of October-2, 2002 at 0.18×10^3 cell/litre at station B. Lowest cell abundance observed was in the months of March-2, 2003 and April-1, 2003 at 0.007×10^3 cell/litre (Figure 1, a).

Chaetocerose affine was observed in almost all the months during 2002-2003 except in September-1-2002, January-1, February-1, and April-1, 2003 from station A but in contrast remain dominant all the months at station B. It contributed 3.9% in the months of December, 2002 and March, 2003 at station A and 4.4% in the month of January, 2003 at station B of the total diatoms (Table 2). Total cell abundance was high at station B as compared to station A. This species has a peak in the month of March-1, 2003 with cell abundance of 4.31×10^3 cell/litre with recorded salinity of 40‰ and temperature 26ºC. Second highest cell numbers were seen in May-2, 2003 with cell abundance of 2.94×10^3 cell/litre from station B. Lowest cell numbers were 0.02×10^3 cell/litre observed in the months of Sep-2, 2002 and May-1, 2003. Similar cell abundance 0.02×10^3 cell/litre was observed in the same months of June-2 in 2002 and 2003. At station A total cell abundance was low 5.12×10^3 cell/litre as compared to station B. Lowest cell abundance recorded was 0.013×10^3 cell/litre in the months of June-2, Nov-1, and Dec-1, 2002 from station A. Higher abundance observed in the month of July-1-2002 was 1.12×10^3 cell/litre (Figure 1, b).

Rhizosolenia setigera: This centric diatom species was dominant at both stations all the year. This species has contributed 13.1% of the total diatoms in the month of June, 2003 at station A and 33.5% of the total diatoms in the month of June, 2003 at station B (Table 2). At

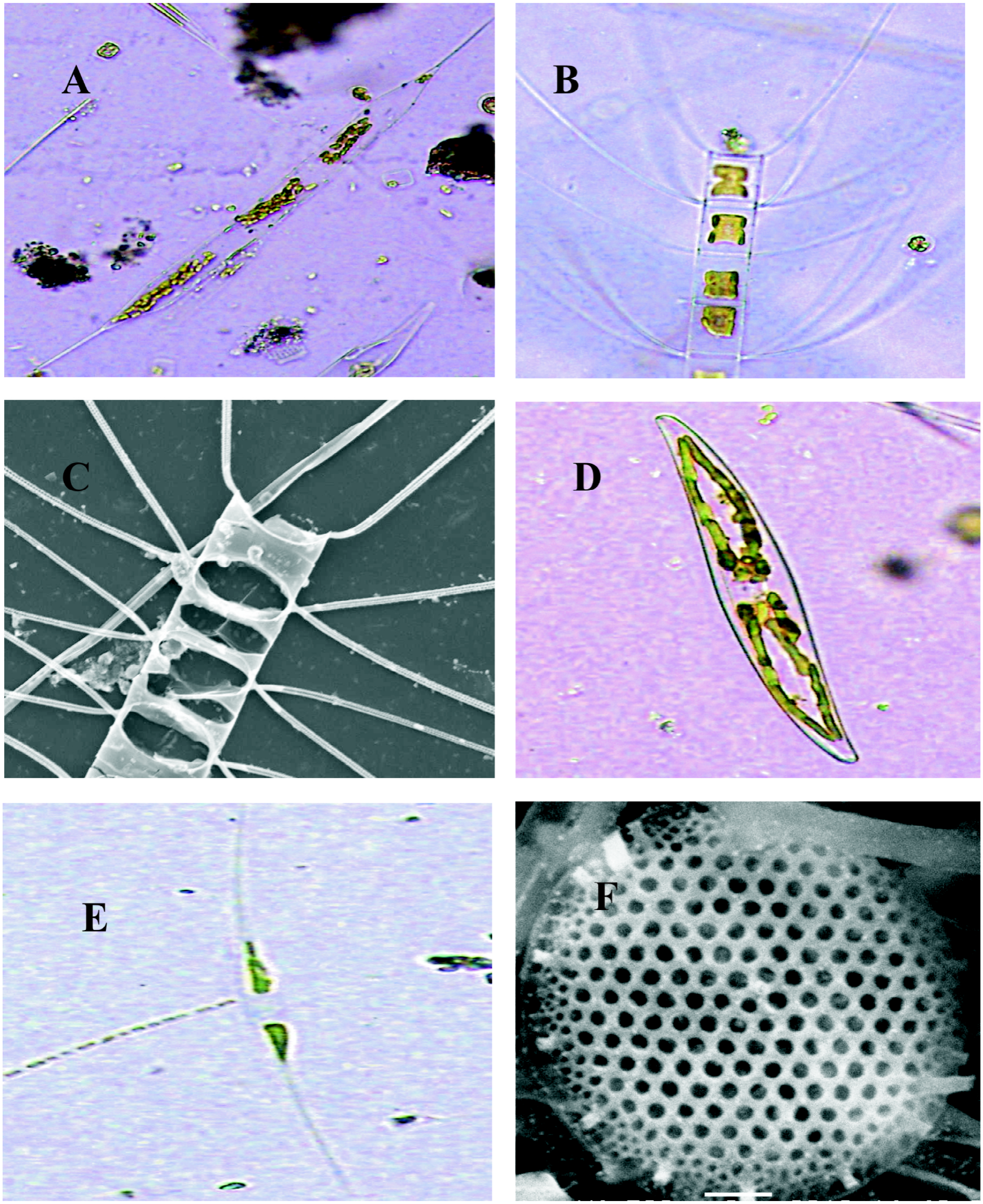

Plate 1: Light microscopy micrographs and scanning electron micrograph: A – *Rhizosolenia setigera*, B – *Chaetocerose affine*, C – *Chaetocerose decipiense*, D – *Pleurosigma* sp 1, E – *Nitzschia clostrium*, F – *Thalassiosira* sp.

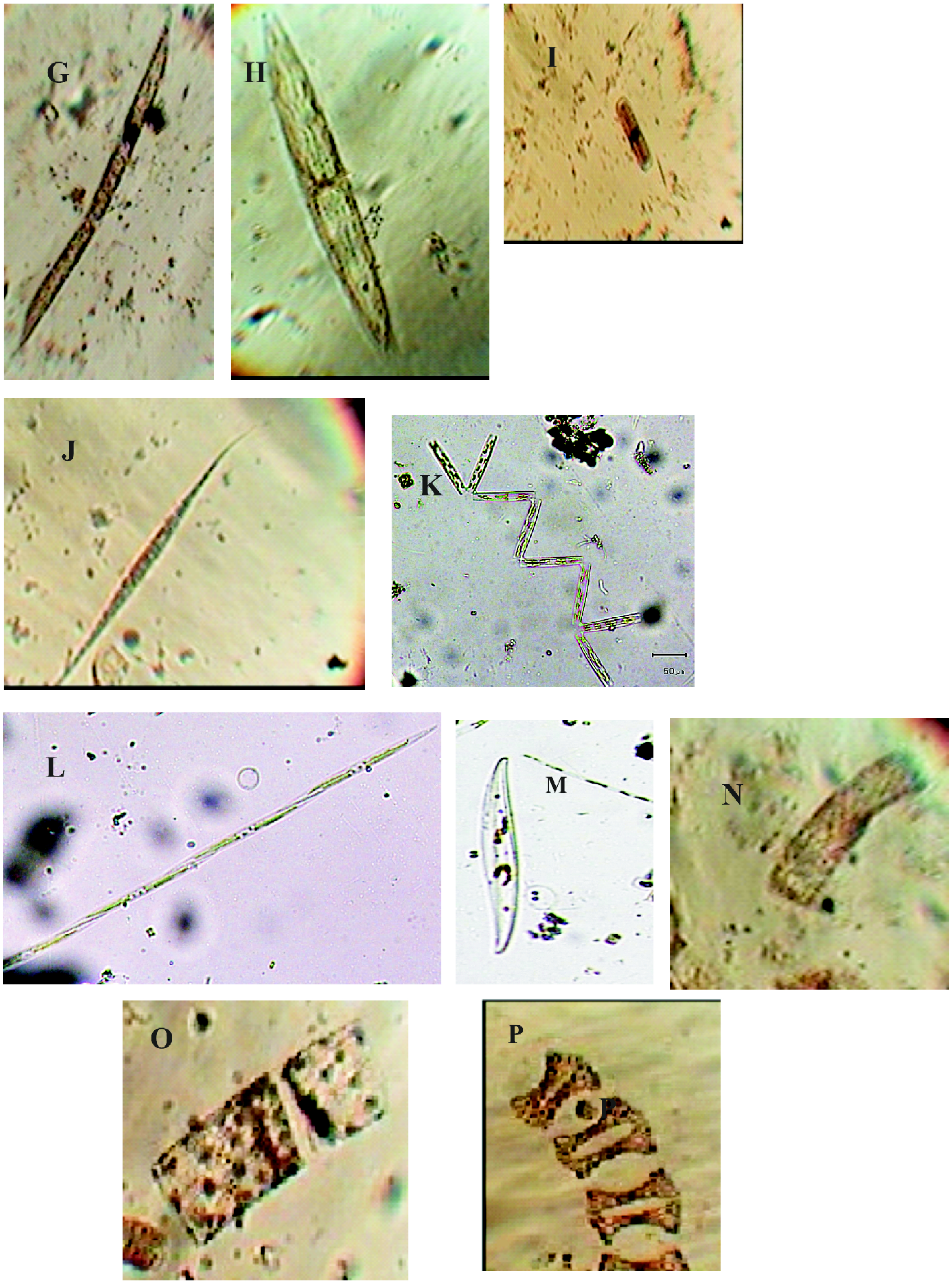

Plate 2: Light microscopy micrographs and scanning electron micrograph: G – *Rhizosolenia imbricate*, H – *Navicula* sp, I – *Pinnularia* sp, J – *Pleurosigma macrum*, K – *Thalassionema nitzschioides*, L – *Pseudonitzschia* sp, M – *Pleurosigma normani*, N – *Guinardia striata*, O – *Guinardia flaccida*, P – *Eucampia* zodiacus.

station B maximum cell abundance observed was 1.007×10^3 cell/litre in the month of May-2, 2003 when salinity was recorded 36.3‰ and temperature 31.0ºC. Second highest cell numbers counted in the month of Feb-2, 2003 were at station B. Lowest cell numbers observed 0.007×10^3 cell/litre in the month of Sep-2, 2002. Low abundance was observed in the months of June-2, Sept-1, Nov-1, Dec-2, 2002 and May-1, 2003. At station A maximum cell density 0.80×10^3 cell/litre was seen in the month of May-2-2003 same as station B but with relatively lower abundance as compared to station B. Lowest cell numbers were observed 0.007×10^3 cell/litre in the month of May-1, 2003 at station A (Figure 1, g).

In pennate type, ***Nitzschia longissima*** occupied a high proportion of the total diatom assemblage at both stations and was the most dominant species from all groups. It constitutes more than 97% of total diatoms in the months of February, 2003 at station A and more than 95% of total diatoms in the month of May, 2003 at station B (Table 2). Its dominancy was high at station B with peak numbers of the cells recorded 15.80×10^3 cell/litre in the month of February-1, 2003. At the time salinity was 40.0‰ and temperature 25.1ºC. Second peak observed in the month of April-2, 2003 was 15. 29×10^3 cell/litre. Lowest cell abundance recorded was 0.07×10^3 cell/litre in the month of August-1, 2002 at station B. Station A has a peak of 12.97×10^3 cell/litre in the same month February-1, 2003 but the abundance is lower as compared to station B. Cell abundance remain high at the second half of February-1, 2003 that was 10.5×10^3 cell/litre and showed little increase 10.6×10^3 cell/litre in the next month of March-1, 2003. Lowest cell abundance recorded was 0.04×10^3 cell/litre in the month of June-2, 2002 (Figure 1, c).

Navicula directa was dominant throughout the year except in the month of June-1, 2002 and June-2, 2003.

Table 2: Minimum to maximum range of percentage (%) contribution of dominant diatom species from stations A and B

Dominant species	*Percentage (%)*	
	Station A	*Station B*
Chaetocerose affine	0.7-3.9	0.06-19.4
Navicula directa	0.6-99.2	0.4-98.46
Nitzschia longissima	2.0-97.9	12.7-95.6
Pleurosigma sp 1	0.5-7.6	0.7-7.7
Rhizosolenia setigera	0.2-25.4	0.02-3.0
Thalassiosira sp	0.2-1.5	0.02-4.4
Thalassionema nitzschiodes	0.3-8.6	0.2-15.4

Almost similar cell numbers were observed at both stations except in the months of April-1, June-1 and July-1, 2003. This species was observed in bloom condition with the peak of cell abundance of 29.567×10^3 cell/litre in the month of September-2, 2002 from both stations, making up 99% of total diatoms in the same month (Table 4). Salinity values were 38‰ and temperature was 29.9ºC at both stations. Second highest cell numbers observed were 7.18×10^3 cell/litre in the month of March-2, 2003. Lowest cell abundance 0.05×10^3 cell/litre which was the same observed in the months of Aug-1, Dec-2, 2002 and May-1, 2003 at both stations. Rest of the months showed almost same and uniform distribution (Figure 1, d).

Pleurosigma sp 1 was also dominant at both stations and comparatively had low abundance at station A than station B. Its contribution to total diatoms was 7.6% in the month of December, 2002 at station A and 7.2% in the month of January, 2003 at station B (Table 2). The salinity was 37.3‰, 41‰ and temperature was 24.0ºC, 24.5ºC at stations A and B respectively. This species also showed its presence throughout the year at station B but at station A absent in the months of Aug-2, Dec-1, 2002 and Jan-1, 2003. The highest cell density 0.253×10^3 cell/litre observed in the month of October-1-2002 at station B and at station A, 0.173×10^3 cell/litre in the month of March-2-2003. Lowest cell densities observed in the months of June-1, Aug-1 and September-1-2002 that was 0.007×10^3 cell/litre from station B and at station A lowest cell abundance was 0.01×10^3 cell/litre recorded in the month June-2, 2002 (Figure 1, e).

Thalassionema nitzschiodes contributed 25% in the months of May and July, 2002 at station A and 22.7% in the month of July, 2002 at station B (Table 2). This species attained its maximum abundance in the month of May-2-2002 with the cell abundance of 0.50×10^3 cell/litre at station A. At station B maximum cell abundance also observed in the same month but in the year May-2-2003 so the maximum abundance appeared only in summer months at both stations. A second peak of cells 0.28×10^3 cell/litre observed in the month of June-1-2003 at station B. Almost absent in winter months, the lowest cell abundance observed in the month of Nov-2-2002 and Dec-1-2002 was 0.007×10^3 cell/litre at both stations (Figure 1, f).

Seasonal Abundance of Dominant and Frequent Species

In pennate group, ***Amphora*** sp was abundant at station B and frequently found at station A. It appears in May-1, Jun-1 and Jul-1-2002 at station A and in May-1, June-1, Sep-1-2002 and July-1-2003 at station B. This genus was found more or less in same months of summer at both stations. Highest cell abundance was observed 0.25×10^3 cell/litre in the month of Jul-1-2003 from station B (Figure 1, h). ***Asterionella formosa*** was abundant at both stations. This species appears in May-1-2002 at both stations then disappears in Aug-1-2002 to Mar-2-2003 at station B. Again appears in the month of April to Jul-1-2003. *Asterionella formosa* is present all the year except in the months of Oct, Dec-1-2002, Jan-2-2003 and Feb-1-2003 at station A. Highest cell abundance observed was 0.25×10^3 cell/litre from station B (Figure 1, i).

Navicula transitranse was encountered as abundant at station A and frequent at station B. Highest cell abundance was 2.9×10^3 cell/litre in the month of June-1, 2002 at station A and at station B 0.2×10^3 cell/litre was the higher cell numbers in the month of July, 2002 (Figure 1, j). ***Pleurosigma*** sp 2 was abundant at both stations. Highest cell density was recorded 0.14×10^3 cell/litre in the month of Apr-1-2003 from station A. This species was completely absent in the months of August and September 2002 from both stations. Lowest cell abundance 0.007×10^3 cell/litre was recorded in June and July 2002 at station B (Figure 1, k).

Navicula sp was abundant at both stations. This species was present from July to Oct-2-2002 at station B and at station A appears in the month of May-2-2002 with lowest abundance of 0.007×10^3 cell/litre. Highest cell abundance recorded was 0.14×10^3 cell/litre in the month of Oct-1-02 from both stations (Figure 1, l). ***Pinnularia*** sp was found abundantly at both stations. This species was present in the month of Jun-1 and Jul-1-2002 at station B and appears in the month of Jul-1-2002 at station A**;** then disappears and again appears from Oct-2002 to May-2003 at both stations. Highest cell abundance recorded was 0.66×10^3 cell/litre in the month Sep-1-2002 from station A (Figure 1, m).

Odontella mobiliensis was frequently present at station A and abundantly recorded at station B. This species showed presence from June-1-2002 to Feb-2003 at station B and May-1, Jun-2, Nov-2-2002 and Mar-2-2003 at station A. Highest cell abundance was observed 0.08×10^3 cell/litre in the month of Oct-2-2002 at station B (Figure 1, n). ***Chaetocerose decipiense*** was frequently found at station B but in lower cell numbers. Higher cell abundance observed was 0.06×10^3 cell/litre in the month of Oct-1, 2002 (Figure 1, o).

Guinardia flaccida was abundant at both stations. This species appears in the month of June to October, 2002 and then absent in November, 2002 and April, 2003 at station B. Highest cell abundance was recorded 0.28×10^3 cell/litre in the month of Jan-2-2003 from station B. *Guinardia flaccida* was completely absent at station A in the months of August, 2002 and April, 2003 (Figure 1, p). ***Eucampia zodiac*** was abundantly found species at both stations. At station B this species was absent in the months of Aug-1-2002, January, Feb-1 and Apr-2-2003. At station A also it was absent in the months of Aug, 2002 and Apr, 2003. Highest cell abundance was observed 0.46×10^3 cell/litre in the month of Feb-2-2003 from station B (Figure 1, q).

In centric group, ***Odontella sienensis*** was abundant at station B observed in May and June-2002; then disappears in July to again appear in August-2, Oct-2 and Dec-2-2002; then disappears in September, November, 2002 and January, 2003 then again shows its presence from February to July-1-2003. Highest cell abundance observed was 0.18×10^3 cell/litre in the month of March-2-2003. This species was frequently found at station A observed in the months of May, June, July and Oct-2-02 (Figure 1, r). ***Odontella aurita*** was frequently found at both stations. This species appears in the month of Jun-02-2002 at station B and May-2 to Oct-2-02 at station A and disappears; then again appears in the same month of Jun-1-2003 at both stations. Highest cell abundance was observed 1.96×10^3 cell/litre in the month of Jun-02-2002 at station A (Figure 1, s).

Planktoneilla sol was frequently found at both stations. At station B this species appears in the months of November and Dec-2002 and then again shows its presence in Feb-2 and July-1-2003. At station A it appears in Jun-2-2002 and then again shows its presence in Nov-1, Dec-1-2002, May and Jul-1-2003. Highest cell abundance recorded was 0.04×10^3 cell/litre in the month of Jul-1-2003 from station A (Figure 1, t). ***Pseudonitzschia*** **sp** was frequently observed at station A, whereas it was found only at four occasions at station B. Highest cell numbers of *Pseudonitzschia* species were observed in July (2307 cell/litre) at station A and in April (1587 cells/litre) at station B (Table 3).

Rhizosolenia imbricata was frequently found at both stations. This species has shown similar cell abundance of 0.093×10^3 cell/litre in the month of July-1-2002 at both stations. At station A maximum cell abundance recorded was 0.446×10^3 cell/litre in the month of June-2-2003 (Figure 1, u). ***Synedra*** sp was abundant at station A and frequently found at station B. It appears in the month of May-2-2002; then disappears in June, Sep-2002 and Feb-2003. *Synedra* sp was present in the months of March and April, 2003 but in lowest cell abundance of 0.007×10^3 cell/litre, then again disappears in the months of May and Jun-2003. *Synedra* sp also appears in the

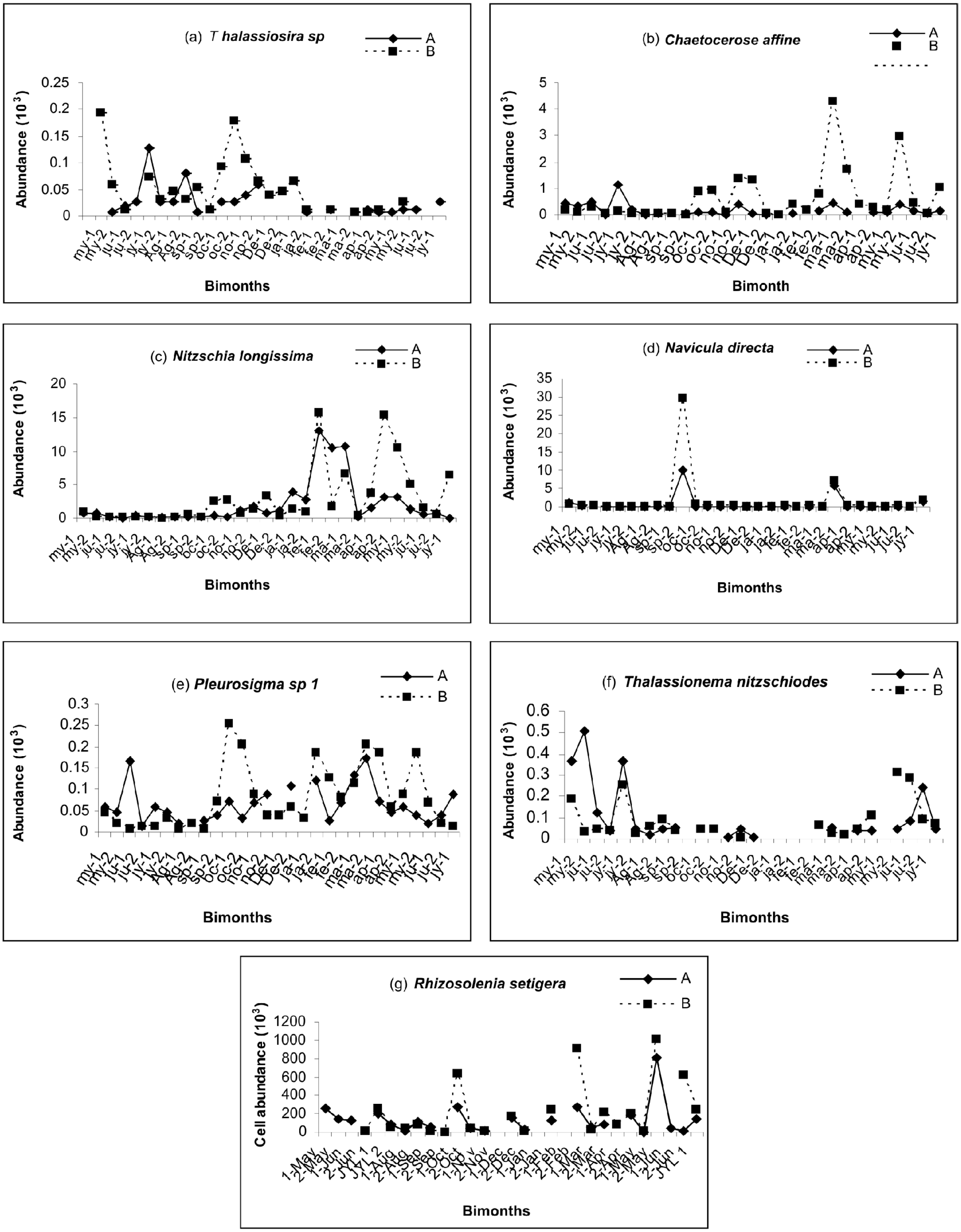

Figure 1: Seasonal variation in abundance of dominant species of diatom assemblage ($\times 10^3$ cells/litre). Note that the scale of abundance is not uniform throughout the graphs. (a) *Thalassiosira* sp, (b) *Chaetocerose affine,* (c) *Nitzschia lonissima,* (d) *Navicula directa,* (e) *Pleurosigma* sp 1, (f) *Thalassionema nitzschiodes* and (g) *Rhizosolenia setigera.*

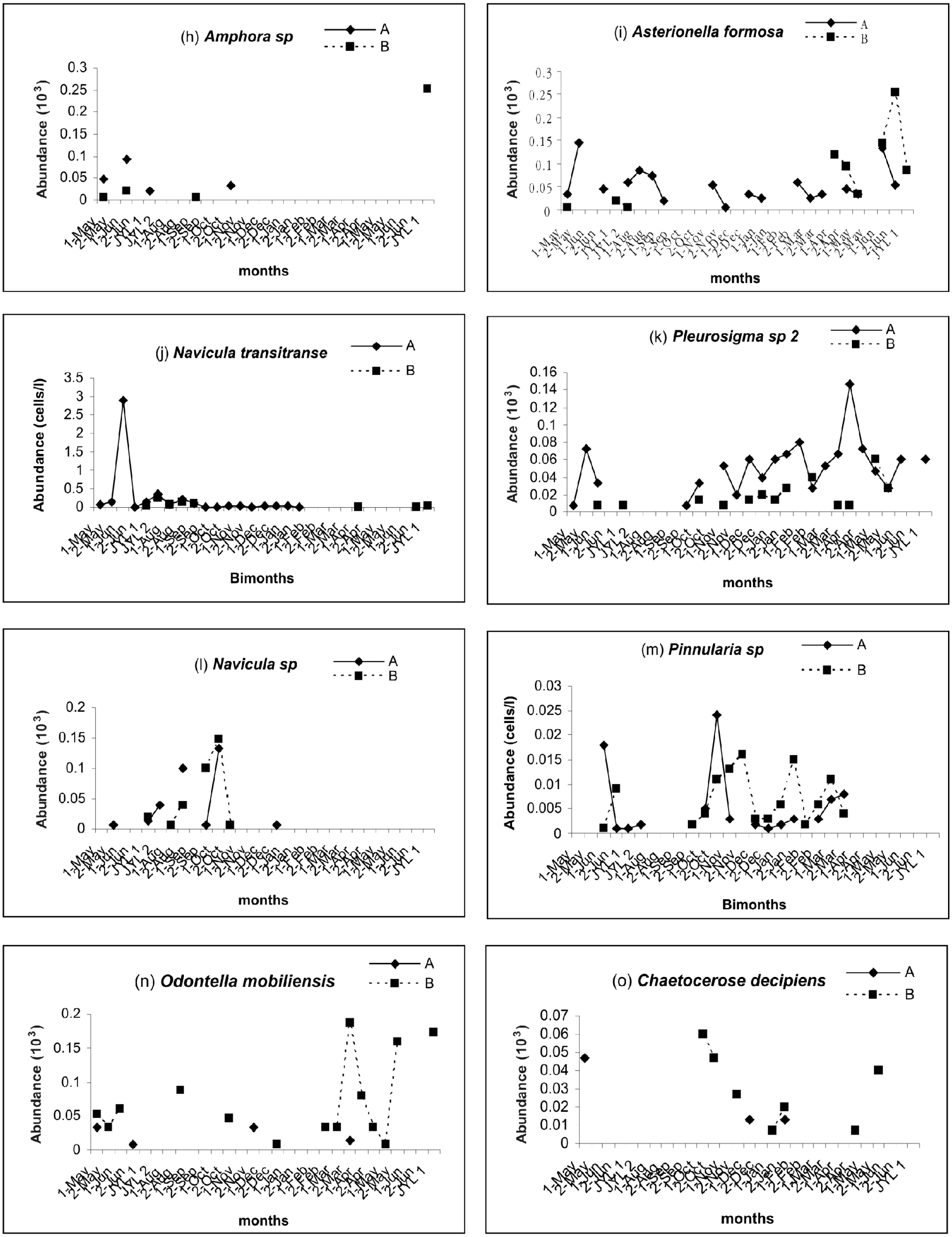

Figure 1 (Contd): Seasonal variation in abundance of dominant and frequently found species of diatom assemblage. (h) *Amphora* sp, (i) *Asterionella formosa*, (j) *Navicula transitranse*, (k) *Pleurosigma* sp 2, (l) *Navicula* sp, (m) *Pinnularia* sp, (n) *Odontella mobiliensis*, (o) *Chaetocerose decipience*.

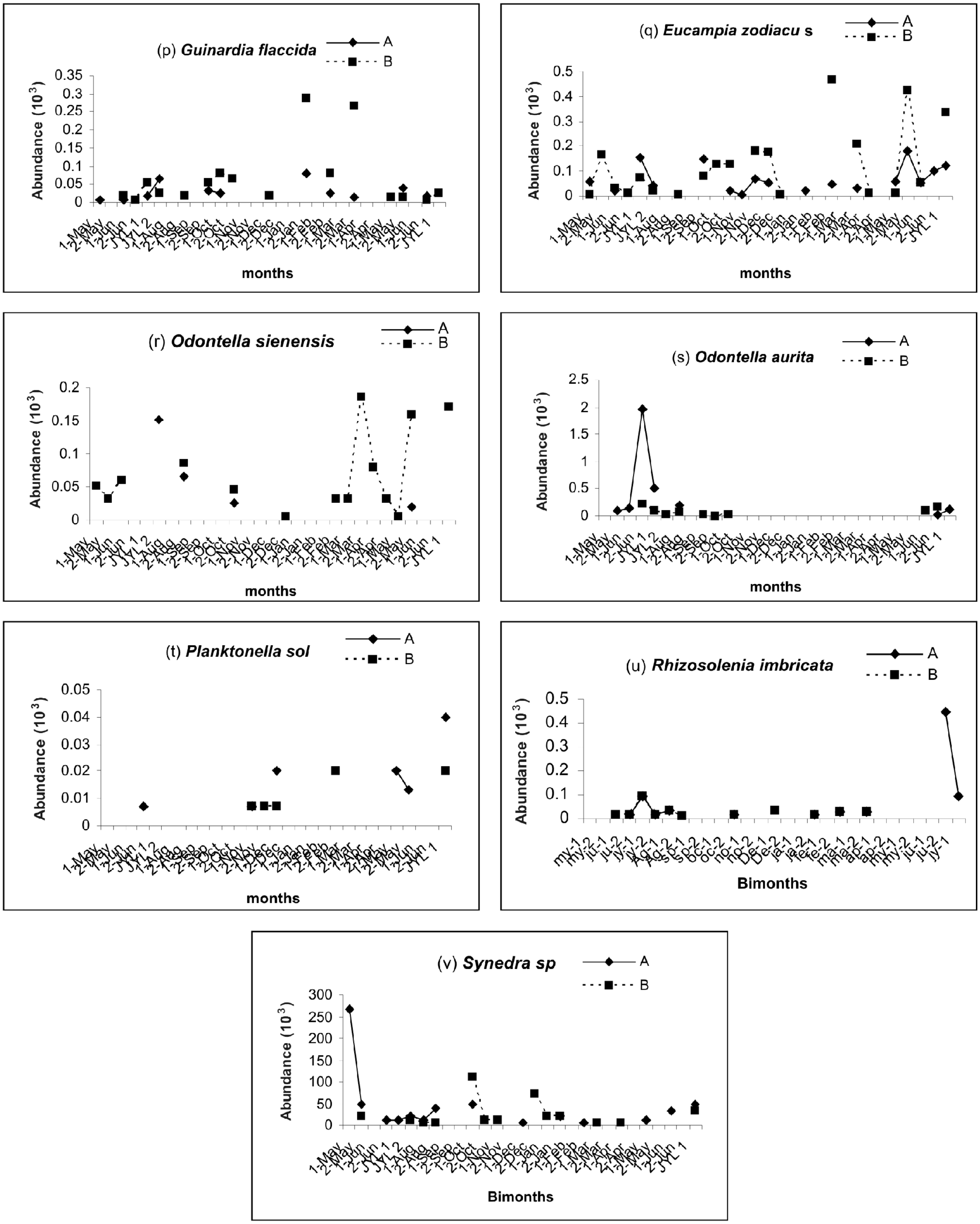

Figure 1 (Contd): Seasonal variation in abundance of dominant and frequently found species of diatom assemblage. (p) *Guinardia flaccida*, (q) *Eucampia zodiacus*, (r) *Odontella sienensis*, (s) *Odontella aurita*, (t) *Plantoneilla sol*, (u) *Rhizosolenia imbricate* and (v) *Synedra* sp.

same month of May-1-2002 with highest cell abundance 0.26×10^3 cell/litre at station A. This species is completely absent in the months of September, Nov, 2002, March and Apr, 2003 at station A (Figure 1, v).

Few species with low abundance are rare species which occur once or twice in a year and can also be considered as indicator species with particular environments. Abundance of rare species is presented in Table 3.

Table 3: Cell abundance (10^3 cells/litre)—Minimum and maximum of rare species from stations A and B

Rare species	*Station A*	*Station B*
	Abundance (10^3 cells/litre)	
Asterionellopsis glacialis	-	0.027-0.10
Cylindrotheca clostrium	-	0.13-0.2
Coscinodiscus radiatus	0.007-0.053	0.02
Corthrone criopilum	0.007-0.01	0.007
Ditylum brightwilli,	0.01-0.833	0.007-0.01
Guinardia striata,	2.82	3.68
Licmophora paradoxa	0.007	-
Nitzschia clostrium	0.64	-
Navicula f delicatula	0.01	-
Pseudonitzschia sp	0.1-2.30	0.007-1.5
Pleurosigma directum	0.007	0.007
Pleurosigma normani	0.027-0.073	0.007-0.02
Pleurosigma macrum	0.007	-
Rhizosolenia styliformis	-	0.02
Rhizosolenia bergonii	-	0.01
Skeletonema sp	-	0.02
Triceracium sp	-	0.02

Water Parameters

Temperature was high all the year except in winter months of November, December, 2002 and January, 2003 at both stations. It varies from 23.50 °C to 31.83 °C at station A in the months of January and July, 2003 respectively. From station B minimum temperature recorded was 22.00 °C in the month of December, 2002 and maximum was 31.17 °C in the month of July, 2003. Salinity shows highest value at station B recorded 41‰ in the month of January, 2003 and lowest value observed was 34.67‰ in the month of July, 2003. Maximum value observed at station A was 40.00‰ in the months of July, November, 2002 and January, 2003. Minimum value recorded was 34.33‰ in the month of August, 2002 (Figure 2).

Statistical Analysis

Statistical analysis between the dominant diatom species and water parameters of both stations A and B was determined (Table 4). All dominant species were correlated with the salinity and temperature at both stations A and B. At station A all the species have shown positive correlation with the salinity except *Rhizosolenia setigera* = –0.2. At station B *Chaetocerose affine* = 0.05 and *Navicula directa* = 0.05 have shown positive correlation with salinity but *Nitzschia longissima* = –0.2, *Pleurosigma* sp 1 = –0.2, *Thalassiosira* sp = –0.05 *Thalassionema nitzschiodes* = –0.1 and *Rhizosolenia setigera* = –0.1 have shown negative correlation with salinity. All dominant species at station B have shown positive correlation with the temperature: *Chaetocerose affine* = 0.05, *Navicula directa* = 0.08, *Nitzschia longissima* = 0.02, *Pleurosigma* sp 1 = 0.15, *Rhizosolenia setigera* = 0.23, *Thalassiosira* sp = 0.20, *Thalassionema nitzschiodes* = 0.29. At station A *Chaetocerose affine* = 0.20, *Navicula directa* = 0.2, *Rhizosolenia setigera* = 0.15 and *Thalassionema nitzschiodes* = 0.34 were positively related with temperature and *Nitzschia longissima* = –0.37, *Pleurosigma* sp 1 = –0.19 and *Thalassiosira* sp = –0.19 were negatively related with temperature (Table 4).

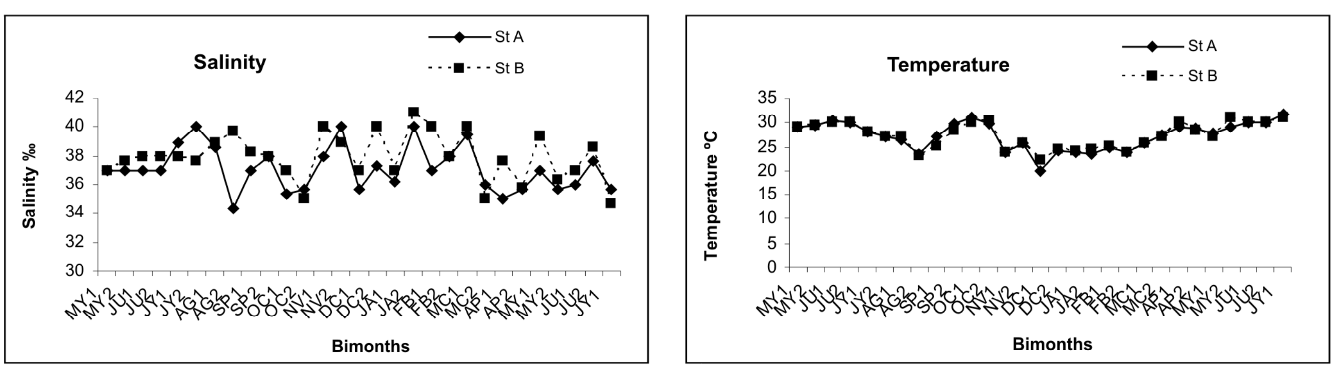

Figure 2: Seasonal variations in salinity and temperature from stations A and B.

Table 4: Correlation of dominant diatom species with temperature and salinity at stations A and B

Dominant species	*Temperature*		*Salinity*	
	A	*B*	*A*	*B*
Chaetocerose affine	0.20	0.06	0.30	0.05
Navicula directa	0.22	0.09	0.07	0.06
Nitzschia longissima	-0.37	0.02	0.21	-0.22
Pleurosigma sp 1	-0.20	0.16	0.13	-0.22
Rhizosolenia setigera	0.16	0.24	-0.25	-0.14
Thalassiosira sp	-0.19	0.20	0.18	-0.05
Thalassionema nitzschiodes	0.34	0.29	0.12	-0.19

Discussion

Diatoms are the dominant phytoplankton group (69%) of the coastal waters of Karachi in terms of their abundance. The diatom species observed during this study have been previously reported from Pakistani waters by Saifullah and Moazzam, 1978; Shameel and Tanaka, 1992; Ghazala et al., 2006 but their seasonal abundance and distribution data is lacking from this region. Diatoms composition showed typical temperate, tropical, subtropical and cosmopolitan species (Schiebel et al., 2004). This mix of species showed that Manora Channel is a port where different ships from various parts of the world visit with regular intervals that can transport the diatom species from different geographical areas. Some species were neritic which showed influx of open sea water into near-shore waters like *Odontella aurita* and *Triceracium* sp. The most diverse genera were *Pleurosigma, Chaetocerose, Rhizosolenia, Navicula* and *Odontella* at both stations. Auxospores in species like *Guinardia flaccida, Odontella mobileinsis* and *Rhizosolenia setigera. Ditylum brightwilli, Odontella sienensis* and *Odontella aurita* were found in a phase of active cell division at the time of sampling in different months.

The dominant species including *Nitzschia longissima, Navicula directa* and *Chaetocerose affine* are consistently seen in high cell abundance. Contrastingly *Pleurosigma* sp 1, *Thalassiosira* sp, *Thalassionema nitzschiodes* and *Rhizosolenia setigera* were seen almost throughout the sampling period but comparatively in less numbers. These all diatoms were also reported as dominant part from other upwelling regions (Lassiter et al., 2006; Chavez et al., 1991; Kobayashi and Takahashi, 2002). It suggests that these diatoms species are more tolerant to nutrient-rich upwelling systems of northern Arabian Sea. Monsoon system is a pronounced feature affecting hydrographics of the Arabian Sea throughout the year. It causes upwelling and brings nutrient-rich cold waters to the upper water columns. The response of diatom species was clearly seen when in late monsoon periods bloom condition of diatom species *Navicula directa* and *Nitzschia longissima* was observed in the months of September, 2002 and February, 2003 respectively contributing high biomass in the diatoms community. The water is anoxic and a minimum value 0.7 mg/litre for dissolved oxygen was recorded at that time. Chaghtai and Saifullah (1992) reported a bloom of *Navicula Boray* (a parent species of *Navicula directa)* from mangrove habitat of Sands pit Karachi, Pakistan. Similar result was reported by Parab et al. (2006) from eastern Arabian Sea.

During high concentrations of diatoms the community consists of pennate species. In pinnate, *Nitzschia longissima* and centric *Chaetocerose affine* was found in high abundance at both stations. *Nitzschia longissima* was also reported as the dominant component of the diatom community with high concentrations from south eastern Arabian Sea by Jayothibabu et al. (2008).

The estimated abundance among species were variable from both stations A and B. The species encountered relatively high abundance at station B as compared to station A indicating differences of their contributions to diatom community biomass. Dominant species are commonly used to analyze nature of habitat in the ecosystem. Among seven dominant species four species belong to the pennate type. Dominance of pennate species over centric types with high abundance suggests that they have better tolerance against environmental variables and pennate species are successful diatom species in this region. Similar result was reported by Gomi et al. (2005) from surface waters of Indian sector of Southern Ocean and Turkish waters by Cetin and Sen (1998).

The abundant and frequent species with both high surfaces to volume ratios (*Navicula* sp, *Pleurosigma* sp, *Pinnularia* sp, and *Synedra* sp) and low surfaces to volume ratios (*Chaetocerose* spp) have difference in their nutrient absorbing capabilities (Panigrahi et al., 2004). It could be a possibility that during the seasonal changes regarding low nutrients and high nutrient conditions in the area the diatom species successive competition occurs.

Temperature is a very important factor and was found positively and strongly related with all the dominant species at station B. At station A three dominant species were negatively related with temperature. At station A salinity was positively related with all dominant species except centric diatom *Rhizosolenia setigera* and at station

B all dominant species were positively related with salinity except *Chaetocerose affine* and *Navicula directa.* It suggests that temperature and salinity are the most significant factors that give shape to the diatom community and control the community changes. The abundance of these dominant species throughout the year was influenced by the seasonal change in temperature and salinity. Similar results were reported by Gasiunaite et al. (2005) from Baltic Sea and Wang et al. (2006) from subtropical area of South China Sea.

The Manora Channel is facing eutrophication problem due to the input of sewage and industrial effluents brought by Lyari river. The region is constantly affected by the pollution. It may be interesting to note that some species like *Licmophora paradoxa, Nitzschia clostrium, Navicula f delicatula* and *Pleurosigma macrum* were exclusively present in the samples collected from station A which is located inside the Manora Channel and has polluted waters. These species may consider as eutrophication indicator species.

This is the first detailed study regarding the diatom species composition, seasonal abundance and distribution from this region. Further assessment on ecological aspect may be useful to describe species in each genus and identify pollution indicator species. This study suggests further investigation of hydrographical and meteorological effects on species diversity in the region for understanding the interaction between the diatoms community and environmental variables.

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