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Phytoplankton Community Structure of a Mangrove Habitat in the Arid Environment of Oman: The Dominance of *Peridinium quinquecorne*

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ABSTRACT

Little is known about the physical, biological and chemical oceanographic conditions of Oman's *Avecenia marina* dominated coastal mangrove ecosystem. This study provided information on the phytoplankton community structure and biomass (Chla) and their variability in relation to chemical and physical changes in the coastal mangrove ecosystem of Bandar Khyran Bay. Monthly assessments of phytoplankton and (chlorophyll a) accompanied by CTD and nutrient measurements were carried out at one station from January 2001 to December 2001, Chla were moderately low throughout in all probability due to the high water temperatures, low nutrient concentrations and high turbidity as well as the absence of diatoms in the phytoplankton community. The contribution of net phytoplankton >20 μm to total biomass was minimal throughout the study period except during December where it accounted for 53% of the total biomass. Phytoplankton populations within the size range of 0.74-<5 μm accounted for the highest biomass, followed by the size fraction (5-20 μm). A total of 25 net phytoplankton taxa were identified during the study. The overall composition of the community did not show any marked seasonal variations. The net plankton was dominated by a single species of dinoflagellate *Peridinium quinquecorne* Abe, 1927 throughout the year comprising more the 90% of the species counts where at times it reached bloom proportions. It has been hypothesized that ability of this species to thrive under a range of physical and chemical conditions allows it to survive and outcompete most other phytoplankton species including diatoms.

Key words: Chlorophyll a, coastal upwelling, dinoflagellate, *Peridinium quinquecorne*, conductivity, temperature, depth sensor

INTRODUCTION

In coastal areas, mangroves are ecologically as well as economically important since they serve as nursery grounds, refuge for many fish and crustacean species (Harrison *et al*., 1994) and provide favorable conditions for algal growth (Faust and Gulledge,1996). Mangroves represent unique tropical environments and are vital to the productivity of adjacent coastal marine communities

(Odum *et al*., 1982).They export their production of organic matter in the forms of detritus and living organisms to the adjacent coastal waters (Woodroffe, 1992).

Throughout the world approximately 54 species of plants belonging to about 20 genera in 16 families have been recognized as mangroves (Tomlinson, 1986). In contrast, the only surviving mangrove species left in the Sultanate of Oman is the most salt-tolerant of all species, i.e., *Avicennia marina* (Fouda and Al-Muharrami, 1996).This is due to the extremely arid and saline conditions prevailing in the Arabian Peninsula, with very little rain in most areas and very limited or no other freshwater runoff (Sheppard *et al*., 1992).

Currently, the total area of mangrove coverage in the Sultanate of Oman is estimated at around 1088 hectares (Fouda, 1995; Fouda and Al-Muharrami, 1996) scattered around the coast at approximately 30 sites. The BK mangroves occupy an area of 83 ha making it the 5th largest mangrove in Oman (Fouda, 1995).

To date there has been no study of the physical, biological and chemical oceanography of Oman mangroves and furthermore their influence on coastal waters remains poorly understood. This manuscript is part of a one-year study of the Bay of BK in which we report the seasonality of phytoplankton in relation to environmental conditions within this mangrove ecosystem.

MATERIALS AND METHODS

Site description: This study was carried out in the Bay of Bandar Khyran (BK) (Fig. 1), located about 25 km from Muscat. BK is a small village at the southeastern margin of the capital area at 23°30'26"N (Latitude) and 58°43'48"E (Longitude). The inner region of the Bay is a shallow tidal mud-flat as result of which the water column is very turbid. All along its margins, the bay is lined with *Avicennia marina* mangrove forest extending about 83 ha (Fouda, 1995).

Sampling strategy: One station was sampled "Mangrove", in the inner region of western side of the Bay in the mangrove channels. Sampling was carried out on a monthly basis (except during

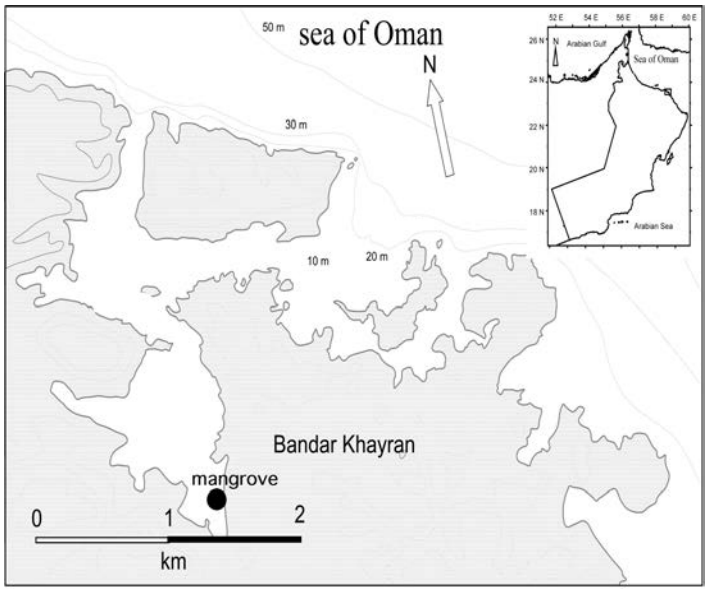

Fig. 1: Bandar Khyran map and sampling station (Al-Hashmi *et al*., 2010)

April, May and June when sampling was done twice) over the period f from January 22-December 25, 2001. Water sampling was undertaken during high tide periods in order to offset tidal influences on our findings and also because it was not possible to reach the station during low tide to perform effective zooplankton tows.

In situ temperature, salinity, dissolved oxygen, light penetration and turbidity were measured using a Idronaut-Ocean Seven'316 CTD (conductivity, temperature, depth sensor) probe. Surface water samples (250 mL) were collected by Niskin bottles for the analyses of nitrate, nitrite, phosphorus and silica. Samples were immediately frozen and then thawed and analyzed for the detection of nutrients using a 5-channel SKALAR FlowAccess auto-analyzer according to the procedure described by Strickland and Parsons (1972).

In situ Chl a profiles were estimated by direct fluorescence using fluorescence probe mounted on the CTD. Size fractionated biomass of phytoplankton was established by filtering 2 L of water samples immediately through three different filters: (1) Whatman GF/F glass fiber filter with 0.74 μm pore size, (2) nytex screening with 5 μm mesh size and (3) nytex mesh screening with 20 μm mesh size and the filters were kept frozen under 4°C in darkness until the time of analysis. In the laboratory, filters were placed into a 90% acetone solution overnight under cold and dark conditions for extraction of Chl a and then ground to facilitate extraction of Chl a. Chl a concentrations were determined using a Turner Design Model 10-AU Fluorometer. Chl a concentrations were corrected for phaeophytin using the acidification method (Strickland and Parsons, 1972). Pure Chl a standard was used to calibrate the fluorometer. Chl a values were calculated using the equation given in (Strickland and Parsons, 1972).

Five hundred mililiter aliquots of water samples were also collected and preserved with 1% Lugol's Iodine solution for phytoplankton species identification and cell count determinations. In the laboratory, samples were allowed to settle in 15 mm diameter tubes before they were counted using an inverted I×50 Olympus microscope. For identifying individual marine diatoms, dinoflagellates, silicoflagellates and large cyanobacteria, the identification and taxonomic studies are based on Round *et al.* (1990) and Tomas (1997). Cell counts were used to determine the abundance of the large phytoplankton community.

A horizontal tow was made with 250 μm net that was fitted with a Hydrobiosflowmeter. Samples were preserved in 5% formaldehyde and later were settled in glass graduated cylinders and sedimentation biovolume was recorded. Density was then calculated in organisms in cubic meter.

Statistical analysis: The community structure was analyzed with non-parametricmultivariate methods using *Primer v.6*. Prior to the analysis, raw abundance data were fourth-root transformedto reduce the influence ofoverly abundant species on thepattern. The Bray-Curtis similarity matrix which reflects changes in relative abundance as well as species composition, was used to calculate a non-metric multi dimensional scaling (MDS) ordination plot. A permutation test on the matrix of similarity (1-way ANOSIM) was used to assess seasonal difference in community structure (Warwick and Clarke, 1991). The BIOENV procedure in primer v.6 was used to correlate phytoplankton community structure with all possible environmental variables (temperature, salinity, dissolved oxygen, nitrate, nitrite, silicate and phosphate). Simpson's biodiversity index was used as a index of biodiversity of phytoplankton (Simpson, 1949).

RESULTS

This investigation of phytoplankton community in a semi enclosed bay with mangrove plays a crucial role in understanding phytoplankton dynamics in response to environment changes. In the Sultanate of Oman, many fragile costal ecosystems, particularly mangroves, are under increasing human pressure and need to be objectively environmentally assessed. This study fills this important and urgent need for baseline information.

These results provide also a contribution to the understanding of the role of inshore-offshore exchange with adjacent areas and their influence on phytoplankton productivity and community structure. Furthermore mangroves are an important source of organic matter continuously produced and transported to adjacent waters.

Over the study period, Sea Surface Temperatures (SST) fluctuated widely from around 21.7°C on January 22 and 33.8°C on June 27 2003 (Fig. 2). The annual cycle of temperature at the sampling site followed a clear cycle with peak temperatures being recorded during summer and minimum temperatures during winter. On 16th July 2003, the study site experienced a sharp down in SSTs of about 2°C.

Salinity showed little seasonal variation during the sampling periods with an average of 37.3 psu. The lowest salinity (36.6-36.8 psu) was recorded during winter (Jan-Feb) and late summer (Aug-Sep) (Fig. 2), whereas the highest salinity (37.8 psu) during early summer (May). Where, as temperature fluctuation in BK mangrove system were quite high, between months or seasons (Table 1). Moreover, long sunshine periods, intense global radiation and low rainfall are the characteristic features of the area, which can a effect phytoplankton distribution of area.

Nitrite concentrations were low throughout ranging between 0.1 and 0.3 μM over the sampling period (Fig. 3) with the exception of a spike of 0.6 μM on 7 February. Nitrate concentrations also were low varying around 1 μM. As was the case of nitrite-N, the maximum nitrate-N concentration of 2.68 μM was recorded on February 7 (Fig. 3). Phosphate concentrations varied around 1 μM from Jan-23 to July-17, reaching a maximum concentration of 1.5 μM on May 29. Between July-31 and November-16 phosphate concentrations remained below 0.5 μM from (Fig. 3).

Table 1: Climatology parameters of muscat area

Month (2001)	Day air temperature (°C)	Sunshine duration (h)	Global radiation (mW cm^{-2})	Rainfall (mm)
Jan.	23.70	9.09		<0.05
Feb.	25.30	9.87		<0.05
Mar.	25.24	9.66		<0.05
Apr.	34.50	11.32	800.57	<0.05
May	39.90	11.73	812.94	<0.05
Jun.	38.40	11.51	760.37	<0.05
Jul.	36.20	10.42	660.10	<0.05
Aug.	35.10	10.92	700.35	<0.05
Sep.	35.30	10.50	657.03	<0.05
Oct.	34.30	10.19	613.10	<0.05
Nov.	30.20	9.29	512.33	<0.05
Dec.	28.40	8.22	465.71	<0.05

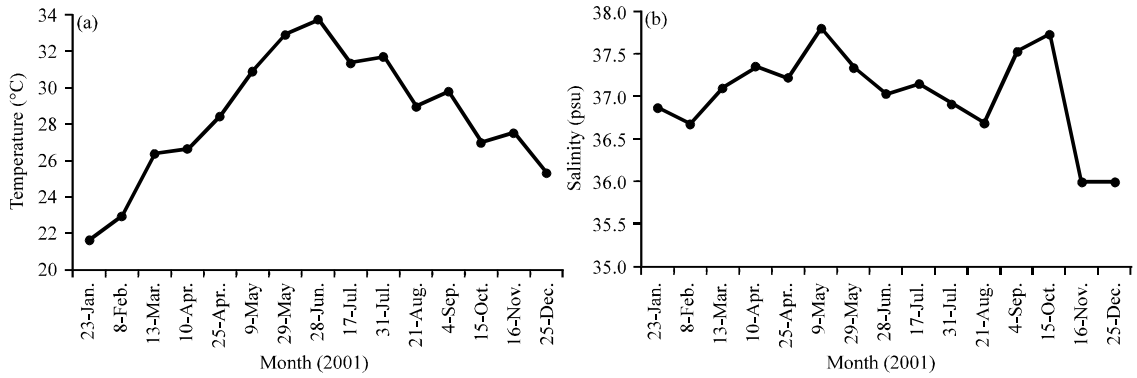

Fig. 2(a-b): Seasonal fluctuations of (a) Surface temperature and (b) Salinity

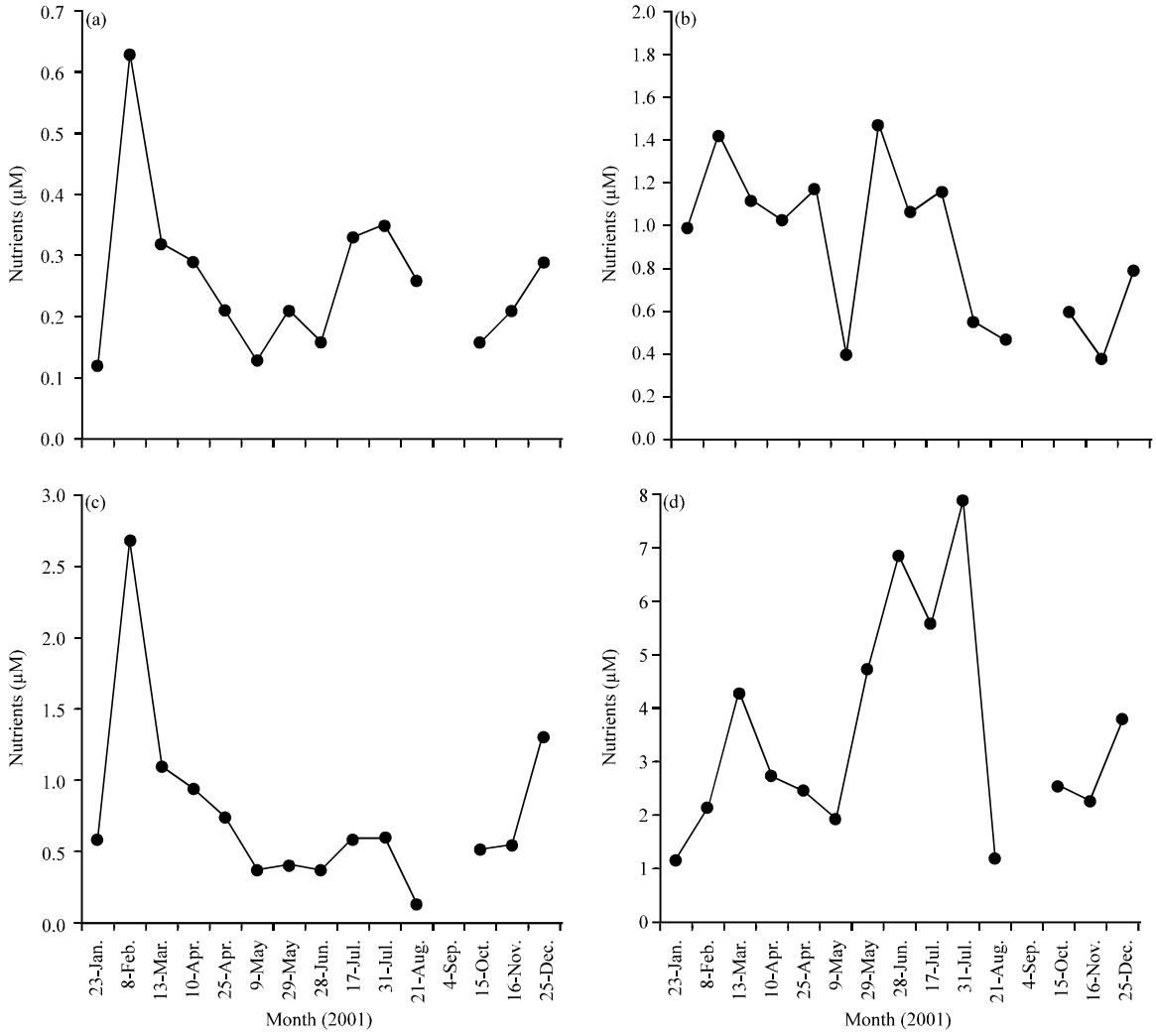

Fig. 3(a-d): Seasonal fluctuations in surface nutrients (a) Nitrite, (b) Phosphate, (c) Phosphate and (d) Silicate

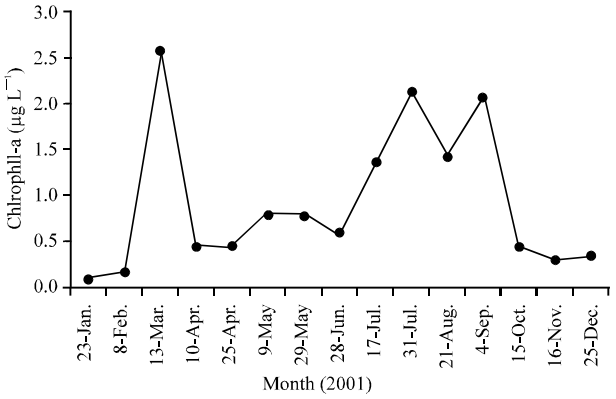

Fig. 4: Seasonal fluctuations in surface chlorophyll a concentrations

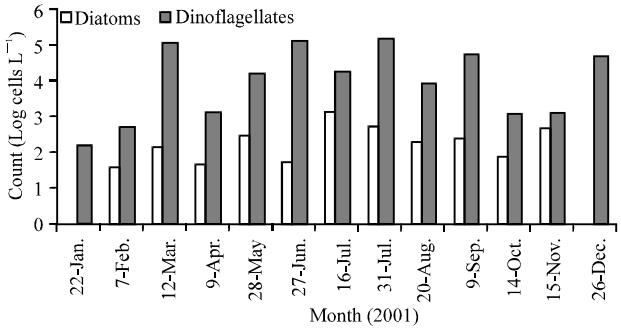

Fig. 5: Changes in diatom and dinoflagellate counts

Silicate concentrations were high (>2.5 µM) throughout the period of study (Fig. 3). Maximum silicate concentrations of 6.9, 5.6 and 7.9 µM were recorded on June 27, July 16 and July 31, respectively.

In general, higher Chl a concentrations (average 1.75 µg L^{-1}) were recorded from during the summer monsoon months from July to September. Chlaconcentrations at other times of the year were lower averaging around 0.4 µg L^{-1} with the exception of March 13 where the highest concentration of Chl a recorded was 2.57 µg L^{-1} (Fig. 4).

A total of 25 net phytoplankton taxa were identified during the study. Dinophyceae (dinoflagellates) and Bacillariophyceae (diatoms) contributed an equal number of species (12 each) and only one taxon of Cyanophyceae (cyano-bacteria).The diatom flora consisted of 11 species from the order Pennales and 1 species from the order Centrales. Among the Pennales, *Dipliones* sp. and *Nitzschia* sp., were found throughout the year. Diatoms were the minor constituents of the total net phytoplankton cell counts (Fig. 5).

Dinoflagellates contributed considerably to the overall phytoplankton cell counts and were the most abundant net phytoplankton group almost throughout the sampling period making up more than 95% of the total phytoplankton. Oscillatoria belonging to Cyanophyceae were also recorded during the sampling period but their contribution to the total net phytoplankton abundance was negligible.

Large fluctuations in population abundance were observed throughout the year, with a maximum 115,584 cells L^{-1}. Generally phytoplankton community within BK mangrove showed a low species diversity (Simpson index = 0.4 on average) and a poorly defined seasonal cycle and

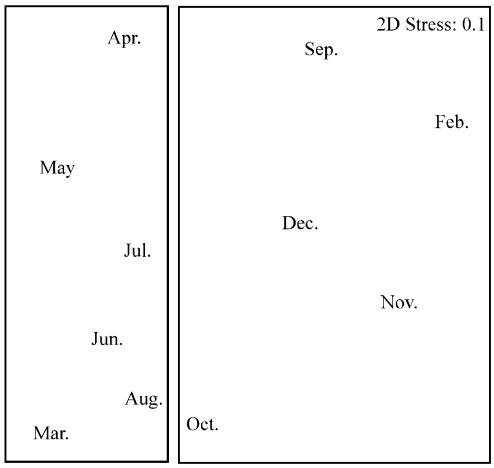

Fig. 6: MDS of phytoplankton seasonal structure

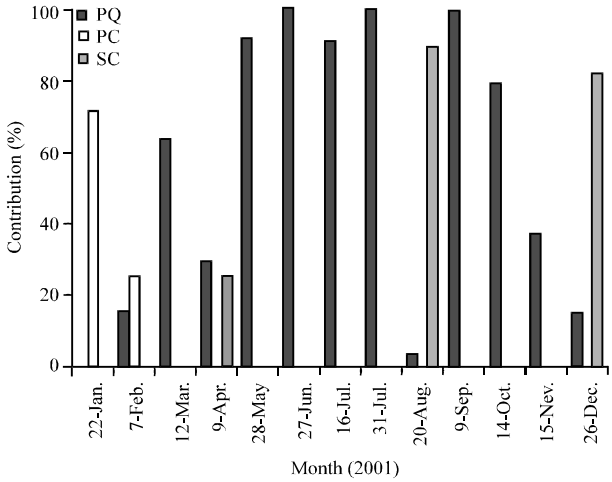

Fig. 7: Contribution of dominant dinoflagellates species to the overall phytoplankton abundance, PQ: *Peridinium quinquecorne*, PC: *Pororocentrum* sp., SC: *Scripsiella* sp., PP: *Protoperidinium* species

higher diversities during winter. Although, there was a visible trend in the relative position of the samples on MDS plot: winter samples appear on the right hand side of the plot (Fig. 6), there was no significant difference between summer and winter samples (Anosim R = 0.0045; p = 0.31). The BESTENV procedure carried out to identify possible linkages between community structure and environment variables, showed that phytoplankton community assemblages were best correlated to changes in temperature, nitrite and phosphate (BEST Rho = 0.371, p = 0.28) but the linkage was not significant.

The net plankton was dominated by a single species of dinoflagellate *Peridinium quinquecorne* (PQ) throughout the year comprising more the 90% of the species counts where it occurred in a bloom condition. In August and December *Scrippsiella* sp. (SC) was replaced by *P. quinquecorne* and comprised more than 80% of the total counts (Fig. 7).

Table 2: Chlorophyll a size class contribution

	Contribution (%)		
	Size fraction (μg)		
Months-2001	0.74-<5	5-20	>20
22-J	55.5	20.8	23.7
07-F	76.9	15.6	7.5
13-M	27.0	36.0	37.0
09-A	35.9	37.9	26.2
24-A	45.0	30.9	24.0
08-M	42.0	33.6	24.4
28-M	66.3	10.1	23.5
27-J	43.2	3.1	53.7
16-J	39.2	48.1	12.7
31-J	44.3	51.0	4.8
20-A	47.4	43.5	9.1
09-S	77.3	15.9	6.8
14-O	67.5	27.1	5.4
15-N	79.7	13.0	7.3
26-D	50.0	12.3	37.8

The size fraction (0.74-<5 μm) made up less than 50% of the total biomass during most of the sampling period but phytoplankton belonging to this size fraction dominated the community on May 28, September 9, October 14 and November 15, making up between 60-80% of the total biomass (Table 2). Phytoplankton belonging to the size fraction 5-20 μm accounted for ~35% of the total biomass between March 12 and May 8 (30.9-37.9%) and from 44-51% between July and August 20. The highest contributions of net phytoplankton (>20 μm) occurred on June 27, March 13 and December 13 when this fraction made 53, 37 and 37.8% of the total biomass, respectively.

DISCUSSION

The temperature fluctuation in the BK mangrove followed a distinct annual cycle of change with low temperatures being recorded in the winter and high sea surface temperatures observed in summer. This cycle is typical of the seasonal cycle in the Sea of Oman. Slight temperature decreases in July were likely due to the intrusion of colder newly upwelled water from the adjacent Bay. In general, the BK bay experiences sharp drops in temperature in July and in August accompanied by shallowing of the thermocline under the influence of wind-driven coastal upwelling along the north coast of Oman (Al-Hashmi *et al*., 2010). Such major changes in temperature have been recognized as the cause for major shifts in the dynamics of coastal ecosystems (Claereboudt *et al*., 2001).

Chlorophyll a concentrations (0.5-2.5 μg L^{-1}) recorded in BK mangrove system are higher than the published values for the adjacent BK bay (0.2-1.5 μg L^{-1}) (Al-Hashmi *et al*., 2010). The seasonal cycle within BK mangrove system however bore a strong resemblance to the adjacent bay, with two periods of increase, the first in March when Chlorophyll a peaked to 2.7 μg L^{-1} and the second during the period between July and September, when Chlorophyll a values were in excess of 1.5 μg L^{-1} .These increases in phytoplankton biomass were clearly preceded by nutrient increases

within the mangrove system, the first in February when the bay comes under the influence of convectional overturned waters due to winter cooling and the second during the summer upwelling season, from July to September.

The phytoplankton compositions vary greatly among different mangrove ecosystems, mainly controlled by nutrient flux, either generated or received from adjacent low land. Phytoplankton biomass within BK mangrove system was made up largely of phytoplankton forms belonging to <5 μm and the <20 μm size fractions. The contribution of net phytoplankton, >20 μm, to total biomass was minimal throughout the year with the exception of December, when it accounted for 53% of the total biomass. Our observations are similar to those of Teixeira and Gaeta (1991) who found that nanoplankton (2-20 μm) constituted over 80% of the total phytoplankton community within a tropical Brazilian mangrove system. These authors were able to demonstrate that these smaller phytoplankton were responsible for a significant part of the total productivity with picoplankton (cells <2 μm) accounting for 3-29% of the total ^{14}C uptake.

The net phytoplankton of Bandar mangrove system are of low diversity and dominated throughout the year by dinoflagellates which made up more than 95% of the total phytoplankton abundance. Previous studies have shown that dinoflagellates usually dominate in aquatic systems with high amounts of humic and fulvic acid (Prakash and Rashid, 1968). Degrading mangrove litter is known to be an excellent source of these compounds. Also floating detritus is known to support dinoflagelates by providing organic matters plus attachments and protection (Faust, 1990a, b) and therefore it comes as no surprise that dinoflagellates were the dominant phytoplankton group within BK mangrove. In contrast, the phytoplankton species composition in the mangrove systems in India, Pakistan and Iran are of high diversity and mostly dominated by large cells of diatoms (Kannan and Vasantha, 1992; Mani, 1994; Chaghtai and Saifullah 1992; Rajkumar *et al*., 2009; Zahed, 2002). The dominance of these diatoms was related to the high nutrients concentration mainly from freshwater and low land sources. Whereas BK mangrove system receives negligible amounts of fresh water from rain, long sun duration and high temperature (Table 1) and therefore has low nutrient concentrations. Also the nutrient availability from regenerative processes with BK mangrove system appeared to be minimal. This could be attributed to the nitrogen uptake by mangroves and their associated bacteria (Zuberer and Silver 1979; Mann, 2000). The nitrate-nitrite levels in this mangrove channel (Fig. 3) remained below the threshold (NO_2+NO_3>1 μM) usually required for the dominance of large cells (Agawin *et al*., 2000).

Net plankton tows showed that the phytoplankton population in BK mangroves was dominated by a single species of a heterotrophic dinoflagellate, *P. Quinquecorne* (Fig. 7), throughout the year accounting for more than 90% of the species counts during March and July-Sept. periods. *P. quinquecorne* has been reported before in mangrove systems (Faust *et al*., 2005). This species along with *Prorocentrum elegans* was recorded as the most intense bloom-forming species in Douglas Cay and their primary grazers were observed to heterotrophic ciliates and nematodes. In the present study, ciliates were found to be very abundant during January and February corresponding with the decline in the abundance of *P. quinquecorne*. *P. quinquecorne* was also found to be very abundant in the Urdaibai estuary, Spain, with the concentrations of this organism reaching their peak at high tide, almost disappearing during the latest stages of the tide (Trigueros and Orive, 2001).

The dominance of *P. quinquecorne* appears to be related to its unique ability to survive under conditions of extreme change in the environment such as that observed in BK mangrove system. Horstmann (1980) observed that *P.quinquecorne* was found close to the surface during the day,

tolerating intense sunlight and descend during the night attaching itself to the dark undersides of solid objects so as not to be washed out with the tide. *P. quinquecorne* is capable of moving at 1.5 mm sec^{-1}, combining the tidal rhythm with a photic response which enables them to maintain their dense population in the tidal area (Trigueros and Orive, 2001). *P. quinquecorne* cells are adapted to both benthic and planktonic shallow-tropical waters and present in tropical tide pools tolerating high temperatures (38-42°C) (Horiguchi and Pienaar, 1991). Also, *P. quinquecorne* can tolerate a varied range of salinities, growing best during warmer periods and at relatively high salinities when they were capable of forming red tide blooms under high light and high temperature (~38°C) (Horstmann, 1980). *P. quinquecorne* was also recorded from Tampa Bay, Florida where temperature was close to 30°C and at salinities above 20% (Gardiner and Dawes, 1987).

Temperature in the BK mangroves averaged at 26°C in winter and above 31°C in summer during high tide while temperature accede 35°C during low tide periods. This system receives long hours of sun duration up to 11 hours per day resulting in a very high air temperature exceeding 39°C during summer (Table 1). *P. quinquecorne* appeared to be the only phytoplankton species capable of tolerating these extremes in temperatures and outcompeting other phytoplankton. Although, *P. quinquecorne* is known to cause anoxia and fish kills during very high cell numbers (Fukuyo *et al*., 1990), no incidences of fish mortalities were observed over the course of our sampling.

CONCLUSION

BK mangrove ecosystems are located in a tropical, arid climatic environment. It receives a negligible amount of fresh water and is considered nutrient deficient. Phytoplankton biomass within BK mangrove was made up mostly of phytoplankton species that belong to the <5 μm and the <20 μm size fractions. The contribution of net phytoplankton >20 μm to total biomass was minimal. The net phytoplankton is of low diversity and dominated by the heterotrophic dinoflagellate, *P. quinquecorne*. This dominance was attributed to the ability of this species to thrive under a variety of physical and chemical conditions which allow it to survive and outcompete most other phytoplankton species including diatoms.

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REFERENCES

Agawin, N.S.R., C.M. Duarte and S. Agusti, 2000. Nutrient and temperature control of the contribution of picoplankton to phytoplankton biomass and production. Limnol. Oceanogr., 45: 591-600.

Al-Hashmi, K.A., M. Claereboudt, A. Al-Azri and S. Piontovski, 2010. Seasonal changes of chlorophyll a and environmental characteristics in the sea of Oman. Open Oceanogr. J., 4: 107-114.

Chaghtai, F.S. and S.M. Saifullah, 1992. First recorded bloom of navicula bory in a mangrove habitat of Karachi. Pak. J. Mar. Sci., 1: 139-140.

Claereboudt, M., G. Hermosa and E. McLean, 2001. Plausible cause of massive fish kill in the Gulf of Oman. Proceeding of the 1st International Conference on Fisheries, Aquaculture and Environments in the Northwest Indian Ocean, October 7-10, 2001, Muscat, Oman, pp: 123-132.

Faust, M.A. and R.A. Gulledge, 1996. Association of microalgae and meiofauna in floating detritus at a mangrove island, Twin Cays, Belize. Exp. Mar. Biol. Ecol., 197: 159-175.

Faust, M.A., 1990a. Cysts of *Prorocentrum marinum* (Dinophyceae) in Floating Detritus at Twin Cays, Belize Mangrove Habitats. In: Toxic Marine Phytoplankton, Graneli, E., B. Sundstrom, L. Edler and D.M. Anderson (Eds.). Elsevier, New York, USA., pp: 138-143.

Faust, M.A., 1990b. Morphologic details of six benthic species of *Prorocentrum* (Pyrrophyta) from a mangrove island, Twin Cays, Belize, including two new species. J. Phycol., 26: 548-558.

Faust, M.A., R.W. Litaker, M.V. Vandersea, S.R. Kibler and P.A. Tester, 2005. Dinoflagellate, diversity and abundance in two Belizean coral reef-mangrove lagoons: A test of Margalefs Mandala. Atoll Res. Bull., 534: 105-131.

Fouda, M., 1995. Status of mangroves resources in the Sultanate of Oman. J. Fac. Sci., 8: 169-183.

Fouda, M.M. and M. Al-Muharrami, 1996. Significance of mangroves in the arid environment of the Sultanate of Oman. Agric. Sci., 1: 41-49.

Fukuyo, Y., H. Takano, M. Chihara and K. Matsuoka, 1990. Red Tide Organisms in Japan: An Illustrated Taxonomic Guide. Uchida Rokakuho, Tokyo, Pages: 430.

Gardiner, W.E. and C.J. Dawes, 1987. Seasonal variation of nannoplankton flagellate densities in Tampa Bay, Florida. Bull. Mar. Sci., 40: 231-239.

Harrison, P.J., S.C. Snedaker, S.I. Ahmed and F. Azam, 1994. Primary producers of the arid climate mangrove ecosystem of the Indus River Delta, Pakistan: An overview. Trop. Ecol., 35: 155-184.

Horiguchi, T. and R.N. Pienaar, 1991. Ultrastructure of a marine dinoflagellate, *Peridinium quinquecorne* Abe (Peridiniales) from South Africa with particular reference to its chrysophyte endosymbiont. Bot. Mar., 34: 123-131.

Horstmann, U., 1980. Observations on the peculiar diurnal migration of a red tide Dinophyceae in tropical shallow waters. J. Phycolol., 16: 481-485.

Kannan, L. and K. Vasantha, 1992. Microphytoplankton of the Pichavaram mangals, southeast coast of India: Species composition and population density. Hydrobiologia, 247: 77-86.

Mani, P., 1994. Phytoplankton in Pichavaram mangroves, east coast of India. Indian J. Mar. Sci., 23: 22-26.

Mann, K.H., 2000. Ecology of Coastal Waters: With Implications for Management. Blackwell Science Inc., USA., pp: 51-59.

Odum, W.E., C.C. McIvor and T.J. Smith, 1982. The Ecology of Mangroves of South Florida: A Community Profile. US Fish and Wildlife Service, Office of Biological Services, Washington, DC., USA.

Prakash, A. and M.A. Rashid, 1968. Influence of humic substances on the growth of marine phytoplankton dinoflagellates. Limnol. Oceanogr., 13: 598-606.

Rajkumar, M., P. Perumal, V.A. Prabu, N.V. Perumal and K.T. Rajasekar, 2009. Phytoplankton diversity in pichavaram mangrove waters from south-east coast of India. J. Environ. Biol., 30: 489-498.

Round, F.E., R.M. Crawford and D.G. Mann, 1990. The Diatoms: Biology and Morphology of the Genera. 3rd Edn., Cambridge University Press, Cambridge, ISBN: 0521363187, Pages: 747.

Sheppard, C., A. Price and C. Roberts, 1992. Marine Ecology of the Arabian Region: Patterns and Processes in Extreme Tropical Environments. 2nd Edn., Academic Press, New York, USA., Pages: 359.

Simpson, E.H., 1949. Measurement of diversity. Nature, 163: 688-688.

Strickland, J.D.H. and T.R. Parsons, 1972. A Practical Handbook of Seawater Analysis. 2nd Edn., Fisheries Research Board of Canada, Canada, Pages: 310.

Teixeira, C. and S.A. Gaeta, 1991. Contribution of picoplankton to primary production in estuarine, coastal and equatorial waters of Brazil. Hydrobiologia, 209: 117-122.

Tomas C.R., 1997. Identifying Marine Phytoplankton. Academic Press, San Diego, California, USA.

Tomlinson, P.B., 1986. The Botany of Mangroves. Cambridge University Press, Cambridge, UK., Pages: 419.

Trigueros, J.M. and E. Orive, 2001. Seasonal variations of diatoms and dinoflagellates in a shallow, temperate estuary, with emphasis on neritic assemblages. Hydrobiologia, 444: 119-133.

Warwick R.M. and K.R. Clarke, 1991. A comparison of some methods for analysing changes in benthic community structure. J. Mar. Biol. Assoc. UK., 71: 225-244.

Woodroffe, C.D., 1992. Mangrove Sediments and Geomorphology. In: Tropical Mangrove Ecosystem, Robertson, A.I. and D.M. Alongi (Eds.). American Geophysical Union, Washington DC., USA., pp: 7-41.

Zahed, M.A., 2002. Effect of pollution on Persian gulf mangroves. Ministry of Agriculture Final Report. Tehran, Iran.

Zuberer, D.A. and W.S. Silver, 1979. N2-fixation (acetylene reduction) and the microbial colonization of mangrove roots. New Phytol., 82: 467-471.