

Seasonal variability of size-classes of phytoplankton biomass in a sub-tropical embayment, Muscat, Sea of Oman

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Abstract

The contribution of three different cell size classes of picoplankton: 0.74-2 μm , nanoplankton: 2-20 μm and microplankton, >20 μm of the phytoplankton population and their relationship to environmental conditions were studied over two annual cycles at one station in Bandar Khyran Bay, Sea of Oman, from May 2006 to August 2008. Nanoplankton was the most important class contributing 54.4% to total Chl *a* (range 6-82%). Its seasonal highest concentrations was during the cold periods when temperature ranged from 28-29 °C in fall and near 24 C in winter when the supply of nutrients was sufficient to sustain their growth. Picoplankton had the second level of the contribution, comprising (23.5%, range 4-74 %) of the total Chl *a*. and their concentration was generally constant (0.04-0.06 $\mu\text{g l}^{-1}$) throughout the study period. The drop of picoplankton population coincided with an increase in the microplankton and nanoplankton populations indicating a high grazing pressure exerted on the picoplankton population. Microplankton size-class occupied the third level of the contribution comprising (22.2%, range 3-65 %). Their general concentration was below 0.1 $\mu\text{g l}^{-1}$ and only dominant when temperatures were lowest and nitrate, nitrite, silicate and phosphate concentrations were the highest. The temporal variability observed was associated with changes in the nanoplankton indicating that in some cases, it is the small fraction of phytoplankton that drives changes in abundances and productivity.

Keywords: Phytoplankton, Chlorophyll *a*, Size-class, Picoplankton, Nanoplankton, Upwelling, Sea of Oman

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Introduction

Phytoplankton include a wide range of photosynthetic organisms that are often classified into various size ranges. The larger phytoplankton ($>20\mu\text{m}$) (Kormas *et al.*, 2002) are those normally captured in nets. The smaller phytoplankton groups are those in the nanoplankton ($2.0\text{-}20\mu\text{m}$) and the picoplankton ($0.2\text{-}2\mu\text{m}$) size ranges that pass through nets. Net phytoplankton consists predominately of two groups, diatoms and dinoflagellates, and the nanoplankton are dominated by members of Chrysophyceae, Prymnesiophyceae, Cryptophyceae and Dinophysis. The picophytoplankton comprise of ($<2\mu\text{m}$) chroococcoid cyanobacteria and of eukaryotic phytoplankton of the same size range (Van den Hoek *et al.*, 1995; Lalli and Parsons, 1997).

Recent evidences indicate that the smallest groups now dominate the phytoplankton assemblages and appear to be of the primary importance in terms of contributing to the overall productivity in estuarine and marine environments (Brown *et al.*, 1999; Caron *et al.*, 1999; Dennett *et al.*, 1999; Tarran *et al.*, 1999; Brown *et al.*, 2002). These organisms are the dominant constituents of phytoplankton communities in terms of both biomass and abundance in oligotrophic oceans (Campbell and Vaultot, 1993). They especially dominate the inter monsoon periods in the Arabian Sea where they may account for more than 50% of the chlorophyll *a* biomass making them responsible for about 50-60% of the total

primary productions in these waters (Burkill *et al.*, 1993; Brown *et al.*, 1999; Dennett *et al.*, 1999; Tarran *et al.*, 1999, Garrison *et al.*, 2000).

In comparison to conventional research that evaluates phytoplankton community at the species level, Chlorophyll *a* size fractionation has proven to be an effective method to study phytoplankton population dynamics (Takahashi and Hori, 1984). Cell size influences the response of the phytoplankton community to environmental variation and hence the primary production (Glibert *et al.*, 1992; Hein *et al.*, 1995). The size of primary producers is used as a tool to understand the ecological characteristics of marine environments and the processes of succession in the phytoplankton assemblages. Different size classes contribute unequally to bloom dynamics (Smayda, 1973; Hallegraff, 1981; Furnas, 1983).

Size-distribution of phytoplankton assemblages is a major factor that controls functioning of the pelagic food web (Legendre and Le Fevre, 1991). As the larger size cells influence sinking and transport rates from the surface to the depth (Malone, 1980; Michaels and Silver, 1988), the smaller cells utilize up to 50 % of the primary productivity (Brown *et al.*, 2002) and therefore, transfer energy and recycle nutrients to the classical food web through the microbial loop (Fenchel, 1982a,b; Azam *et al.*, 1983; Caron *et al.*, 1991).

The present study focuses on temporal variability in size-fractionation of a natural phytoplankton population in Bandar Khyran Bay, Sea of Oman, to estimate the relative contribution of the different size classes to the overall phytoplankton community and their relationship to environmental conditions.

Materials and methods

The study was carried out in Bandar Khyran Bay which is a shallow, semi-enclosed basin located east of Oman's capital city, Muscat (Fig.1). It has an area of about 4 km² and an average depth of 10 m. Surface water samples were collected at a fixed station twice a month from May 2006 to August 2008.

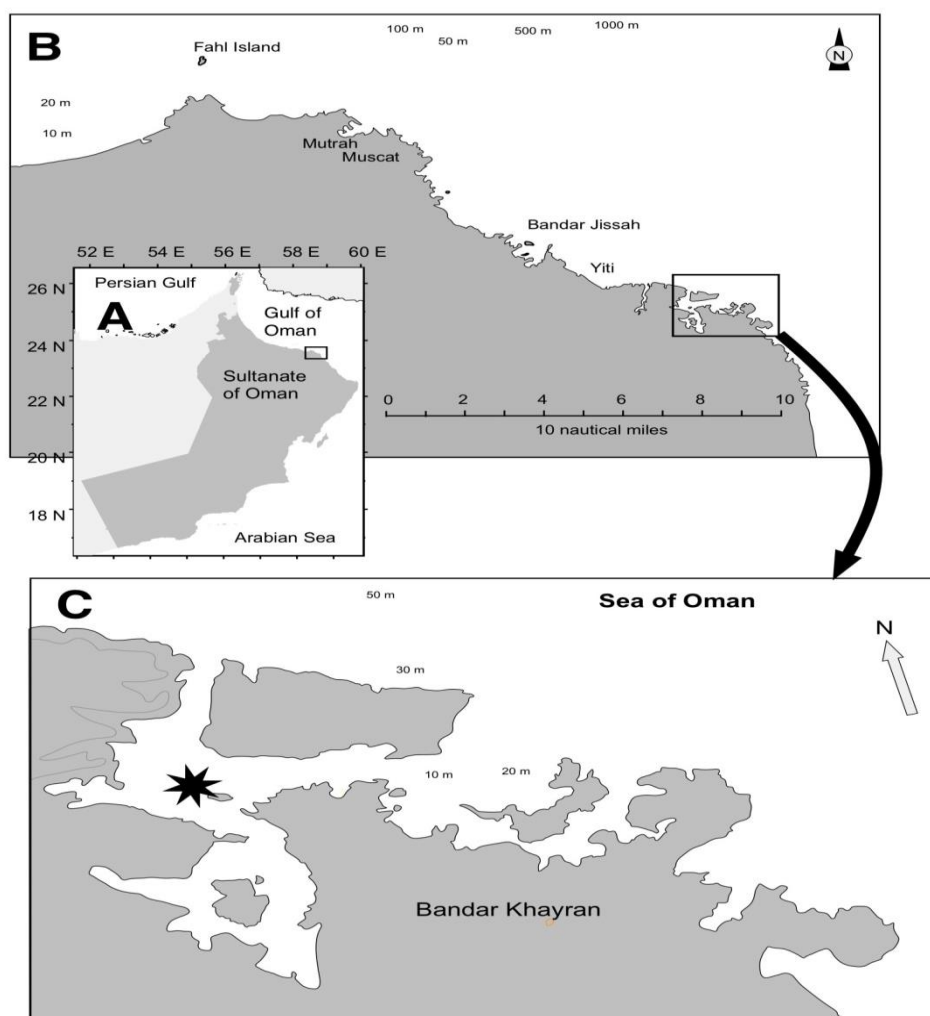


Figure 1: Map of Oman(A), coast of Muscat(B) and sampling site(C).

Sub-surface water samples representative of the mixed layer were collected at 1 m with Niskin bottle. Samples for the analyses of nitrate, nitrite, phosphorus and silica were also

used for cell size distributions. For nutrient analysis, water was filtered through a Whatman GF/F filter and immediately made frozen. Nutrients were determined with a 5-channels

SKALAR Flow Access auto-analyzer according to the procedures described in Strickland and Parsons (1972) and modified by the manufacturer of the analyzer (Skalar analytical, 1996). For cell size distributions (0.74-2, 2-20 and >20 μm) three sets of filters were used: Whatman GF/F glass fiber filter with 0.7 μm pore size, GF/C with 2 μm pore size and 20 μm aperture nylon mesh. Cells retained by the 0.74 μm belongs to the picoplankton, and those retained by 2 μm and 20 μm pore size filters belong to the nanoplankton and microplankton, respectively (Sieburth *et al.*, 1978). Filters were kept frozen in the dark until analysis. Filters were then placed into a 90% acetone solution and left overnight at 4°C in the dark for pigment extraction. Chl *a* concentration was determined using a Turner Designs 10-AU fluorometer. Fluorescence values were corrected for phaeophytin using acidification (Parsons *et al.*, 1984). Water temperatures were obtained from a conductivity-temperature-depth instrument using an Idronaut-Ocean Seven 316 C.T.D. (IDRONAUT Srl, 2003). The Bray–Curtis similarity

matrix was used to obtain multi-dimensional scaling (MDS) ordinations. The similarity/permutation test ANOSIM (Warwick and Clarke, 1991) was used to compare the statistical difference between seasons based on the Euclidian distance measure On Primer 5. The Principal Component Analysis (PCA) is used to elucidate the statistical relationships between 10 parameters (biological, chemical and physical) measured as well as to understand their clustering patterns.

Results

The distribution of temperature in Bandar Khyran Bay shows a semi-annual mode of variability with a clear maximum during summer months June–July when sea surface temperatures exceeds 31.5°C and a minimum during winter months December–march when temperature drops to 23°C (Fig. 2) However there is a clear drop of temperature below 29°C during August–September with little variability between the years. Summer of the year 2006 was cooler than those of 2007 and 2008.

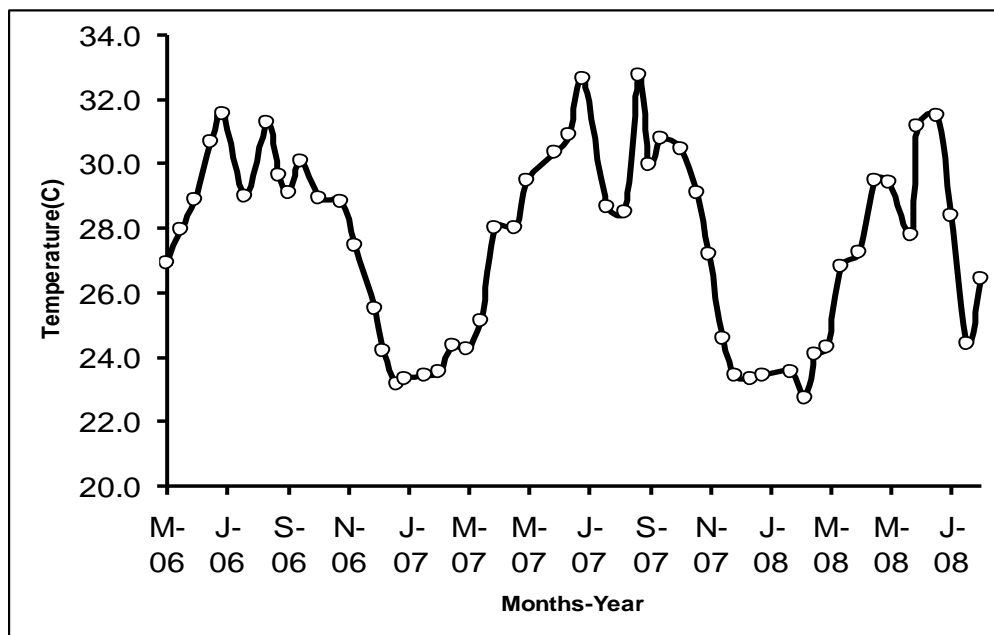


Figure 2: Annual distribution of temperature (°C) in Bandar Khyran Bay.

Concentrations of $\text{NO}_3 + \text{NO}_2$ showed high variability among sampling periods (0.1 -7.9 μM). Concentration maximum ranged from 5- 7.9 μM during December 2006- February 2007 (Fig. 3). Silicate maximum values were 2.3-3.5 μM between October 2006 and February 2007. Similarly, the highest phosphate concentration (0.5-1 μM) was recorded between October 2006 and February

2007. Unusually high ammonia concentration (3.2 μM) was measured in the summer 2006 (June). Ammonia concentrations fluctuated greatly and were highest during September 2006- December 2006, while concentrations during 2007 remained below 1 μM except on March 2007 when concentration was 2.26 μM (Fig. 3).

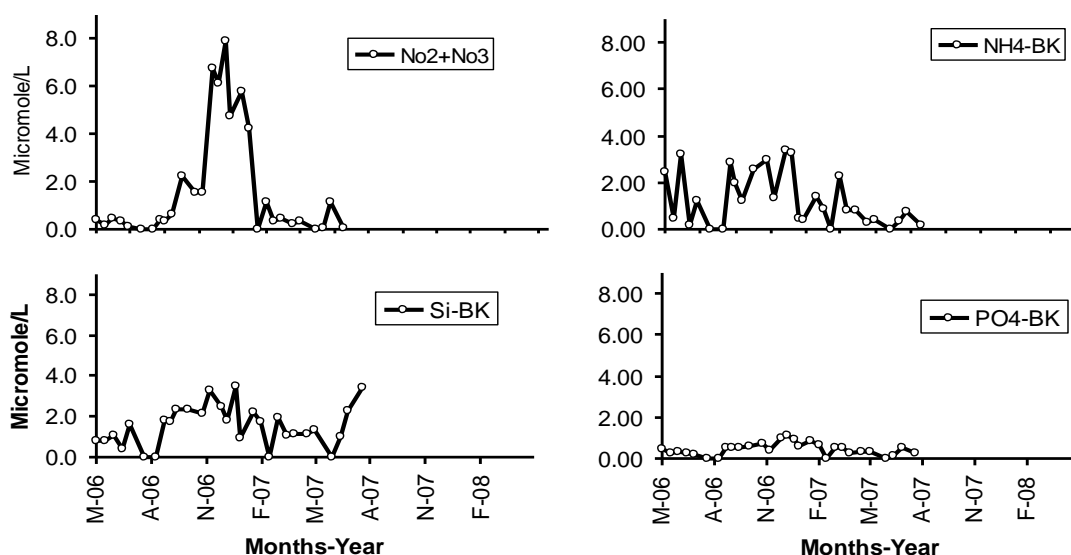


Figure 3: Distribution of major nutrients (µmol/L) in Bandar Khyran Bay.

Nanoplankton (2-20 μm) was the most important class contributing 54.4% to total Chl *a* (range 6-82%) (Figs.4,5). Its seasonal distribution exhibited high concentrations, $>0.2 \mu\text{g l}^{-1}$ and above the median during the cold periods when temperature ranged from 28-29 $^{\circ}\text{C}$ in fall

and near 24 $^{\circ}\text{C}$ in winter (Fig. 6). A sharp drop in contribution for this size-class was recorded from June 2007 to May 2008, except for a single sample in December 2007, when its contribution to total Chl *a* was about 75%.

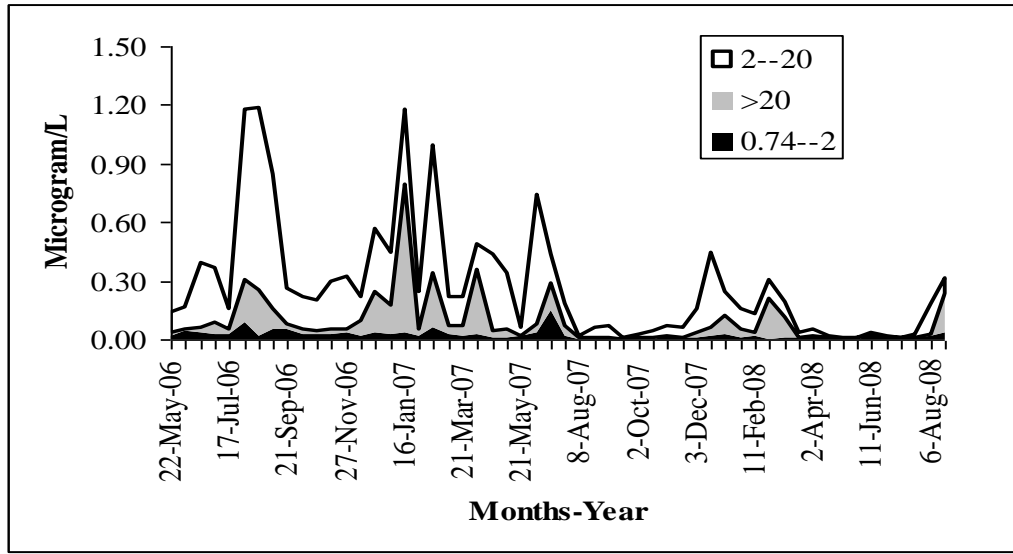


Figure 4: Chlorophyll *a* size class ($\mu\text{g/L}$) distributions in Bandar Khyran Bay.

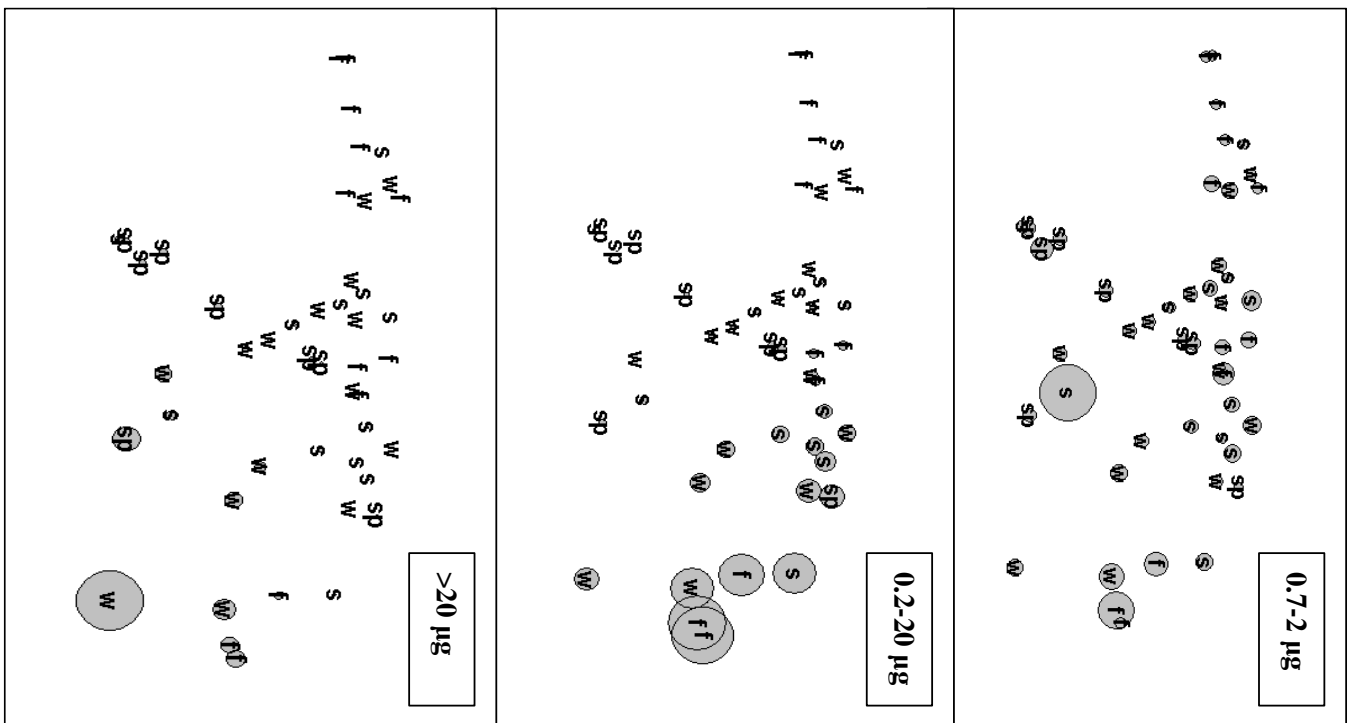


Figure 5: Two-dimensional and multi-dimensional scaling plots of the different size-class during 3/4 seasons. The biomass of the various size classes was superimposed as a bubble plot where the diameter of the disk correspond to the abundance of the different size classes. f= fall, w =winter, s=summer.

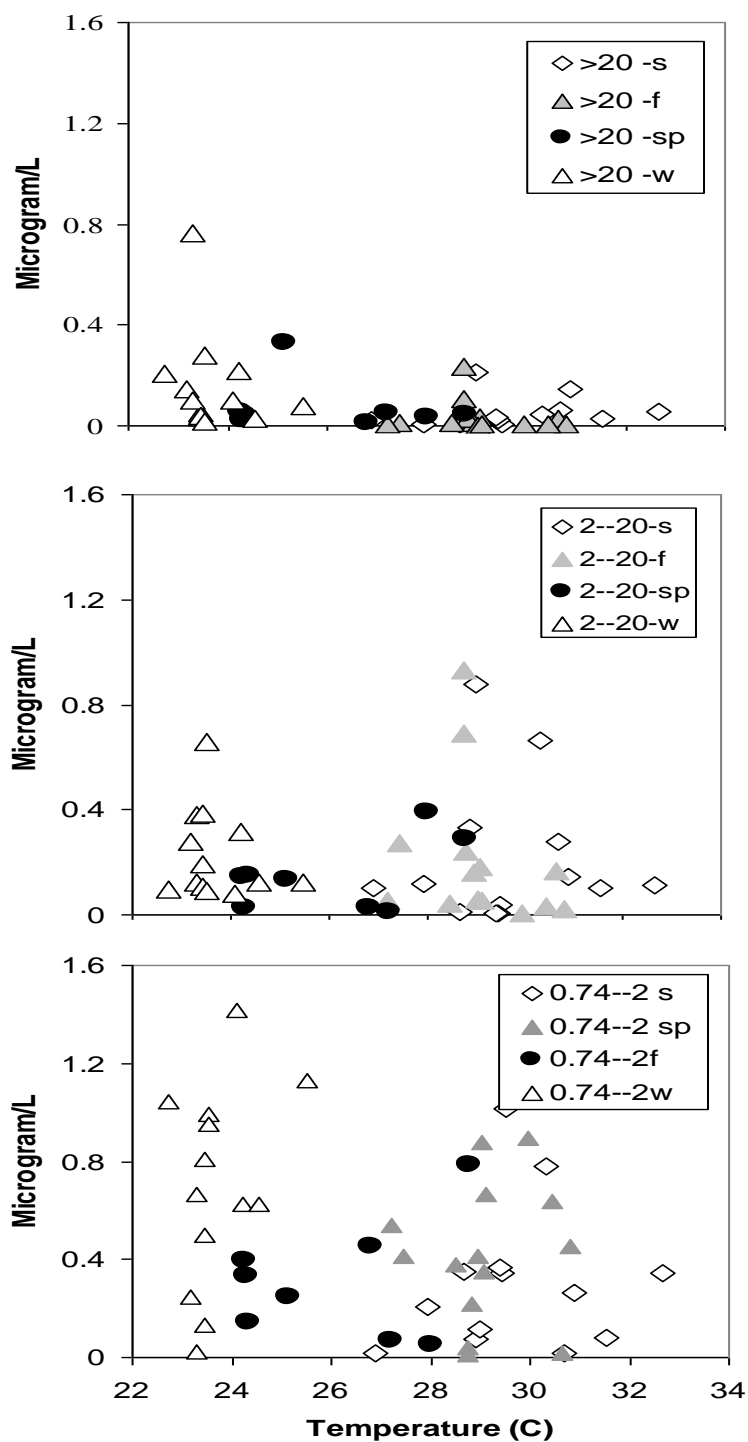


Figure 6: Size-class biomass (Chl *a*) according to water temperature and season in Bandar Khyran; s=summer; sp=spring; f=fall; w=winter.

Picoplankton of the size-class (0.7-2 μ m) showed the second level of the contribution, comprising 23.5%, and a range of 4-74 % of the total Chl *a*. (Figs. 4,5). Picoplankton concentration was

generally constant (0.04-0.06 μ g l⁻¹) throughout the study period. Their highest densities, 0.08-0.1 μ g l⁻¹, was exhibited when temperature was below 29°C, and a drop of concentration was

seen during warmer temperatures (Fig.6).

The microplankton (>20 μm) size-class occupied the third level of the contribution comprising 22.2%, and a range of 3-65 % (Figs. 4,5). Their general concentration was below $0.1 \mu\text{g l}^{-1}$ (median) and only exceeded this value when water was cooler during winter and fall (Fig. 5). The highest contribution of this class (Chl *a* of $0.76 \mu\text{g l}^{-1}$, 65%) was recorded on 16 January 2007. The contribution of microplankton to total Chl *a* was much higher during May 2006-April 2007 than the rest of the study period when sharp and sudden decline was recorded.

The MDS plot and a 1-way anova showed significant seasonal changes in overall size-class distribution between summer and winter (Stress=0.03; Anosim R= 0.124; $p=0.01$) (Fig.7). A PCA analysis conducted for all samples revealed that PC1 and PC2 were responsible for 34.4% and 19.2 % of the total variability respectively (Fig.8). PC1 was well correlated to major nutrients (PO_4 , NO_2+NO_3 and NH_4) and inversely related to temperature. PC2 was well correlated to picoplankton and silicate. Both nanoplankton and macroplankton were somewhat linked to salinity and responded to changes in the major nutrients (Fig. 8).

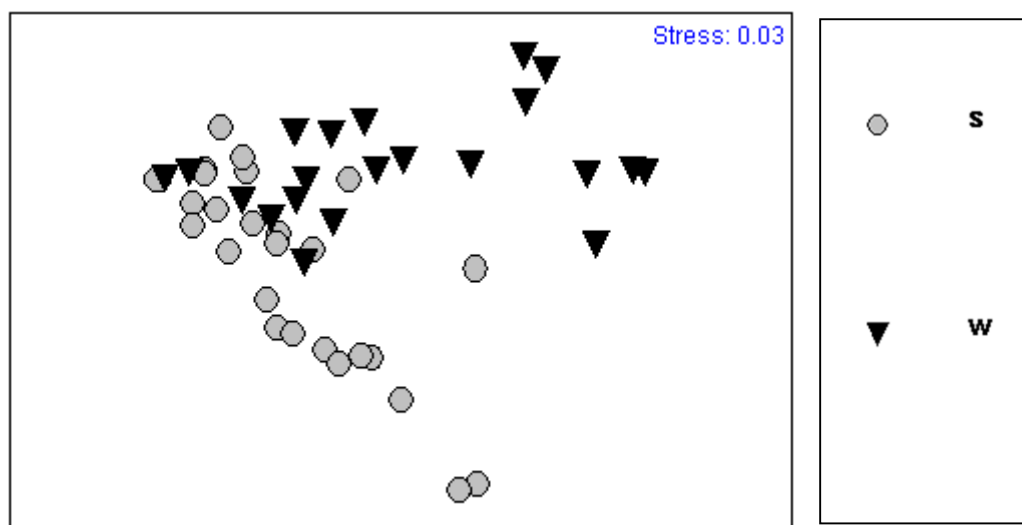


Figure 7: MDS seasonal structure in samples collected in Bandar Khyran bay station W=winter S=summer.

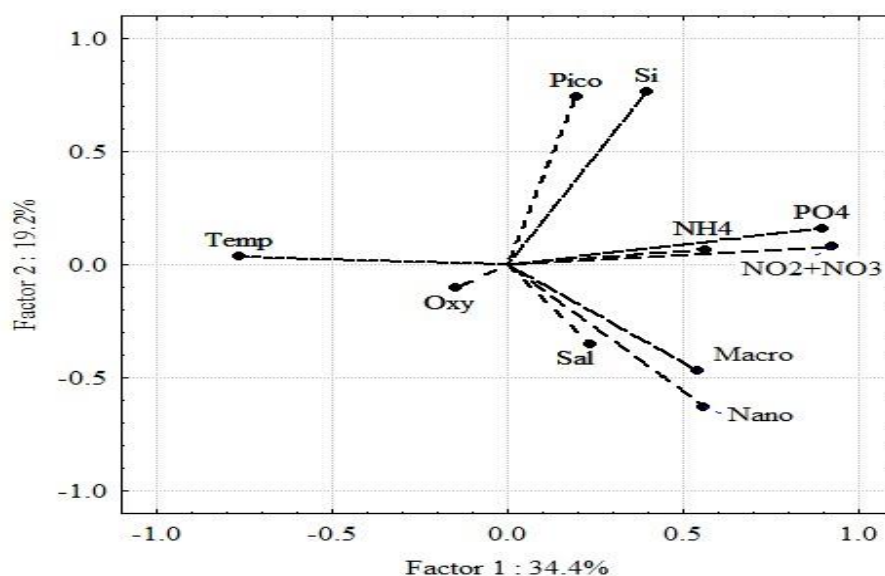


Figure 8: Principal component analysis (PCA) showing original variables and principal components (Pico=icoplankton, Macro=macroplankton, Nano= nanoplankton, Sal= salinity, Temp=temperature).

Discussion

During this study, nanoplankton dominated most of the sampling periods and contributed significantly to the total production especially from May 2006–May 2007 when there was sufficient supply of nutrients, particularly ammonium. Nanoplankton were reported to enhance their production during ammonium abundance as they have the highest uptake rates of ammonium in the phytoplankton (Glibert *et al.*, 1992; Ferrier and Rassoulzadegan, 1991). This high supply of ammonia probably was released from the unusually early decomposition of *Noctiluca scintillans* bloom during an abnormally late summer in 2006. *N. scintillans* blooms are a feature of the fall-winter season in the Sea of Oman (Al-Hashmi *et al.*, 2012). Also regenerated nutrients are considered a primary growth stimulating factor for pico and nanoplankton (Probyne, 1985; Sin *et al.*, 2000).

Nutrient loadings may cause changes in the nutrient ratios, thus affecting the species composition of the phytoplankton community and the higher trophic levels (Turner *et al.*, 1998; Philippart *et al.*, 2000). Nanoplankton are important contributor to phytoplankton assemblages in both temperate and tropical environments and are responsible of a significant fraction of primary production (Hallegraff, 1981; Gin *et al.*, 2000) and they are more abundant in coastal waters than in the oligotrophic waters (Gobler *et al.*, 2005; Pan *et al.*, 2007).

Even though there was a high supply of ammonium from May–October 2006, microplankton were only dominant when temperatures were lowest, between December 2006–January 2007 (Fig. 6), and when nitrate, nitrite, silicate and phosphate concentrations were highest. Phytoplankton growth was reported to

increase with incubation temperature until optimum growth is obtained, and then growth rate decreased considerably with increasing temperatures (Eppley, 1972). This resulted in clear separation between summer and winter population (Fig. 7). Temperatures below 29.5°C might be optimum for phytoplankton growth, as long as essential nutrients are supplied (Fig. 6). Nutrients were likely temporarily injected across the thermocline during the north-west monsoon's coastal upwelling events. It is well documented that among other chemical and physical factors, a higher nutrient supply tends to stimulate the growth of large phytoplankton (Malone, 1980; Malone *et al.*, 1993) (Fig. 8). The data indicates that diatoms were dominant during fall-winter of 2006 when high nutrients concentrations were found (Fig. 3).

Picoplankton was a less important contributor to the total phytoplankton biomass being almost constant throughout the sampling period. A previous study, in Bandar Khyran Bay (Al-Hashmi *et al.*, 2010) found that on average 67 % of the total production was contributed by the 0.74-5 µm size-class fraction. This suggests that probably the 2-5 µm size-class is the dominant size of the nanoplankton. Members of nanoplankton groups are capable of acquiring energy by phagotrophy and photosynthesis, i.e. combining both autotrophic and heterotrophic modes of feeding (Sanders and Porter, 1986). They ingest photosynthetic microorganisms in the picoplankton size-class exerting extensive predation

pressure on picoplankton of natural communities in different ecosystems (Caron *et al.*, 1991; Sanders *et al.* 1992; Reckermann and Veldhuis, 1997; Caron *et al.*, 1999). Therefore, a high grazing pressure exerted by nanoplankton could be the major reason for the observed drop of picoplankton abundance. The drop of picoplankton contribution coincided with an increase in the microplankton and nanoplankton populations from May-September 2006. During this period we observed the highest nutrient concentrations favoring the growth of larger cells (Malone, 1980). Moreover, Bandar Khyran system receives long hours of sun duration and picoplankton do not have sufficient photoprotective substances to avoid this radiation that could reduce photosynthesis and damage the cells (Teira *et al.*, 2005; Finkel *et al.*, 2010).

It is commonly accepted that variability in total biomass and productivity is associated with changes in the large-sized fractions, and the picoplankton remain fairly constant (Raimbault *et al.*, 1988; Chisholm, 1995; Rodríguez *et al.*, 1998). However, the temporal variability observed in this study was associated with changes in the nanoplankton (Fig.7), indicating that in some cases, it is the small fraction of phytoplankton that drives changes in abundances and productivity (Brown *et al.*, 1999). This was clearly seen when a major decrease in Chl *a* concentrations occurred after July 2007 when a decrease in nanoplankton cells was observed.

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