TEMPORAL VARIATION IN THE COMMUNITY STRUCTURE OF PHYTOPLANKTON: INFLUENCE OF DISSOLVED NUTRIENTS

INTRODUCTION

The ocean is a dynamic ecosystem and hence, the inhabitant organisms, including the tiny plankters, remain in a state of continuous change. Based on the accepted notion that plankton are unable to swim against water currents (Omori and Ikeda, 1984) and are thus transported passively by the flow field during different intervals of time. This behavior in plankton ecology with respect to time is known as temporal variations. Temporal variability is an essential function of significance in the aquatic ecosystem metabolism. The temporal variation in plankton community depends on the disparities in the abiotic and biotic features of the water bodies (Ottman *et al.,* 1965, 1966; Eskinazi *et al.*, 1997; Webber, 1998; Koening *et al.,* 2003; Linton and Warnce, 2003) or on the local environmental conditions (Linden *et al.,* 1992; Shushkina and Vinogradov, 1992; Fernandez *et al.,* 1993 and Kokurkuna and Mikaelyam, 1994). The abiotic factors e.g. physical process such as tidal advection, wind induced mixing, eddies water mixing, under water light, toxic compounds and other physicochemical features including nutrients play a significant role in temporal distribution of plankton in oceanic waters (Fernandez *et al.,* 1993; Fraber-Lorda *et al.,* 1994; Flagg *et al.,* 1994).

Temporal variation however, fluctuates with the variant environmental conditions, thus exhibiting some common patterns of distribution of species that have been studied widely. Nonetheless, there are several patterns of temporal distribution among the species within the community that remains still unknown. Therefore, it is becoming clear that all types of variations (time space, space x time) need to be more explicitly provoked if ecological models are to be made truly useful tools for understanding and managing natural ecosystem (Risser *et al.*, 1984). However, marine environment is repeatedly subjected to high temporal variability with frequent reorganization of relative abundance and plankton species composition, as a result of interaction between physical, chemical and biological variables. Any permutation in the interactions of these variables induces stress to the plankton community leading to an abrupt loss of biodiversity of the marine environment. These environmental variables fluctuate with time, as with all planktonic organisms inhabiting different niche in marine ecosystem leading to decline in the population count (Obrebski *et al.,* 1992; Kimmer and Orsi, 1996; Orsi and Ohtsuks, 1999; Kimmerer, 2002). In view of the fact that, many environmental factors affect the plankton assemblages and its community structure thereby bringing temporal variations. Therefore, these variations are either categorizes into short-term or long-term basis with respect to the physical and biological mechanisms in the ecosystem. Further, these distinctions are considered as an essential prerequisite for assessing alterations caused by perturbations in the biome (Underwood, 1992).

Amongst the various environmental variables in marine environment, dissolved nutrients ($NO_3^- - N, NO_2^- - N$, $PO_4^{3-} - P$ and $SiO_4 - Si$) are considered to contribute to a significant extent in brining spatio-temporal variations in the plankton community. The nutrients, which includes, inorganic nitrogen, phosphorus and silicate determines the production of phytoplankton serving as food for higher trophic levels. These shifts in inorganic nutrients ration further effect the species composition of plankton in marine ecosystem (Brett *et al.,* 1999). Nutrient levels, in addition to their role in dictating competition, can be a major factor in defining the community structure. The increase in the nutrient concentrations classically increases the phytoplankton assemblages that in turn promote the zooplankton population in a community. Therefore, the nutrients play a vital role owing to their variation in their concentration from several inputs and biogeochemical processes in the marine ecology. The nutrients also exhibit seasonal variation, which attributes to the intake of nutrients by different biota and the replenishment of nutrients under different seasons.

There exists a close association between phytoplankton cell numbers and sudden decline or raise in the various nutrients. This could be accounted for by the rapid release of the nutrient on the death of the phytoplankton organisms or by their ingestion and excretion by organisms at higher tropic level as suggested by Steele (1958) and Martin (1965, 1968). The changes in the nutrient level can occur very frequently or in a matter of days brining temporal variation among the community. Therefore, changes in the nutrient concentration with the seasons should correlate significantly with temporal variations within the communities. These changes bring microscale and macrospatial distribution of organisms, which are very frequent, drastic and recent, all influencing the diversity of the marine ecology. However, besides all these changes in the environment, the organisms those are capable of withstanding these effects will be able to survive and few of them may cross the frontiers to be a part of new biota. Consequently, it is believed that nutrient limitation is responsible for the dominance of a limited number of plankton species in a marine ecosystem. Above and beyond there is a lack of temporal perspective, which is of concern because the mechanisms that generate spatial patterns may be different from those, leading to temporal change. Nutrient levels, in addition to their role in dictating competition among the species, are a major factor in defining the community structure.

The spatial and temporal variation in plankton community structure has been studied for several coastal and oceanic water bodies world over (Eskinazi *et al.*, 1997; Webber, 1998; Koening *et al.,* 2003; Linton and Warnce, 2003). However, even though Gujarat has got the longest coastal area this aspect of plankton biology has been largely neglected. **Hence, it was thought worth studying the temporal distributions in plankton community, in accordance with the variations in dissolved nutrients in the marine waters at Diu, Veraval and Alang in the Suarashtra region of Gujarat, India.**

METHODS

DISSOLVED NUTRIENTS ANALYSES

The dissolved nutrients analyses were carried out as per the treatise, 'Standard Methods for the examination of water and wastewater', prepared and published jointly by the American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF). (Refer Chapter 2 for details).

STATISTICAL ANALYSIS

Statistical procedure employed a variety of multivariate technique. All statistical analyses were carried out using Origin 7 and Primer Ver.5.2.4 (Clark and Warwick, 1994)

RESULTS

SEASONAL CONCENTRATION OF DISSOLVED NUTRIENTS:

DIU: The mean values of dissolved nutrient concentration (Table 3.1) revealed that there occurred seasonal fluctuations in all the nutrients in the coastal waters of Diu. The total oxidized nitrogen seems to be influenced by the seasons, as significant variations in values was observed during the three successive seasons *viz.* pre monsoon, monsoon and post monsoon. The maximum concentration of nitrate (1.49mg/L) was recorded after the onset of rain. The nitrite also showed a similar trend with a maximum average value of 0.39mg/L during monsoon. Summer exhibited low average values of 0.12 and 0.02mg/L of total oxidized nitrogen respectively. Elevated phosphate phosphorous concentration of 1.2mg/L was observed in post monsoon. However, the other two seasons, winter and monsoon recorded lower concentration of phosphate phosphorous, while the least value of 0.6mg /L was noted during summer season. The silicates fluctuated between a minimum concentration of 4μg/L in winter and to a maximum value of 6.93μg/L in post monsoon (Table 3.1 and Figure 3.1).

VERAVAL: Total oxidized nitrogen (nitrate and nitrite values) shows a temporal variation in its concentration at the sampling station in Veraval. The nitrate to nitrite proportion showed a hike in concentration in monsoon season. While the lowest concentration of the nitrate and nitrite was observed during winter. However, the overall concentration of nitrate was more than nitrite at Veraval. The phosphate-phosphorous showed the highest average of 1.08mg/L in monsoon and the lowest of 0.5mg/L was recorded in summer. Silicates also showed seasonal variations with minimum concentration of 5.78μg/L in winter whereas maximum concentration of 8.79μg/L was observed in monsoon season (Table 3.1 and Figure 3. 2).

ALANG: The nutrient concentration showed seasonal fluctuations at Alang. The total oxidized nitrogen showed a varying degree of fluctuation. The nitrate concentration showed the highest average value of 0.232mg/L in winter, while the lowest average of 0.05 mg/L occurred in the post monsoon. An apparent hike in the nitrite concentration was also evident during winter. In rest of the season i.e. summer and monsoon, the mean nitrite value remained more or less even. The phosphate phosphorous reached its maximum values during monsoon (0.99mg/L) while the lowest average was recorded in pre monsoon. Winter and post monsoon exhibited values of 0.55 and 0.8 mg/L respectively. The silicate showed its minimum concentration during summer while the maximum value was recorded after the rains (Table 3.1 and Figure 3.3).

DIVERSITY OF PHYTOPLANKTON

The floristic component of aquatic biota is dominated Cyanophyta, Crysophyta, and Phyrophyta. A checklist of the aquatic microflora observed during the current study is presented as follows:

DIVISION: CYANOPHYTA (Blue – Green Algae)

CLASS: CYANOPHYCEAE

ORDER: NOSTOCALES

FAMILY: OSCILLATORIACEAE

1. *Trichodesmium sp*

FAMILY: PLEUROSIGMATACEAE

2. *Pleurosigma sp*

FAMILY: OSCILLATORIALEAE

3. *Grammotophora Sp*

DIVISION: CHRYSOPHYTA

CLASS: BACILLARIOPHYCEAE

ORDER: BACILLARIALES

FAMILY: CLIMACOSPHENACEAE

4. *Climacosphenia elongate*

FAMILY: COSCINODISCOIDEAE

5. *Coscinodiscus sp*
6. *Coscinodiscus janesianus*
7. *Coscinodiscus gigas*
8. *Melosira sp*

FAMILY: NAVICULACEAE

9. *Navicula sp*
10. *Navicula sp1*

FAMILY: CYMBELLACEAE

11. *Amphora lanceolata*

FAMILY: NITZSCHIACEAE

12. *Nitzschia sp*
13. *Nitzchia longissma*

FAMILY: SURIRELLACEAE

14. *Surirella sp*

ORDER: PINNALES

FAMILY: FRAGILARIACEAE

15. *Thalassiothrix sp*

16. *Fragilaria sp*

17. *Fragillaria hyaline*

18. *Thalassionema sp*

19. *Asterrionlla japonica*

20. *Licmophora sp*

FAMILY: DIATOMACEAE

21. *Diatoma sp*

FAMILY: ACTINODISCACEAE

22. *Actinoptychus undulates*

FAMILY: BIDDULPHIEAE

23. *Biddulphia sp*

24. *Biddulfia obtusa*

25. *Biddulfia heteroceros*

FAMILY: LAUDERIACEAE

26. *Thalassiosira sp*

DIVISION: PHYROPHYTA

CLASS: PHYRROPHYCEAE

ORDER: PERIDINALES

FAMILY PERIDINIACEAE

27. *Protoperidinium sp*

28. *Triceratium sp*

ORDER: CENTRALES

FAMILY: SOLENIAE

29. *Rhizosolenia sp*

ORDER: PROROCENTRALES

FAMILY PROROCENTRACEAE

30. *Prorocentrum sp*

TEMPORAL VARIATION IN PHYTOPLANKTON ABUNDANCE AND DIVERSITY

Thirty species of phytoplankton belonging to 3 divisions, 3 classes, 6 orders and 17 families were recorded during the study period. Chrysophyta were the most dominant group (23 species), followed by, Cyanophyta (3 species) and Phyrophyta (4 species). However, *Coscinodiscus* was the most abundant species and was found persistent throughout the seasons. Photomicrographs of few representative species are included in the figures 3.15 and 3.16.

Total phytoplankton abundance was highly variable in both space and tim e along with the variations in the nutrient concentration in the seawaters. The phytoplankton density increased gradually from 8440 cells to 59040 cells No./L with an average of 20705 cells No./L and 41423 cells No./L in Alang and Diu respectively. Significant variations among the plankton community were mainly dependent on the season, stations and its respective hydrological features. The comparisons between the phytoplankton populations of all the three stations *viz* Diu, Veraval and Alang in different seasons revealed that Diu located at the open coast of the Arabian Sea generally harboured higher phytoplankton abundance compared to Veraval and Alang, located at the Gulf of Cambay. The phytoplankton abundance showed temporal trends at all three stations during different seasons. The trend is more or less distinct to all the sites at different seasons (Figure 3.4). The overall abundance in all the three stations was primarily due to Crysophyta. The seasonal comparisons of the phytoplankton abundance showed that Alang and Veraval recorded the lowest density during pre monsoon; this may be primarily due to relative decline in the nutrient concentration and increase in salinity that might induce a drop in phytoplankton cell numbers. Conversely, post monsoon season was associated with the higher phytoplankton abundance with a density of 59040 cells No./L at Veraval. A variable (temporally) mix of chrysophyta, and cynophyta was abundantly found during the post monsoon season at Diu. However, maximum density of phytoplankton species was recorded at Diu and Alang during the monsoon season (Table 3.2).

DIU: The phytoplankton diversity and abundance in Diu during winter remained high. The phytoplankton species like *Thalassiosira sp* showed the maximum percentage of abundance (22.57%) followed by *Coscinodiscus sp* (17.08%) and *Coscinodiscus janesianus* (14.13%) in winter. The summer month seems to be a lean season with an apparent drop in diversity and abundance of phytoplankton. The pinnate diatoms were dominant with *Nitzschia* showing maximum abundance of 16.69%. *Thalassionema* (13.35%), *Navicula* and *Pleurosigma* showed equal distribution of 10.01% while centric diatom, *Biddulfia sp* showed 12.42% of abundance in summer months at the coastal waters of Diu. However, the monsoon seems to be very assuring with maximum species abundance and diversity. The species however exhibited similar trend of distribution, as in summer. *Coscinodiscus sp* with 18.22% presence was the dominant species followed by *Coscinodiscus janesianus* (12.37%), *Thalassionema sp* (12.07%) and *Pleurosigma sp* (11.80%) during monsoon. The observed high density of phytoplankton in monsoon could be a result of increased nutrient content in the seawater. A considerable runoff along with suspended load during monsoon enriches the coastal waters with allochthonous nutrients. Moreover, during monsoon salinity and temperature was found substantially reduced. Shaikh, *et al.,* (1986) noted high species diversity and abundance in the Mediterranean and Indian Ocean reflecting positive monsoonal influence. Nonetheless, in the succeeding season, (post monsoon) a significant reduction in the abundance and diversity of phytoplankton was observed at Diu. However, *Coscinodiscus janesianus* exhibited its maximum presence compared to all other seasons of the year. Likewise, *Coscinodiscus* and *Nitzschia sp* were also found abundant during post monsoon (Figure 3.8.1, 3.9 and Table 3.4). Balasubrimanian (2001) reported reduction in the phytoplankton population during post monsoon at Manoli and Hari Islands. The total plankton volume was reported declined during post monsoon at Park Bay and Mandapam. This variation in the productivity could be due to limited salinity as well as light conditions during post monsoon (Suresh and Mathew, 1999).

VERAVAL: This station also exhibited a seasonal variation in phytoplankton the abundance and diversity. In Veraval phytoplankton abundance and diversity were relatively low during winter. Phytoplankton species *Pleurosigma* showed the maximum percentage of abundance. Pre monsoon though indicated a low abundance of the phytoplankton population; the diversity however, reached its maximum value of 2.4. Amongst the phytoplankton, *Pleurosigma* and *Nitzschia longissima* were the abundant species. High values of diversity could be a result of low nutrient availability and grazing pressure (Fredy and Ferdinand, 2006). The maximum abundance of phytoplankton was in monsoon and a concurrent increase in diversity was also noted. *Coscinodiscus sp* was the dominant species with the highest percentage of presence (22.25%). The other species that were dominant the Veraval coast were *Thalassionema (*14.74%), *Pleurosigma* (14.40%), *Coscinodiscus gigas* (12.51%), *Fragilaria* (9.73%) and *Thalassiosira* (8.34%). The highest abundance was observed during post monsoon though the divesity dropped to 2.09. *Thalassionema* and *Thalassiosira* showed the maximum abundance of 22.30 and 20.44%. This was followed by *Fragilaria sp* (11.15%), *Fragilaria hyaline* (9.44%) and *Coscinodiscus gigas* with 16.72% of total abundance which prevailed during post monsoon (Figure 3.8.2, 3.10 and Table 3.5). This substantial increase in the distribution, abundance, composition and productivity of phytoplankton during post monsoon could be due to nutrient enrichment as opined by Mangesh, *et al.,* (1996).

ALANG: The diversity and abundance of phytoplankton altered through time at Alang. The diversity was maximum during winter at this site. In winter, *Treubaria* exhibited the maximum abundance followed by *Coscinodiscus janesianus* and *Triceratium.* However, phytoplankton abundance and diversity was found reduced during pre monsoon. Further, as observed in Veraval, population of few species bloomed during summer in Alang, resulting in a decrease in diversity. The maximum abundance of phytoplankton species was observed during the monsoon. This might be due to the addition of nutrients from the surface run off and peripheral sources that might have stimulated specific group of phytoplankton to bloom hence, increasing the density in the coastal waters of Alang. Centric diatoms, *Coscinodiscus janesianus* and *Coscinodiscus sp* both were equally dominant. *Thalassiosira and Melosira* also showed dominancy with 19.16 and 11.79%. Compared to that of the rainy season the phytoplankton abundance and diversity exhibited a relative drop in the post monsoon. This might be attributed to the decreased essential nutrients concentration those are required for the growth of the phytoplankton. *Thalassionema* showed the maximum percentage of abundance during post monsoon (Figure 3.8.3, 3.11 and Table 3.6).

NUTRIENTS AND PLANKTON COMMUNITY

In order to comprehend how the dissolved nutrients influence phytoplankton community structure and bring in temporal and spatial variation, one way ANOVA without replication was performed with nutrients and phytoplankton as selected factors. Further, the phytoplankton data were subjected to one way ANOSIM to test the significant seasonal difference in plankton diversity between the three stations, in relation to that of the nutrients, thus brining temporal variations among the species.

In the present study, total phytoplankton abundance was in a state of change both in time (seasons) and in space (stations). The seasonal variation between the stations was dependent on its hydrological parameters, showing significant interaction between the nutrients and phytoplankton species (Table 3.8). The Tukey's mean comparison on the interaction of nutrients on the phytoplankton diversity with its two measures, richness and evenness, was performed. The results showed that among the nutrients; the oxidized nitrogen and phosphate phosphorus seems to have a substantial influence on the overall diversity of phytoplankton at Diu and Veraval respectively. While the number of species present (richness) and the relative abundance (evenness) does not seems to be influenced by the seasonal variations in the nutrient concentrations. Moreover, in Alang, nutrients except silicates did not show any significant effect on the community diversity. However, the Tukey's mean comparison test revealed the following:

i. Nutrients seem to be a reasonable factor influencing the community stability of the three stations, even though the magnitude of change was different for each station.
ii. Silicates appear to be the key nutrient influencing the relative abundance of diatoms at all the selected study stations.

However, in order to determine whether there exists any significant difference between the nutrient concentration and community structure of the phytoplankton species among the stations, one-way analysis of similarity ANOSIM was performed. The results of the ANOSIM help to clarify the relationship between the samples and confirm the apparent difference between each station at the community level. Table 3.7, represents the results of the similarity analysis for each parameter (nutrient). The results also include their effect on the diversity between each station. Only 15 permutations are possible in the analysis for difference between all the three stations. The pair wise comparisons of the nutrients and plankton diversity revealed significant similarity between the three stations. However, the results of the R statistics (relative measure of the degree of separation of samples) were different (Clarke and Warwick, 1994). In pair wise comparison phosphate and total oxidized nitrogen seems to be more involving in brining temporal distribution among the species. The values of the R statistic in the global test for difference between the groups increases strongly from 0.25 at Diu to large value of 1 at Alang, and the global R value indicates a distinction between the three stations i.e. Veraval (0.222) and Alang (0.333), while Diu with R values of 0. This difference may be resulted from the seasonal change in the balance of the nutrient contents (Table 3.7).

Figure 3.5, 3.6 and 3.7, depict frequency distribution of the phytoplankton at various study sites wherein it can be seen that the diversity bars were positioned towards the right corners and on the left side after the dotted demarcation is the nutrient contents. The permutations test analyses, for difference between the samples of the three stations, showed that R static varied from 0 to 1, showing that there is significant difference between all the three stations. Moreover, the nutrient contents followed a similar pattern of distribution with maximum values during the rainy season (Table 3.1).

Thus, it can be concluded that analysis of variance (ANOVA) and analysis of similarity (ANOSIM) revealed a significant correlation between the dissolved nutrients and the phytoplankton community, between the three stations and within the stations at distinct seasons. By and large, maximum diversity was in monsoon at Diu and least during summer season at Alang. Although pinnate diatoms dominated the three stations, the individual distinctiveness indicates that centric diatom particularly *Coscinodiscus sp* were the most dominant at all the three study stations during all the four seasons. Table 3.9, represents the distribution of centric and pinnate diatoms at the three study stations. However, due to the limited statistical evidence, no absolute conclusion can be drawn for the observed seasonal and station wise variation even though, a tidal influence or other such hydrographic conditions can not be ruled out. However, the dissolved nutrients in the marine waters have an important effect on the plankton community causing temporal distribution within the species. This assertion is clearly supported by the ordinations results for each of the three different stations of the Suarsahtra coast.

The multivariate non-metric multidimensional scaling (NMDS) ordinations was performed using none transformations to assess the temporal variations among the plankton communities during different seasons. The similarity matrix performed for total individuals of phytoplankton community at different seasons showed high correlations with total community and also exhibited temporal variations. The NMDS ordinations of the plankton community indicate that when the total individuals in a population are high, the relationship between the communities decreases, thereby retaining the temporal pattern of distribution. The plots at all the three stations have zero value. Further, figures of the MDS plots superimposed with bubbles to understand the relative/proportional distribution of phytoplankton at the three different stations during the study period. The ordination plot of Diu indicated that phytoplankton population during monsoon and post monsoon showed maximum similarity exhibiting high temporal variability among the community. A comparable map of ordinations is obtained for population of phytoplankton population during winter and pre monsoon season. Being far from each other, it shows less resemblance with total community. Hence, the ordination bubble formed resides far-off, presenting temporal variations, which were similar to other populations in the community (Figure3.12)

In Veraval phytoplankton populations during monsoon and post monsoon in the year 2004 showed the highest similarity consisting of minimum number of species. However, the NMDS plot illustrates a distance among the bubbles showing a strong temporal trend between two communities during the two different seasons. Equally, the phytoplankton populations during the winter and pre monsoon season in Veraval specified an inclusive distance between the populations representing less correlation with a strong swing in the community pattern increasing the temporal gradation between the two communities. (Figure 3.13)

Similarly, the community structure in the third station (Alang) showed relatively similar trend in the temporal distribution of the phytoplankton population at varied seasons during the study period. The maximum similarity was noticed between phytoplankton populations during monsoon and winter, as indicated by the proximity between the ordinations bubbles, thus retaining a temporal pattern of assemblages. The phytoplankton population in pre monsoon and post monsoon exhibits moderate to lower similarity (Figure 3.14).

DISCUSSION

The phytoplankton community structure in the present study area showed temporal variation. It is apparent from further analysis that these changes are closely linked to the dissolved nutrient content that too revealed a seasonal alteration. It has been well documented that the hydrodynamics characteristics of the marine environment are the most relevant factor, which regulates the structure of phytoplankton communities (Kiørboe, 1993; Legendre and Rassoulzadegan, 1995). As described earlier, in the present study, phytoplankton showed temporal variation in community structure in accordance with the changes in the hydro chemical (dissolved nutrients) concentrations in the Seawater. Numerous studies were conducted to investigate the seasonal changes in plankton abundance. The studies were even focused on to the interactions between phytoplankton and zooplankton population along with dissolved nutrients. These are considered as the essential factors that control the abundance and community structure at different regions of the world's ocean (Nikitin 1939; Kurmorskaya, 1955; Lazareva, 1957; Suzhina, 1964; Delalo *et al.,* 1965; Konsoluv, 1974; Kovalev, 1980; Porum, 1980; Pastemak, 1983; Koval, 1984; Mashtakova, 1985; Konsulov, 1986; Nikitin, 1993; Abdel and Gharib, 2006). However, the conclusions remained divided.

During the present study, it was noted that seasonal differences in the plankton diversity had occurred in all the three stations of the Saurashtra Coast. Diu showed maximum phytoplankton abundance during the monsoon and post monsoon seasons. Many opined that available food production; grazing, competition and predation are the essential factors that regulate plankton compositions (Knatz, 1978; Wooldridge and Melville Smith, 1979; Bradley, 1990; Hoffmeyer, 1994 and Calbert, *et al.,* 2001). However, Meybeck, (1982) suggested that amongst all the related components, nutrient concentration is one of the most important variable components of coastal areas. Its transport by river run-off has been well documented around the World. Consequently, the spatial and temporal response of coastal phytoplankton will be highly affected by the amount and composition of nutrient supply by rainfall run-off and river discharges (Mann, 1982). The results suggest that the measurement of phytoplankton diversity were significantly affected by the hydrochemical parameters thereby brining temporal allocation between the communities. The quantitative approach used in the present study enabled questions to be answered about the possible differences in the community structure during different seasons in the three stations. Evidence from the analysis of variance (ANOVA) revealed that total oxidized nitrogen and phosphate phosphorus were significantly influencing the phytoplankton diversity in two stations *viz* Diu and Veraval. The phytoplankton also exhibited an increase in abundance in accordance with that of total oxidized nitrogen and phosphate phosphorus. Reports of visible algal blooms in coastal waters, in response to total nitrogen, support the present notion (Pritchard *et al.,* 2003). Similarly, Kazuyasu and Akihiko (1986) reported about the phosphorus induced population dynamics of phytoplankton in Tokyu Bay waters. The organic phosphorous is reported positively correlated with the phytoplankton production. This nutrient concentration varied seasonally, showing spatial and temporal pattern of distribution. Val, (2006) revealed a strong positive response of marine phytoplankton biomass to nutrient enrichment that is in agreement with other liminological and oceanographic literature.

Further, among the studied nutrients, silicates appear to be influencing the species abundance to a greater extent in all the three stations of the Saurashtra coast. The phytoplankton population especially diatoms are highly dominant in waters with high silicate concentration as indicated by (Wasmund, *et al.,* 2005). The presence of large number of *Coscinodiscus sp* during the current study itself supports this fact. The silicate appears to be the single largest nutrient that limits algal growth. This nutrient had profound influence on phytoplankton proliferation as evident from the strong negative correlation between chlorophyll–a and silicates reported from the backwaters of Cochin (Devassy *et al.,* 1974, 96). This endorses the concentrations of silicates in the coastal waters. Related observations were reported earlier from the tropical waters. In the tropical coastal ecosystem, the role of nutrient controlling phytoplankton growth is more prominent than the other physicochemical characteristics (Smetacek, 1988, 1993). This variation in the nutrient contents seasonally brings in temporal distribution among the community. Moreover, any shift in the silica can have profound impact on the species composition of phytoplankton community during some of the season (Horner, *et al.,* 1973).

In the present study, though the overall phytoplankton diversity seems to be influenced by the seasonal variation in nutrient concentration, however, the other two factors that represents diversity i.e. species richness and evenness, remained resistant to these nutrient factors. Numerous factors are reported regulating the magnitude of the seasonal pattern and species composition of phytoplankton. This include light, temperature, nutrients, physical transport processes and herbivory. As suggested by Boyton, and co-workers (1982) these factors also affect phytoplankton assemblages on both the ecological scale and at the level of individual cells. On the ecological scale, environmental factors influence phytoplankton through species selection. In addition, adaptation to these changing environmental conditions regulates the physiological scale by the intracellular biochemical mechanisms including changes in enzymes and pigment concentration in such a way as to provide a near optimal response for specific species. The relative significance of these factors apparently varies from one system to the next. The high density of diatoms and dinoflagellates leads to a low species diversity, a common fact in estuaries. The specific diversity in tropical seas also directly relates to the mechanism that reacts to a continuous interaction between communities of different water bodies and between those limited by nutrients. However, when the nutrients are higher, development of many species can occur with high reproduction rates. This maintains a steady evenness pattern thereby affecting the diversity (Lacerda, *et al.,* 2004).

Besides, the statistical analyses also reveal notable difference between the species diversity and nutrient concentration along the three stations of the Suarashtra coast. Though total oxidized nitrogen and phosphates are considered as the important limiting factors, the aggregation of all the factors produced apparent changes in the community structure, thus, brining temporal amendments within the community. This has been to some extent depicted by ANOSIM.

In the present study, the total phytoplankton population at the intertidal zone did not show profound alteration, though some trivial distinction between the three stations *viz* Diu, Veraval and Alang cannot be overruled. However, there exists a significant correlation between the nutrient and phytoplankton community. Zhauhui, *et al.* (2006) stated that in a coastal ecosystem with appropriate water temperature, sufficient salinity, as well as quick recovery of nutrients played an important role in the high abundance of phytoplankton and frequent outbreaks of blooms.

Further, in order to understand the interrelation between the environmental and biological parameters including phytoplankton diversity, the data were subjected to multivariate ordinations (Multidimensional scaling). The ordination plot showed that there exists a fair degree of similarity among the plankton community indicating a reasonable gradient in the temporal distribution among the floral compositions at all the three stations. The maximum temporal variation subsists during the monsoon and post monsoon season with increase in the number of individual and species diversity at all the three stations (Figure3.4). This is characterized by the renewal of nutrients in the surface waters by up welling and land runoff during monsoon period. Diu showed the maximum similarity with more inclination towards temporal distribution of plankton species than compared to Alang and Veraval. The other two stations Veraval and Alang also indicated higher resemblance amongst the community exhibiting temporal changes in the species composition during different seasons. All these changes in the plankton community at all the three study stations are mainly attributed largely to the alteration in the physicochemical conditions, moderately due to natural disturbance and partly due to the pollution in the coastal waters of Diu, Veraval and Alang. Temporal distribution among the diversity pattern of various phytoplankton species occurs due to rapid deterioration and loss of ecosystem, especially in the coastal areas (Bolger 2001 and Ellingsen, 2001). Ayya, *et al.* (2005) analysed the temporal variations among the plankton community in the lagoon waters using similarity coefficients and reported high level heterogeneity between the samples.

Interestingly, in the present study, the most significant factor that was found altering the phytoplankton community is the dissolved nutrient content in the seawater. A fluctuation in the nutrient concentration corresponds with variations in the phytoplankton population. Further, at all the three stations (Diu, Veraval and Alang) the phytoplankton densities were high during monsoon and post monsoon. Mukohopadya, *et al.* (Unpublished) observed a hike in phytoplankton species richness and density during post monsoon at Mahanadi estuary. This possibly could be aided by high phosphate concentration or favourable N: P ratio. Moreover, chlorophyll-a exhibited major peaks in pre and post monsoon seasons which were attributed to higher planktonic productions as a result of upwelling and favourable marine conditions. Furthermore, all the three stations represented a proportional distribution of low density and diversity during summer (pre monsoon) months. Similar observations made by Verlecar e*t al.,* (1996) substantiate the present findings. However, pre monsoon did not reflect an increase in chlorophyll-a concentration. Distribution of species, nevertheless, indicated that the phytoplankton density and diversity during pre monsoon represents few species as compared to monsoon. Paradoxically, Redekar and Wagh (2000) reported increase in diatom numbers during summer (pre monsoon) and low cell counts recorded during rainy seasons (monsoon). However, the chlorophyll-a, it was observed, remained high during monsoon. This could be due to the heavy dispositions of chlorella. The subsequent synchronized variations in dissolved nutrient concentrations in rest of the seasons at the study stations of the Saurashtra coast were observed. Thus, the expected increase in the phytoplankton population is the resultant utilization of the nutrients by the phytoplankton organisms. From, the stoichiometric compositions of nutrient in the seawaters, the concentration of each nutrient plays an important role in temporal distribution among the phytoplankton species in a community. Station wise contribution of nutrients for the phytoplankton production indicated high concentration of total oxidized nitrogen at Veraval during monsoon. Similarly, high levels of reactive phosphate were encountered during post monsoon season. Hence, it can be expected that phytoplankton diversity and richness will be higher during monsoon season. On the contrary, increase in phytoplankton diversity and species richness was observed during winter in Veraval. The reason attributed for the low diversity in monsoon could be due to higher turbidity during rainy season. This restricts the penetration of the light in the water column thereby reducing the photosynthetic production. The other basis for such an allocation provides a differential nutrient uptake related to the presence of different phytoplankton species in the ecological unit (Eppley *et al.,* 1969; Lewis, 1976; Friebele *et al.,* 1978). Selvaraj, *et al.* (2003) indicated that community structure showed seasonal variations in the total cell number which generally corresponded with that of photosynthetic productivity values. Thus, higher values of phytoplankton cells were noted during the winter months due to occasional blooming of certain species of diatoms. This is more associated with high nutrient concentration in the near shore waters due to climate change.

There also occurs a strong gradient in the nutrient concentration along the coastal waters. This was noted as an unusual hike in the nitrate concentration in Alang during winter with a fair reduction in the plankton density, this might be probably due to remineralization, varying load and dynamic water exchange at the coastal waters of the ship-breaking yard. The gradient in the nutrient concentration, especially high concentration of nitrate was invariably noted in estuaries during winter (Ogilvie *et al.,* 1997). The seasonal increase occurred due to maximum denitrification during winter. The low temperature in winter favoured denitrification over nitrate ammonification that increases the nitrate concentration (Lloyd *et al.,* 1997; Robertson and Kuenen, 1990). This may be also due to pollution arising out of ship breaking unit. Nonetheless, Reay, *et al.* (2001) gave a much differing observation that rates of phytoplankton growth, and nitrate uptake increases with the elevated temperatures. Additionally, Hansen, *et al.* (1996) stated that nutrients like nitrates always showed a significant increase in concentration until the onset of the spring bloom.

Seasonal fluctuations were even prominent in seawaters of Diu. The total oxidized nitrogen and phosphates increased considerably after the rains (post monsoon). Probably the increase in the freshwater inflow from land runoff, enriched with nutrients and organic matter may be responsible for the increase in the nutrient contents in the marine waters. Interestingly these additional disturbances added to the nutrient and organic load in the marine environment that coincided with the relative successional changes in the growth of the phytoplankton population. This is evident from the raise in phytoplankton population during post monsoon season at Diu. Gopinathan, *et al.* (1984) recorded higher phytoplankton density during post monsoon period in the backwaters. Similar observations were made in the other coastal waters of India (Gopinathan, 1972; Joseph and Pillai, 1975 Murugan and Ayyakkannu, 1993). The abundance of phytoplankton during post monsoon indicates the utilization of nutrients under well lighted period and calm water conditions and the movement of neritic plankton into the coastal waters during high tide. This considerably concurred with the developments in the higher tropic levels (zooplankton) and their general distribution, all closely linked to hydrological conditions in the marine environment. In spite of these facts, the current observation contradicts with that of Kyewalyanga, *et al.* (2004) who stated that, there is no correlation between plankton densities and abiotic variables such as nutrients and water temperature in oceanic waters.

The statistical analyses have revealed a strong association between the silicates and phytoplankton population from all the three stations. Silicates significantly affected the phytoplankton cell numbers at Diu, Veraval and Alang especially during the monsoon months. Stephan and co-workers (1982) noted a hike in diatom and dinoflagellates cell numbers with the increase in silicate concentration in estuarine waters. The monsoon showers and resultant land runoffs may contribute to the higher silicate concentrations in the monsoon month (Rajashree and Panigrahi, 1992). Thus, silicate and chlorophyll-a are considered to be the best indicators of the cell density. Studies on aquatic ecosystem have attempted to identify the indicator species and on the basis of that categorize the ecological integrity of the ecosystem (Patrick and Palavage, 1994).

Considering the distribution pattern described for the three stations of the Saurashtra coast, it is likely that the dominance of few opportunistic phytoplankton species within community means that the physical, biological and chemical factors are controlling its temporal distribution. Temporal and spatial pattern are often interdependent. The phytoplankton species compositions relates not only to local hydrodynamic features but also to biological processes, inducing primary productivity and the migratory behaviours of organisms.

Hence, from the above discussion it could be concluded that plankton communities exhibit temporal variation with respect to the alterations in the physiochemical characteristic of marine waters. The temporal distributions of the plankton species were largely influenced by the changes in the dissolved nutrients level in Coastal waters. However, nutrients solely cannot be considered as a complete contributing factor for the determination of temporal variations in a community. Besides, from the statistical analysis it is clear that no factor acts in isolation and any variations in the biological and physical variables, such as food quality, turbidity and salinity may influence the plankton community as a whole, contributing to the spatial and temporal variations among the community.

Table3.1. Hydrochemical parameters (dissolved nutrients) during different seasons at the three stations at Saurashtra.

DIU

Parameters	Winter	Pre monsoon	Monsoon	Post monsoon
$NO_2^- - N$ mg/L	0.15 ± 0.021[@]	0.12 ± 0.00	1.49 ± 0.04	0.26 ± 0.20
$NO_3^- - N$ mg/L	0.132 ± 0.076	0.02 ± 0.00	0.39 ± 0.02	0.238 ± 0.06
$PO_4^3 - P$ mg/L	0.75 ± 0.001	0.6 ± 0.00	0.86 ± 0.00	1.2 ± 0.41
SiO_3-Siμg/L	4 ± 0.013	4.85 ± 0.02	5.15 ± 0.02	6.93 ± 0.01

VERAVAL

Parameters	Winter	Pre monsoon	Monsoon	Post monsoon
$NO_2^- - N$ mg/L	0.072 ± 0.00[@]	0.2 ± 0.00	1.49 ± 0.00	0.26 ± 0.00
$NO_3^- - N$ mg/L	0.073 ± 0.00	0.088 ± 0.00	0.149 ± 0.00	0.095 ± 0.00
$PO_4^3 - P$ mg/L	0.60 ± 0.00	0.500 ± 0.00	1.08 ± 0.00	0.8 ± 0.00
SiO_3-Siμg/L	5.78 ± 0.18	6.98 ± 0.02	8.79 ± 0.14	6.8 ± 0.24

ALANG

Parameters	Winter	Pre monsoon	Monsoon	Post monsoon
$NO_2^- - N$ mg/L	0.232 ± 0.02	0.177 ± 0.03	0.06 ± 0.07	0.05 ± 0.01
$NO_3^- - N$ mg/L	2.135 ± 0.05	0.09 ± 0.00	0.048 ± 0.00	0.245 ± 0.01
$PO_4^3 - P$ mg/L	0.55 ± 0.00	0.35 ± 0.00	0.99 ± 0.01	0.8 ± 0.00
SiO_3-Siμg/L	7.52 ± 0.01	6 ± 0.07	9.89 ± 0.09	12 ± 0.23

[@] Values are expressed as mean ± Standard Error (SE); n = 3

Table3.2: Composition of phytoplankton community during different seasons of the three study stations at Saurashtra.

DIU

Seasons	S	N	J′	d	H'
Winter	11	20590	0.9512	1.007	2.617
Pre monsoon	7	10580	0.925	0.6475	2.422
Monsoon	12	35960	0.888	1.049	2.781
Post monsoon	11	26910	0.8642	0.9804	2.546

VERAVAL

Seasons	S	N	J′	d	H'
Winter	11	32792	0.923	0.9617	2.213
Pre monsoon	13	29960	0.9358	1.164	2.4
Monsoon	12	43900	0.9404	1.029	2.337
Post monsoon	11	59040	0.8725	0.9103	2.092

ALANG

Seasons	S	N	J′	d	H'
Winter	11	18950	0.924	1.015	2.06
Pre monsoon	7	8440	0.8982	0.6637	1.748
Monsoon	10	33930	0.8286	0.8627	1.908
Post monsoon	9	21500	0.8349	0.8019	1.834

S =Total species, N = Total individuals, d =Species richness, j =Evenness, H' = Diversity

Table 3.3. Annual composition of phytoplankton community at the three study stations of Saurashtra.

Stations	S	N	J′	d	H'
Diu	4	165692	0.2496	0.9734	1.349
Veraval	4	94040	0.262	0.9406	1.304
Alang	4	82820	0.2649	0.9276	1.286

S =Total species, N = Total individuals, d =Species richness, j =Evenness, H' = Diversity

Table 3.4: Seasonal variation in species abundance (No./L) and percentage of occurrence phytoplankton species at Diu

Species	Winter Cells No/L	%	Pre monsoon Cells No/L	%	Monsoon Cells No/L	%	Post monsoon Cells No/L	%
Actinoptychus undulates	1500[@]	4.57	0[@]	0	1860[@]	4.24	4820[@]	8.16
Amphora lanceolata	0	0	1640	5.47	3000	6.83	0	0
Asterionella japonica	0	0	1670	5.57	0	0	0	0
Biddulphia sp	1500	4.57	3720	12.42	0	0	0	0
Biddulphia hetrocerous	0	0	1200	4.01	0	0	0	0
Biddulphia obtusa	1800	5.49	0	0	0	0	0	0
Coscinodiscus janesianus	4632	14.13	2330	7.78	5430	12.37	15000	25.41
Coscinodiscus gigas	3200	9.76	2000	6.68	4500	10.25	8330	14.11
Coscinodiscus	5600	17.08	1000	3.34	8000	18.22	10020	19.97
Diatoma sp	1640	5.0	0	0	0	0	0	0
Fragilaria sp	0	0	0	0	3500	7.97	3000	5.08
Fragilaria hyalina	0	0	0	0	0	0	2540	4.30
Navicula sp	0	0	3000	10.01	0	0	3430	5.81
Nitzschia sp	0	0	5000	16.69	1500	3.42	8150	13.80
Grammatophora sp	0	0	400	1.34	0	0	500	0.85
Pleurosigma sp	0	0	3000	10.01	5180	11.80	0	0
Prorocentrum sp	0	0	0	0	1500	3.42	0	0
Rhoicosigma sp	1330	4.06	0	0	0	0	0	0
Thalassionema sp	1840	5.61	4000	13.35	5300	12.07	2000	3.39
Thalassiosira sp	7400	22.57	1000	3.34	3000	6.83	1250	2.12
Treubaria sp	2350	7.17	0	0	0	0	0	0
Rhizosolenia sp	0	0	0	0	1130	2.57	0	0

[@] Median value; n=3

Table 3.5: Seasonal variation in species abundance (No./L) and percentage of occurrence phytoplankton species at Veraval

Species	Winter Cells No/L	%	Pre monsoon Cells No/L	%	Monsoon Cells No/L	%	Post monsoon Cells No/L	%
Actinoptychus undulates	0[@]	0	0[@]	0	1300[@]	3.62	0[@]	0
Biddulphia sp	2000	9.71	0	0	0	0	0	0
Biddulphia hetrocerous	600	2.91	0	0	0	0	0	0
Biddulphia obtusa	1200	5.83	0	0	0	0	2000	7.43
Climacosphenia elongata	0	0	0	0	0	0	800	2.97
Coscinodiscus gigas	2600	12.63	1500	14.8	4500	12.51	4500	16.72
Coscinodiscus sp	1500	7.29	1500	14.8	8000	22.25	1000	3.72
Diatoma sp	1640	7.97	0	0	0	0	320	1.19
Fragilaria sp	0	0	0	0	3500	9.73	3000	11.1
Fragilaria hyalina	0	0	0	0	0	0	2540	9.44
Navicula sp	0	0	0	0	0	0	500	1.86
Nitzschia sp	0	0	0	0	0	0	0	0
Nitzschia longissima	0	0	2000	18.90	1500	4.17	750	2.79
Grammatophora sp	0	0	400	3.78	0	0	0	0
Pleurosigma sp	3500	17.0	3180	30.06	5180	14.40	0	0
Prorocentrum sp	1000	4.86	0	0	1500	4.17	0	0
Thalassionema sp	0	0	0	0	5300	14.74	6000	22.30
Thalassiosira sp	3200	15.54	1000	9.45	3000	8.34	5500	20.44
Treubaria sp	2350	11.41	0	0	450	1.25	0	0
Thalassiothrix sp	0	0	1000	9.45	0	0	0	0
Triceratium sp	0	0	0	0	600	1.67	0	0
Rhizosolenia sp	1000	4.86	0	0	1130	3.14	0	0

[@] Median value; n=3

Table 3.6: Seasonal variation in species abundance (No./L) and percentage of occurrence phytoplankton species at Alang

Species	Winter Cells No/L	%	Pre monsoon Cells No/L	%	Monsoon Cells No/L	%	Post monsoon Cells No/L	%
Biddulphia sp	1000[@]	5.28	0[@]	0	0[@]	0	0[@]	0
Coscinodiscus janesianus	3500	18.47	2500	29.62	8000	23.58	1000	4.65
Coscinodiscus sp	1500	7.92	1500	17.77	8000	23.58	1000	4.65
Fragilaria sp	0	0	0	0	1500	4.42	3000	13.95
Fragilaria hyalina	0	0	0	0	0	0	0	0
Melosira sp	1500	7.92	2000	23.70	4000	11.79	0	0
Nitzschia sp	0	0	0	0	0	0	500	2.33
Licmophora sp	600	3.17	0	0	1000	2.95	2500	11.63
Oscillatoria sp	0	0	0	0	0	0	0	0
Pleurosigma sp	1500	7.92	0	0	0	0	0	0
Protoperidinium sp	1000	5.28	0	0	1500	4.42	0	0
Surirella sp	1000	5.28	0	0	0	0	0	0
Thalassionema sp	0	0	0	0	250	0.74	8000	37.21
Thalassiosira sp	800	4.22	600	7.11	6500	19.16	0	0
Trichodesmium sp	0	0	420	4.98	0	0	1500	6.98
Trochommina sp	0	0	420	4.98	0	0	0	0
Thalassiothrix sp	0	0	0	0	180	0.53	0	0
Triceratium sp	2350	12.40	0	0	0	0	0	0
Treubaria sp	4200	22.16	1000	11.85	3000	8.84	3500	16.28

[@] Median value; n=3

Table 3.7. ANOSIM randomization test to confirm statistically significant differences between the hydrochemical parameters and phytoplankton community in each station at Saurashtra.

DIU

SAMPLE	FACTORS
Total oxidized nitrogen	C
PO_4-p mg/L and SiO_3-Si µg/L	L
Phytoplankton Diversity	H

*C, L & H are factors for identification.

Global Test
Number of permutations: 15 (All possible permutations)
Sample statistic (Global R): 0.
Significance level of sample statistic: 53.3%

Groups	R Statistic	Significance level %	Possible permutations	Actual permutations	Number observed
C,L	-0.25	100	3	3	3
C,H	0.25	66.7	3	3	2
L,H	0	66.7	3	3	2

VERAVAL
Sample statistic (Global R): 0.222
Significance level of sample statistic: 53.3%

Groups	R Statistic	Significance level %	Possible permutations	Actual permutations	Number observed
C,L	-0.25	100	3	3	3
C,H	0.75	33.3	3	3	1
L,H	0	66.7	3	3	2

ALANG
Sample statistic (Global R): 0.333
Significance level of sample statistic: 33.3%

Groups	R Statistic	Significance level %	Possible permutations	Actual permutations	Number observed
C,L	0	100	3	3	3
C,H	1	33.3	3	3	1
L,H	0	66.7	3	3	2

The pair wise R values give absolute measure of how separated the groups are
R > 0.75: groups being well separated
R > 0.5: groups overlapping but clearly different
R > 0.25: groups barely separable at all.

Table 3.8. Results of One Way ANOVA based on phytoplankton diversity indices - species richness and evenness. The fixed factor for the analysis is nutrients.

DIU

Parameters	NO_2^-N mg/L	$NO_3^- - N$ mg/L	$PO_4^3 - P$ mg/L	$SiO_4 - Si$ µg/L	PD	SR	SE
NO_2^-N mg/L	NS	NS	NS	Yes*	Yes*	NS	NS
$NO_3^- - N$ mg/L	NS	NS	NS	Yes*	Yes*	NS	NS
$PO_4^3 - P$ mg/L	NS	NS	NS	Yes*	Yes*	NS	NS
$SiO_4 - Si$ µg/L	NS	NS	NS	NS	Yes*	Yes*	Yes*

VERAVAL

Parameters	NO_2^-N mg/L	$NO_3^- - N$ mg/L	$PO_4^3 - P$ mg/L	$SiO_4 - Si$ µg/L	PD	SR	SE
NO_2^-N mg/L	NS	NS	NS	Yes*	Yes*	NS	NS
$NO_3^- - N$ mg/L	NS	NS	NS	Yes*	Yes*	NS	NS
$PO_4^3 - P$ mg/L	NS	NS	NS	Yes*	Yes*	NS	NS
$SiO_4 - Si$ µg/L	NS	NS	NS	NS	Yes*	Yes*	Yes*

ALANG

Parameters	NO_2^-N mg/L	$NO_3^- - N$ mg/L	$PO_4^3 - P$ mg/L	$SiO_4 - Si$ µg/L	PD	SR	SE
NO_2^-N mg/L	NS	NS	NS	Yes*	NS	NS	NS
$NO_3^- - N$ mg/L	NS	NS	NS	Yes*	NS	NS	NS
$PO_4^3 - P$ mg/L	NS	NS	NS	Yes*	NS	NS	NS
$SiO_4 - Si$ µg/L	NS	NS	NS	NS	Yes*	Yes*	Yes*

Yes* The means are significant at $P \leq 0.05$ level.
NS Not significant
PD Phytoplankton diversity
SR Species richness, SE Species evenness

Table 3.9. Phytoplankton recorded at the low tide zone of the intertidal region of Diu, Veraval and Alang during the study period

CENTRIC DIATOM SPECIES	DIU	VERAVAL	ALANG
Biddulphia sp	+	+	+
Biddulphia obtusa	+	+	–
Coscinodiscus janesianus	+	–	+
Coscinodiscus gigas	+	+	–
Coscinodiscus sp	+	+	+
Melosira sp	–	–	+
Thalassiosira sp	+	+	+
Rhizosolenia sp	+	+	–
Trochommina sp	–	–	+
Diatoma sp	+	+	–
PENNATE DIATOM SPECIES			
Amphora lanceolata	+	–	–
Navicula sp	+	–	–
Navicula sp1	–	+	–
Nitzchia sp	+	+	+
Nitzschia longissima	+	–	+
Pleurosigma sp	+	+	+
Surirella sp	–	–	+
Thalassiothrix sp	–	+	+
Fragillaria sp	+	+	+
Fragillaria hyalina	+	+	+
Actinotychus undulates	+	+	–
Asterionella japonica	+	–	–
Grammatophora sp	+	+	+
Protoperidinium sp	–	–	+
Rhoicosigma sp	+	–	–
Thalassionema sp	+	–	–
Treubaria sp	+	+	–
Rhizosolenia sp	+	+	–
Triceratium sp	–	+	–
Licmophora sp	–	–	+

+ Indicates relative abundance of species within that station.

Figure3.1: Graphical layout of the variations in the nutrient concentration during different seasons at Diu

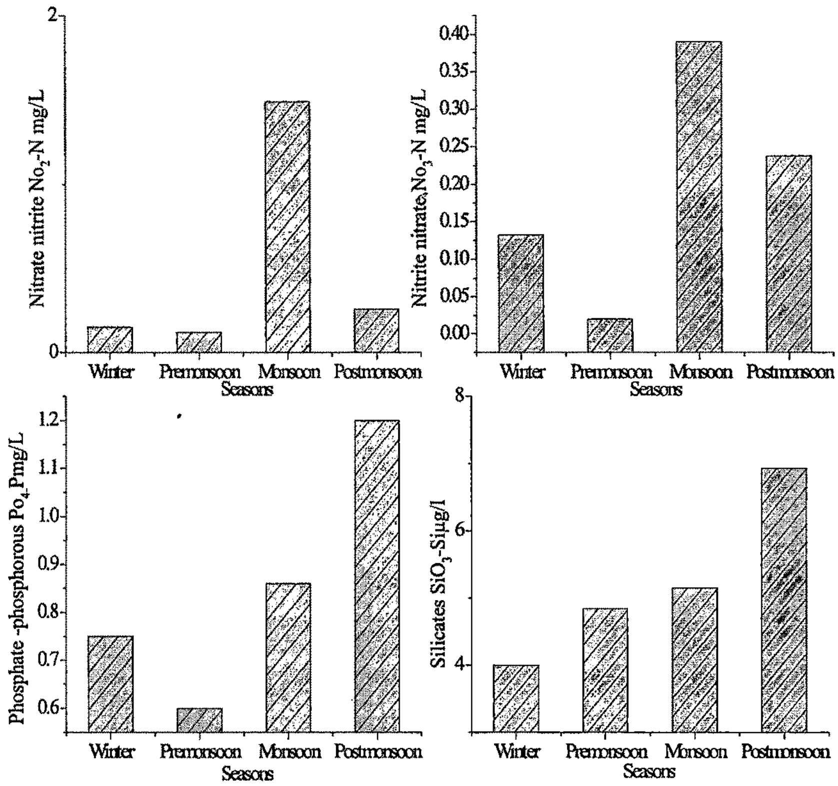


Figure3.2: Graphical layout of the variations in the nutrient concentration at different seasons at Veraval

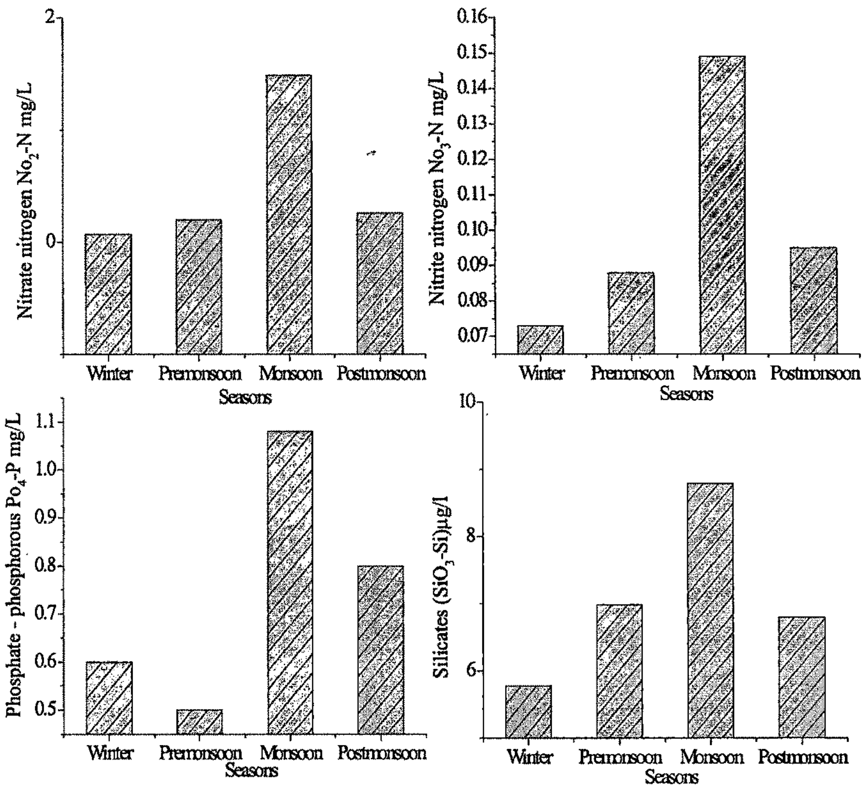


Figure3.3: Graphical layout of the variations in the nutrient concentration at different seasons at Alang

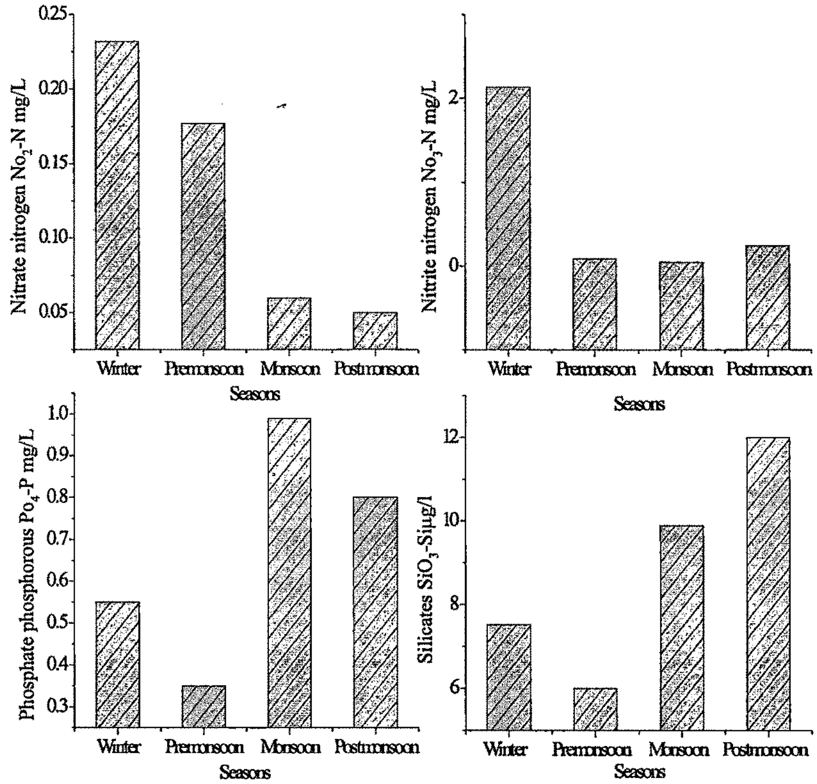


Figure 3.4. Temporal variations in the phytoplankton populations in the coastal waters of Diu, Veraval and Alang.

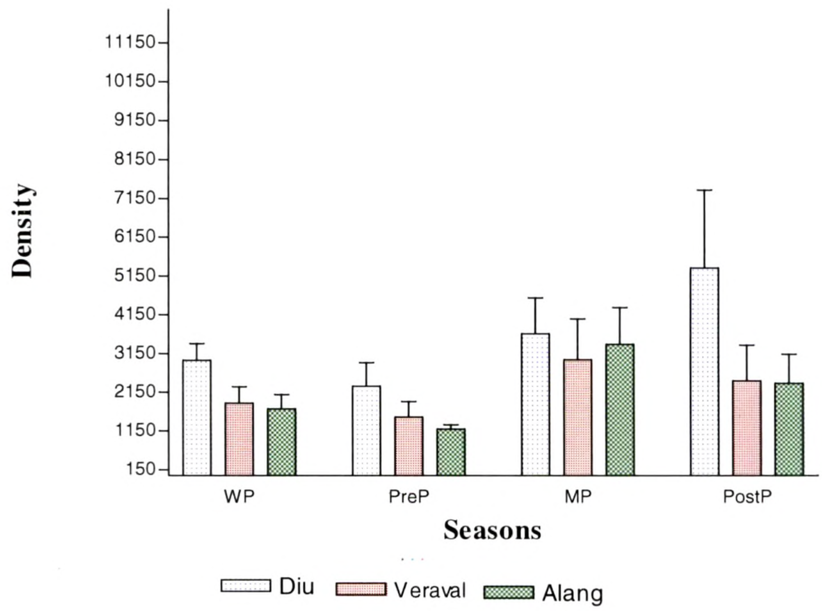


Figure3.5. Frequency distribution of the phytoplankton diversity at Diu (Refer Table 3.7).

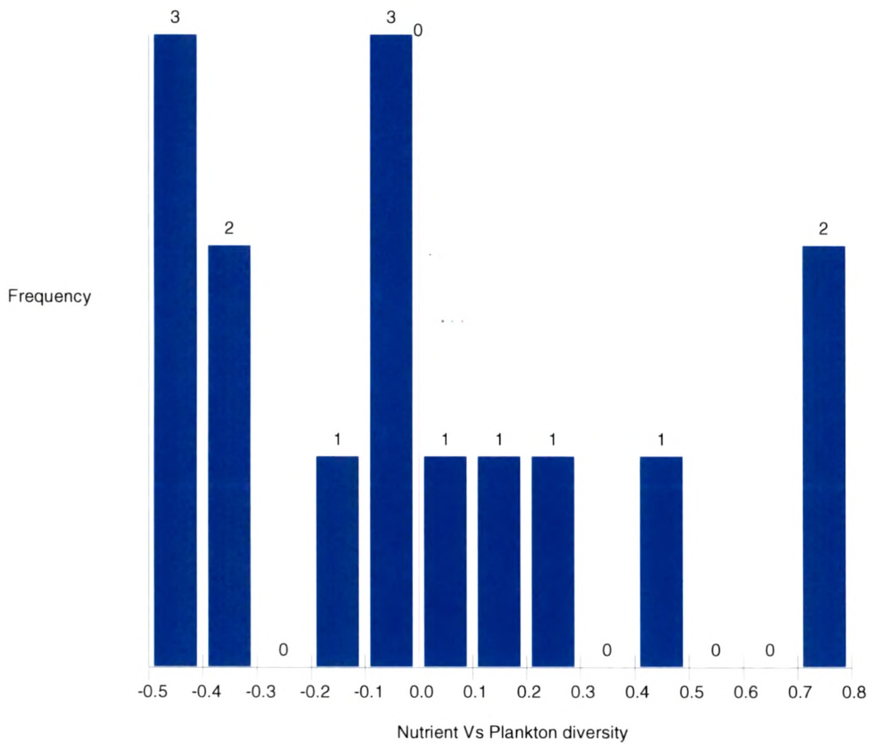


Figure 3.6. Frequency distribution of the phytoplankton diversity at Veraval (Refer Table 3.7)

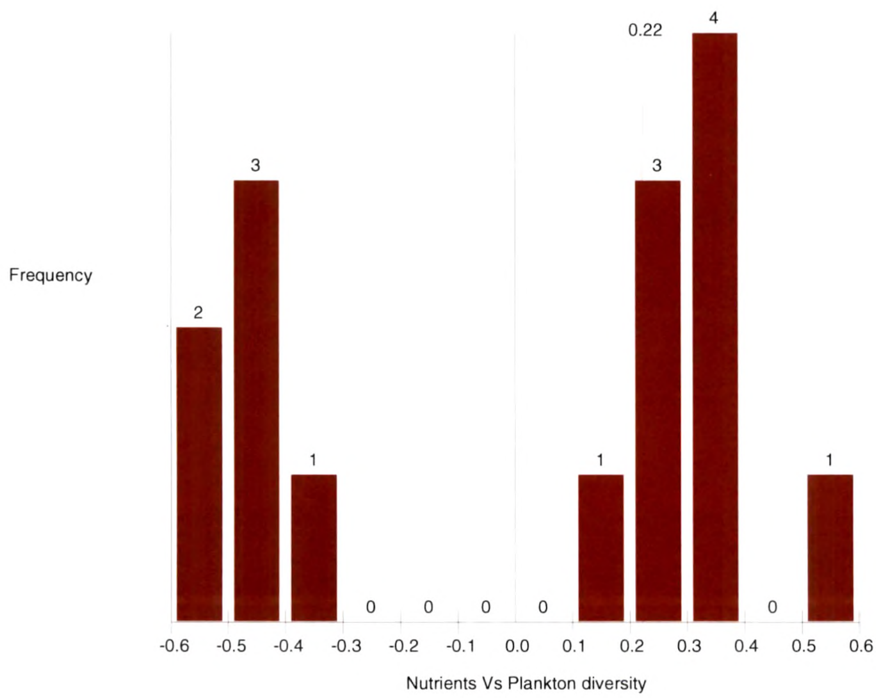


Figure 3.7. Frequency distribution of the phytoplankton diversity at Alang (Refer Table 3.7)

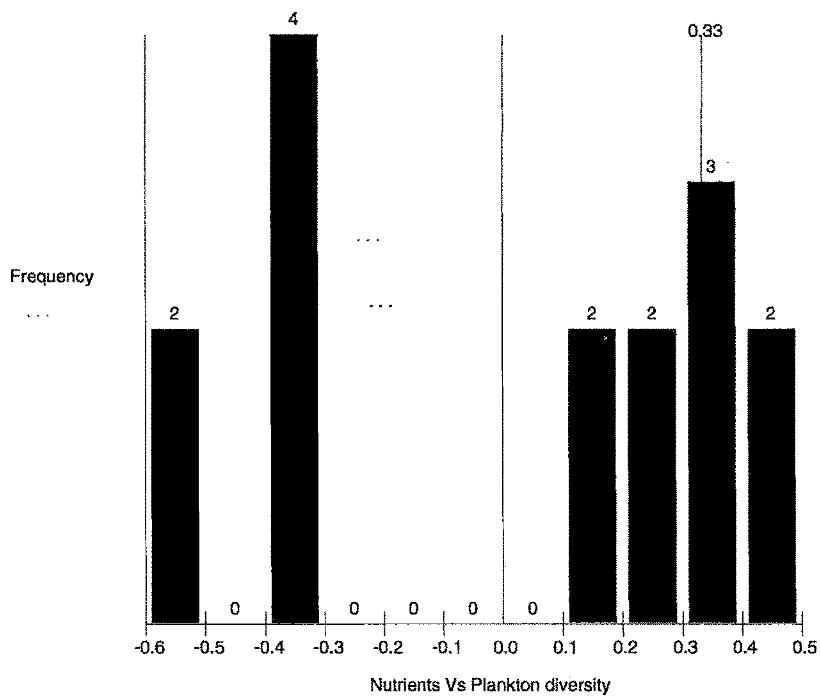
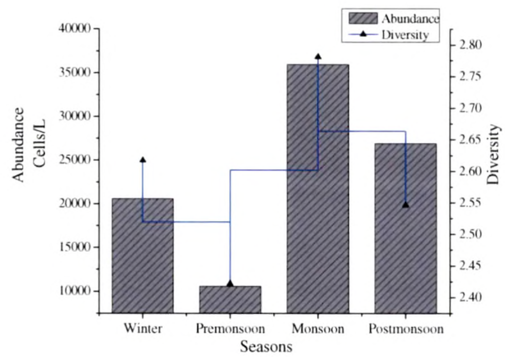
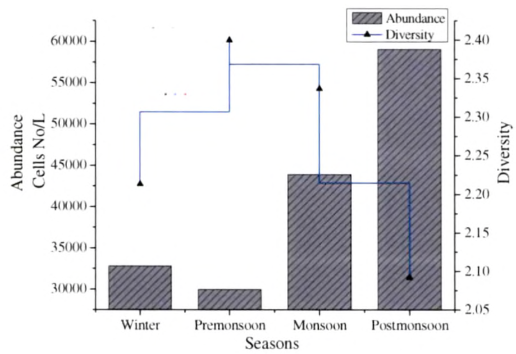


Figure 3.8: Species abundance and diversity of the phytoplankton observed during different seasons at three stations of the Saurashtra coast.

3.8.1 DIU



3.8.2 VERAVAL



3.8.3 ALANG

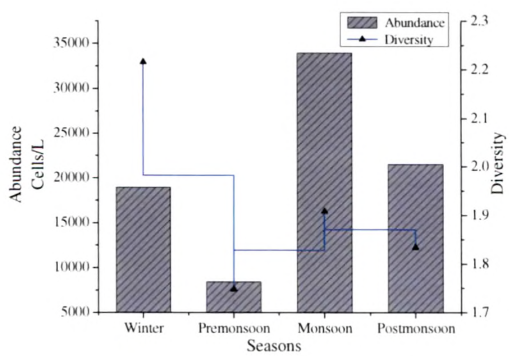


Figure 3.9: Graphical representations of the seasonal distributions of phytoplankton populations at Diu, indicating temporal distribution between the communities. (Refer Table 3.4)

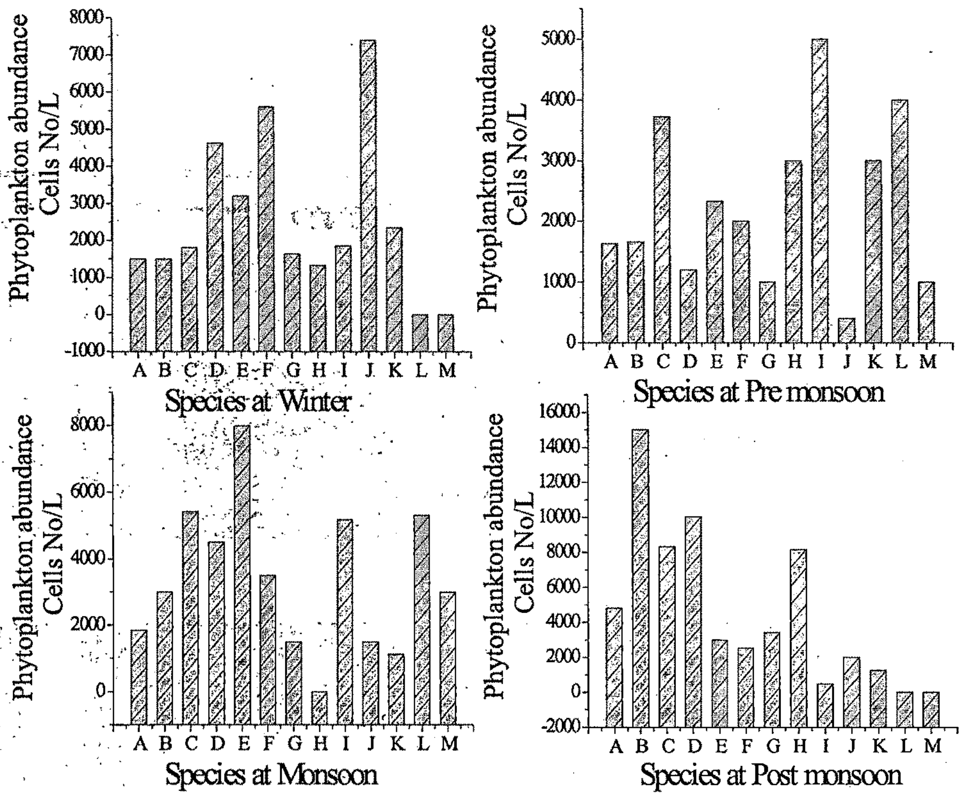


Figure 3.10. Graphical representations of the seasonal distributions of phytoplankton populations at Veraval, indicating temporal distribution between the communities (Refer Table 3.5)

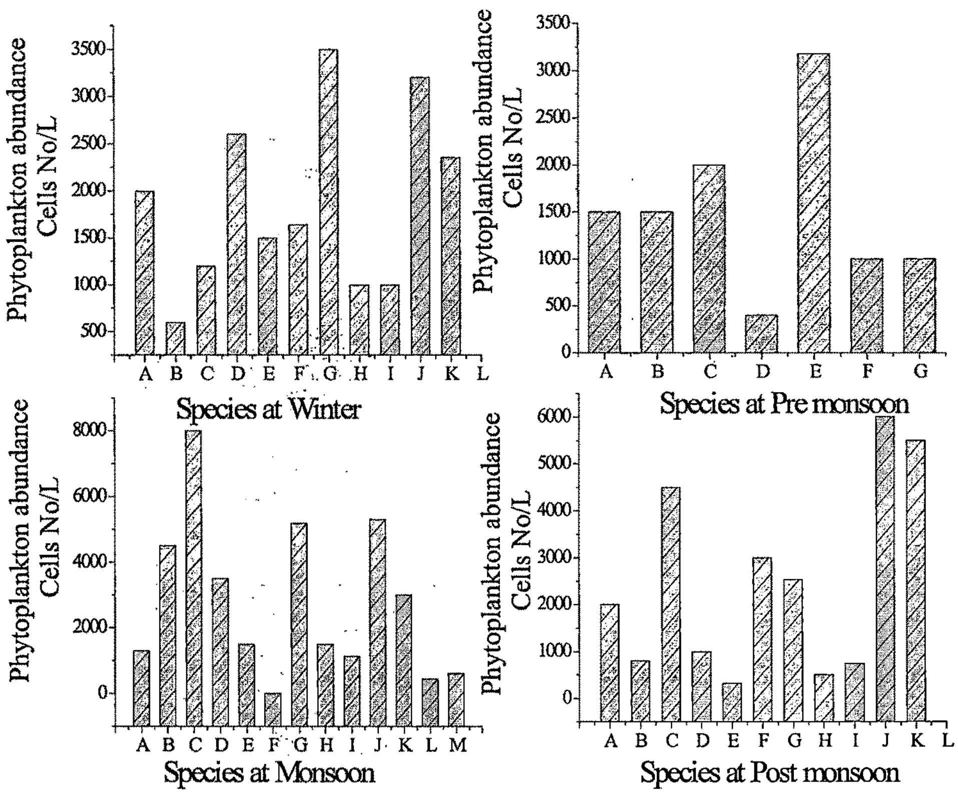


Figure 3.11. Graphical representations of the seasonal distributions of phytoplankton populations at Alang, indicating temporal distribution between the communities. (Refer Table 3.6)

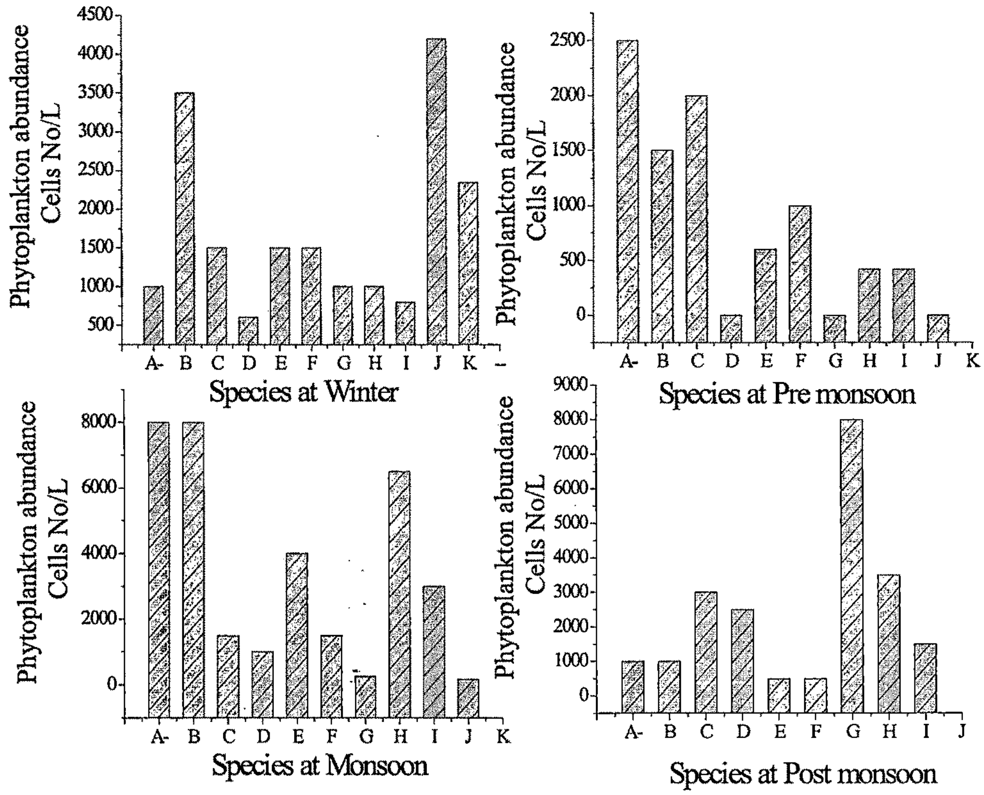


Figure 3.12. Non metric MDS ordination plot showing similarities between samples during various seasons after none transformation. Bubbles show the relative size of plankton population during different seasons at Diu

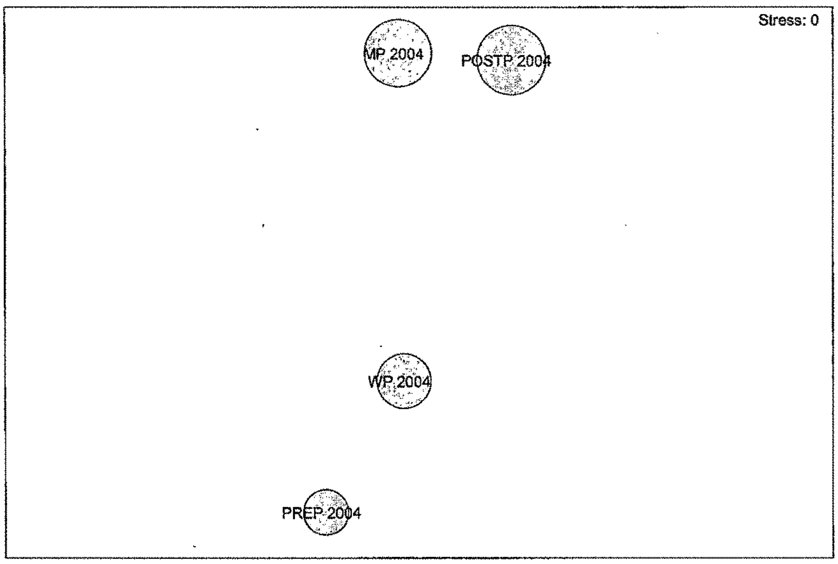


Figure 3.13. Non metric MDS ordination plot showing similarities between samples during various seasons after none transformation. Bubbles show the relative size of plankton population during different seasons at Veraval.

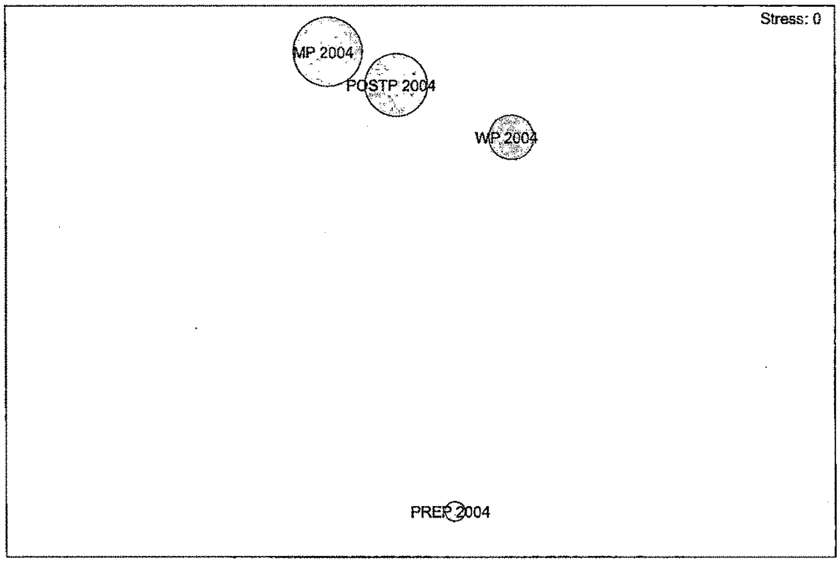
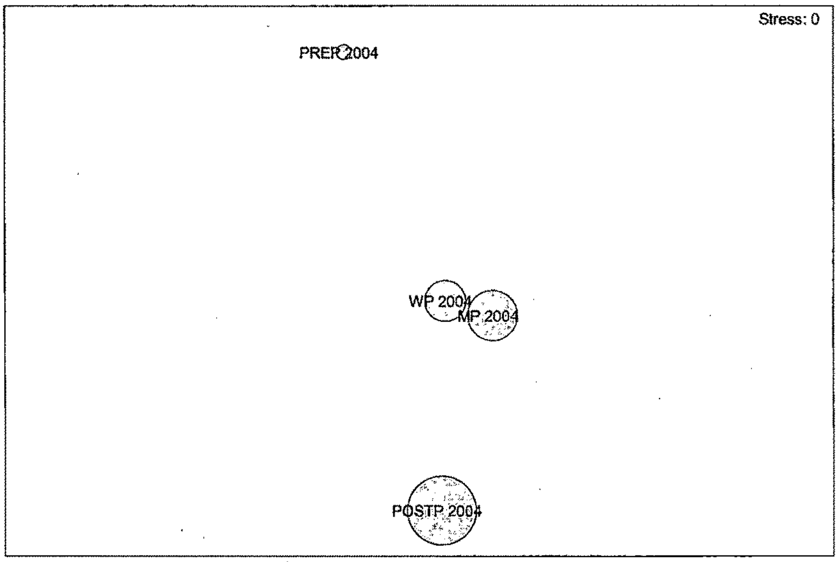
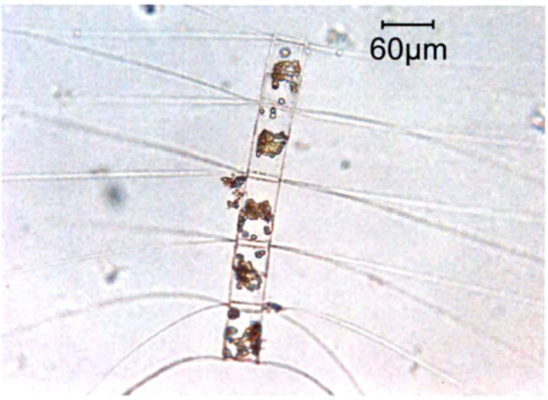
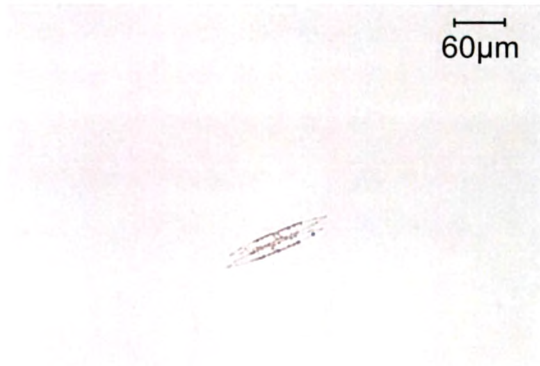


Figure 3.14. Non metric MDS ordination plot showing similarities between samples during various seasons after none transformation. Bubbles show the relative size of plankton population during different seasons at Alang



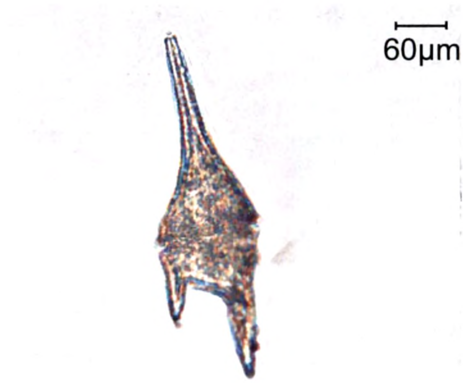


Chetocerous sp.

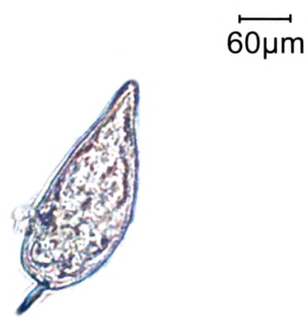


Nitzachia sp.

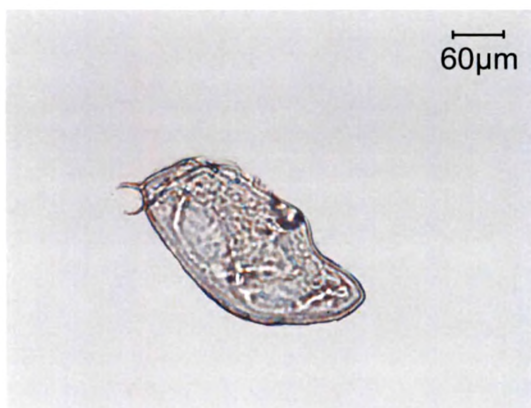
Peridinium sp.



Ceratium sp.

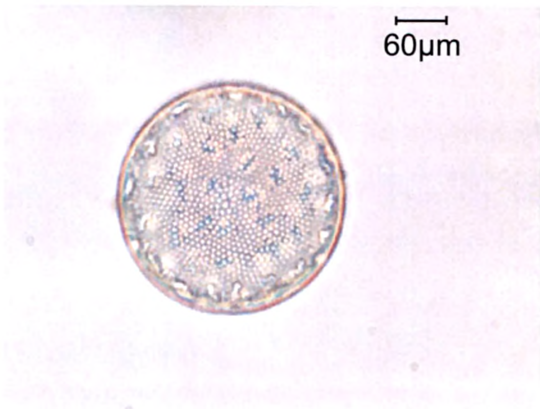


Prorocentrum sp.

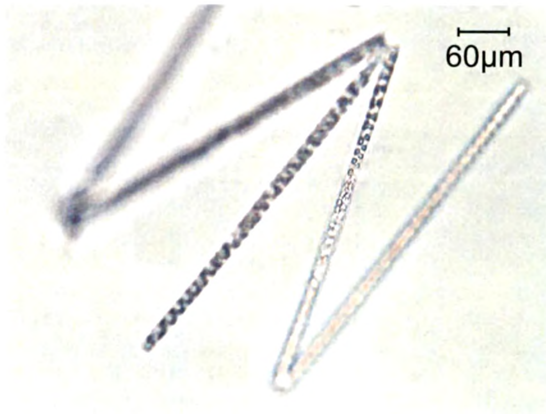


Dinophysis sp.

Figure 3.15 Few representatives of phytoplankton species recorded at Saurashtra coast



Coscinodiscus sp.



Thalossiothrix sp.

Biddulfia sp.

Figure 3.16 Few representatives of phytoplankton species recorded at Saurashtra coast