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Biodiversity in the occurrence of different species of phytoplankton along the Chennai coast

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ABSTRACT

Phytoplankton is the major food of zooplankton and small pelagic occurring along the Chennai coast. The distribution of phytoplankton vary from place to place and the occurrence of different species decides the biodiversity of the ecosystem. This paper describes the occurrence and the characteristics of most common phyto organisms along the Chennai coast using primer 6.0 software. The phytoplankton distribution consists of dissolved volume, *Ceratium species, Navicula, Bidulphia, Nitzschia, Gyrosigma* and *Chlorella* during the year'2011. The occurrence of the phytoplankton, *Chaetoceros*, 38.01%, followed by *Thalasirrothrix* is 11.95%, *Nitzschia* is 8.94%, *Navicula*, 8.19%, *Gyrosigma* is 7.22%, *Bidulphia* is 6.57%, *Coscinodiscus*, 5.85%, *Pleurosigma*, 5.81%, *Ceratium* species, 4.58%, *Chlorella* is 2.74% and dissolved volume is 0.03% of the total phytoplankton distribution. The primer graphs for eclidean distance of different months for different species of phytoplankton were drawn. From the bray Curtis similarity graph it is evidenced that the distribution of phytoplankton component. *Chaetocerus* is far from the other species since its occurrence is more during the month of Jan'11. From the similarity graph, it is found that *Chaetoceros* and *Coscinodiscus* are closely related, *Ceratium* species and *Pleurosigma* are closely related, *Navicula* and *Bidulphia* are closely related. The occurrence of *Chlorella* is not closely related to any species. Bubble plots displays the individuals species abundances in relation to the overall community pattern. Funnel graphs are drawn for the number of phytoplankton. As the temperature increases during the summer month the phytoplankton decreases. The environmental variables, temperature, pH, salinity, TSS, TDS, dissolved oxygen, chlorophyll a, b and c, primary productivity, gross and net, nutrients, phosphate and ammonia vary significantly with the phytoplankton occurrence. The correlation coefficient of occurrence of *Ceratium-Nitzschia* (0.78), *Ceratium- Thalassirothrix*-(0.98), *Ceratium-Pleurosigma* (0.90), *Navicula-Bidulphia* (0.57), *Navi cula-Nitzscia* (0.10), *Navicula -Gyrosigma* (0.95), *Navicula-Chaetoceros* (0.93), *Navicula- Coscinodiscus* (0.57), *Navicula-Pleurosigma* (0.19), *Bidulphia-Nitzschia* (0.50), *Bidulphia - Gyrosigma* (0.31), *Bidulphia- Chaetoceros* (0.25), *Bidulphia- Coscinodiscus* (0.94), *Nitzschia-Thalassirothrix* (0.82), Nitzschia-*Coscinodiscus*(0.34), *Nitzschia-Pleuro -sigma* (0.64), *Gyrosigma-Chaetoceros* (0.99), *Gyrosigma-Coscinodiscus* (0.33), *Gyro sigma-Pleurosigma* (0.26), *Chaetoceros-Coscinodiscus* (0.26), *Chaetoceros –Pleurosigma* (0.30), *Gyrosigma-Chlorella* (0.09), *Chaetoceros-Chlorella* (0.05). The species richness, d varies from 0-2.40, Pielous's index of evenness (*J*') varies from 0-0.97, Shannon–Wiener's diversity index (*H*'), 0-2.32, simpson's dominance index, ≤, 0-0.9. The species richness, species evenness, species diversity and dominance index are all significant at $p \le 0.05$. The correlation between the environmental variables and the phytoplankton species distribution were worked out.

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Key words : *Environmental variables, Phytoplankton, Chennai coast, Biodiversity, Correlation, Species evenness*

Introduction

The flora and fauna of the diverse ecosystem like Chennai coast is changing and has to be monitored for the occurrence of certain species of phytoplankton. The most common phytoplankton of Chennai coast includes dissolved volume, *Ceratium, Navicula, Bidulphia, Nitzschia, Gyrosigma and Chlorella* species during the year 2011. The distribution among the months is diverse. These phytoplankton forms the food material for the zooplankton and thus forms the important component of the food web of the fishes. The natural occurance of these phytoplankton species and its correlation with other species occurrence were studied. These species occurrence is highly dependant on the hydrographic parameters like temperature, salinity, pH, dissolved oxygen, chlorophyll, a, b & c, primary productivity, gross, net, nutrients nitrate and ammonia. (Wen Tseng Lo, 2012). The most productive phytoplankton in number were correlated with these hydrographic parameters and its level of correlation were worked out. These correlations among months and among species are given in primer graphs as similarity graph, bubble plots and funnel graphs for easy understanding of the ecosystem. The species richness, species evenness, species diversity and dominance index were worked out individually for each species and its level of significance at $p \leq 0.05$ significance was worked out.

Materials and Methods

The seawater samples were collected at equal intervals between months and stored in lab for analysis in the electron microscope. The electron microscope used was (Model.N1X Halogen) Lamp, 6V, 20W. Rating, 220-240V, 50- 60Hz, 0.4A. The analysis software used was Primer 6.0. The samples were counted in the counting chamber. The temperature was measured using thermometer, hydrographic variables, salinity was measured using salinometer, pH using pH meter, total soluble solids were measured using tss meter, dissolved oxygen using dometer, chlorophyll a, b and c were measured using spectrophotometer, primary productivity were measured using dark bottle method, nutrients, phosphate and ammonia were measured spectrophotometer. Spss

16.0 package was used. Microsoft Excel was used for the graphical presentation and correlation analysis. In Primer 6.0 software the data was transformed using log(n) to normalize the data for homogenization of residual variances and then bray Curtis similarity matrix graphs were drawn for the species. The similarity of species composition of phytoplankton was analysed by Bray Curtis similarity analysis based on a similarity matrix of fourth root transformed abundance(Bray and Curtis,1957) Non-Metric multi-dimen - sional scaling (MDS) was also used to provide a two-dimensional (2D) visual repre - sentation of assemblage structure (Kruskal and Wish, 1978). Statistical significance was determined at $\alpha = 0.05$. Dendrograms of station associations by Bray–Curtis similarity analysis based on similarity matrix of fourth root-transformed abundance. The dendro - grams from the cluster analyses divided into four groups at a similarity level of ~20% for 12 months.

Results and Discussion

Correlation between hydrographic variables: The hydrographic variables of temperature, salinity, pH, dissolved oxygen, total soluble solids, chlorophyll a, b & c primary productivity, gross, net and nutrient nitrate and ammonia are interrelated with each other and the pearson correlation coefficient was worked out. Temperature with salinity (0.46), temperature with pH (-0.59), temperature with dissolved oxygen (0.56), temperature with total soluble solids (0.41), temperature with chlorophyll a(-0.01), temperature with chlorophyll b(-0.01), temperature with chlorophyll c (-0.04), temperature with primary productivity, gross (-0.15), temperature with primary productivity, net (- 0.12), temperature with nutrient nitrate (-0.33) and temperature with nutrient ammonia (-0.13). Salinity with pH (-0.32), salinity with dissolved oxygen (0.62), salinity with total soluble solids (0.55), salinity with chlorophyll a (-0.61), salinity with chlorophyll b(-0.60), salinity with chlorophyll c(-0.62), salinity with primary productivity, gross (-22), salinity with primary productivity, net (-0.00), salinity with nutrient, nitrate (-0.26) and salinity with nutrient ammonia (-0.03). pH with dissolved oxygen (-0.37), pH with total soluble solids(-42), pH with chlorophyll a (0.03), pH with chlorophyll b (0.10), pH with chlorophyll c (0.09),pH with primary productivity, gross (0.27), pH with primary productivity, net(0.16), pH with nutrient nitrate(0.31) and pH with nutrient ammonia. (0.56), dissolved oxygen with total soluble solids(0.46), dissolved oxygen with chlorophyll a (0.10), dissolved oxygen with chlorophyll b (0.068), dissolved oxygen with chlorophyll c (0.04), dissolved oxygen with primary productivity, gross(0.15), dissolved oxygen with primary productivity, net (0.23), dissolved oxygen with nutrient nitrate (-0.30) and dissolved oxygen with nutrient ammonia (-0.22), total soluble solids with chlorophyll a (0.26), tss with chlorophyll b (-0.31), tss with chlorophyll c (-0.29), tss with primary productivity, gross (-0.21),tss with primary productivity, net (0.15), tss with nutrient nitrate (-0.22), tss with nutrient ammonia (-0.16), chlorophyll a with chlorophyll b (0.98), chlorophyll a with chlorophyll c (0.98), chlorophyll a with primary productivity, gross (0.40), chlorophyll a with primary productivity, net (0.29), chlorophyll a with nutrient nitrate (-0.02) and chlorophyll a with nitrate ammonia (-0.01), chlorophyll b with chlorophyll c (0.99), chlorophyll b with primary productivity, gross (0.40), chlorophyll primary productivity, net (0.32), chlorophyll b with nutrient nitrate(0.07) and chlorophyll b with nutrient ammonia (0.01) chlorophyll c with primary productivity, gross (0.39), chlorophyll c with primary productivity, net(0.31),chlorophyll c with nutrient nitrate (0.12) and chlorophyll c with nutrient ammonia (-0.03), primary productivity, gross with primary productivity, net (0.61), primary productivity, gross with nutrient nitrate (-0.01) and primary productivity with nutrient ammonia (0.23), primary productivity, net with nutrient nitrate (0.00) and primary productivity with nutrient ammonia (0.43), nutrient nitrate with nutrient ammonia (0.22). Chlorophyll a, b and c differences are non significant and all other hydrographic variables including temperature, salinity, pH, dissolved oxygen, total soluble solids, primary productivity, gross and net and nutrient, nitrate the differences are significant among months at 5% level of significance. Eucledian distance distribution for the months with respect to hydrographic variables is shown in primer graph. (Fig. 1). The Eucledian distance distribution for the various hydrographic variables is shown in Fig. 2.

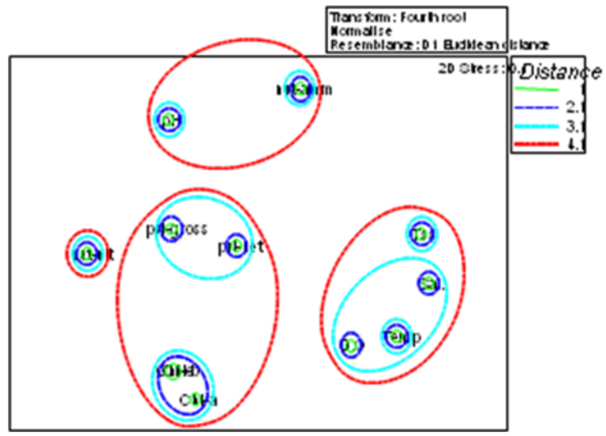

Fig. 2. Eucledian distance distribution for the hydrographic variables

Correlation among species: The selected species and its occurrence correlation is discussed. The positive correlation coefficient exist between C*eratium and Nitzschia* (0.78), *Ceratium sp.* and *Thalassirothrix* (0.98), *Ceratium* and *Pleurosigma* (0.90), *Navicula* and *Bidulphia* (0.57), *Navicula and Nitzschia* (0.10), *Navicula* and *Gyro sigma* (0.95), *Navicula* and *Chaetocerus*

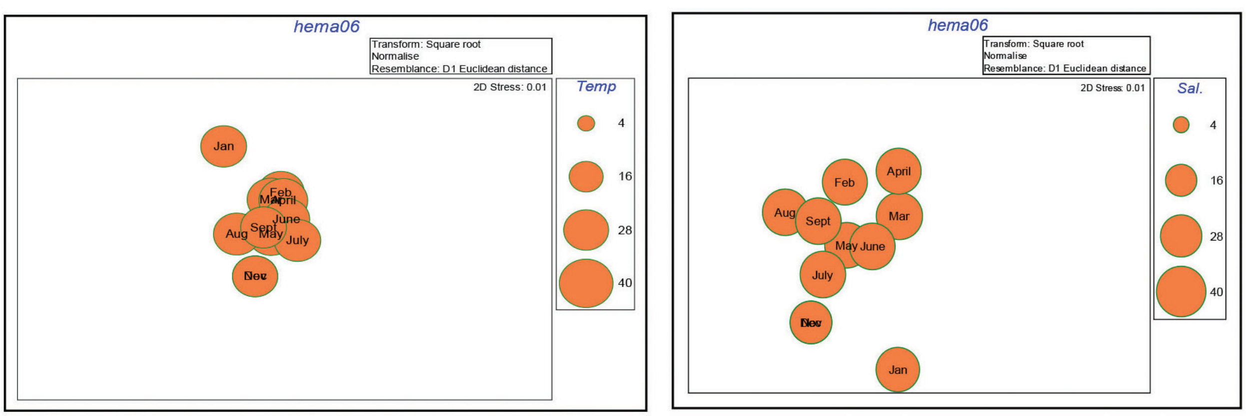

Fig. 1. Eucledian distance distribution for the months with respect to hydrographic variables

(0.93*), Navicula and Coscino discus* (0.57) and *Navicula and Pleurosigma* (0.19), *Bidulphia* and *Nitzschia*(0.50), *Bidulphia and Gyrosigma (*0.31), *Bidulphia* and *Chaet -ocerus* (0.25), *Bidulphia* and *Coscinodiscus (*0.94), *Nitzschia and Thalassirothrix* (0.82), *Nitzschia* and *Coscinodiscus* (0.34), *Nitzschia* and *Pleuro sigma* (0.64), *Gyrosigma* and *Chaetocerus (*0.99), *Gyrosigma – Coscinodiscus* (0.33), *Gyro sigma-Chaetocerus*(0.99), *Gyrosigma-Coscinodiscus* (0.33*), Gyrosigma-Pleurosigma* (0.26), *Gyro sigma-Chlorella* (0.09), *Thalasirr-othrix-Pleurosigma* (0.97), *Chaetocerus-Coscinodiscus* (0.26), *Chaetocerus -Pleurosigma* (0.30), *Chaetocerus-Chlorella* (0.05). The negative correlation between species were alo worked out for the year 2011 along Chennai coast. *Ceratium sp. –Navicula* (-0.13),*Ceratium sp.-Bidulphia*(-0.10),*Ceratium sp.-Gyrosigma(*- 0.11*), Ceratium sp. – Chaetocerus* (0.07), *Ceratium sp.-Coscinodiscus* (-0.23),*Ceratiumsp.- Chlorella* (-0.21), *Navicula-Thalassirothrix* (-0.14), *Navicula–Chlorella* (-0.00*), Bidulphia-Thalassirothrix* (0.06), *Bidulphia - Pleurosigma* (-0.10), *Bidulphia-Chlorella* (0.05), *Nitzschia-Gyrosigma* (-0.04),*Nitzschia-Chaetocerus* (-0.05), *Nitzscia-Chlorella*(-.13), *Gyrosigma-Thalassir othrix* (0.19), *Thalassirothrix-Chaetocerus* (-0.12), *Thalassiro thrix- Coscinodiscus* (-0.19), *Thalassirothrix-Chlorella* (-0.10), *Coscino -discus-Pleuro sigma* (- 0.17), *Coscinodiscus-Chlorella* (0.02), *Pleurosigma –Chlorella* (-003). The differences in dispersed volume, Ceratium species, *Bidulphia, Nitzschia, Thalassirothrix, Coscinodiscus, Pleuro sigma* and *Chlorella* are non significant among months at 5% level of significance. The differences in *Navicula, Gyrosigma* and *Chaetocerus* are significant among months at 5% level of significance. The differences in dispersed volume, *Ceratium* species, *Bidulphia, Nitzschia, Thalassirothrix, Coscinodiscus, Pleurosigma* and *Chlorella* are non significant among months at 5% level of significance. The differences in *Navicula, Gyrosigma* and *Chaetocerus* are significant among months at 5% level of significance. Species distribution for the month of Jan'11 and Dec'11 in the Bray Curtis similarity graph in primer software. (Fig. 3).

Correlation between species and hydrographic variables: The environmental variables are correlated with the different species. The positive correlation exists between dispersed volume and salinity(0.07), dispersed volume and dissolved oxygen (0.11), dispersed volume and primary productivity, gross(0.19), *Ceratium species* and salinity (0.09), *Ceratium species* with dissolved oxygen(0.41), *Ceratium species* with total soluble solids(0.17), *Ceratium species* with chlorophyll a (0.10), *Ceratium species* with primary productivity, gross(0.09). *Navicula* with temperature (0.09), *Navicula* with salinity (0.20), *Navicula* with total soluble solids(0.13), *Navicula* with nutrient nitrate (0.39). B*idulphia* with salinity(0.07), *Bidulphia* with pH(0.07), *Bidulphia* with dissolved oxygen(0.05), *Bidulphia* with total soluble solids(0.02), *Bidulphia* with chlorophyll b (0.01), *Bidulphia* with chlorophyll c (0.07), *Bidulphia* with nutrient nitrate (0.812). *Nitzschia* with salinity (0.042), *Nitzschia* with dissolved oxygen (0.41), *Nitzschia* with total soluble solids(0.19), *Nitzschia* with chlorophyll a (0.06), *Nitzschia* with primary productivity, gross (0.01) *Gyrosigma* with temperature (0.208), *Gyrosigma* with salinity(0.31), *Gyrosigma* with tss (0.18) and *Gyro sigma* with nutrient nitrate (0.15).*Thalassirothrix* with temperature (0.00), *Thalassirothrix* with salinity(0.14), *Thalassirothrix* with dissolved oxygen(0.45), *Thalassirothrix* with total dissolved solids (0.18), *Thalassirothrix* with chlo-

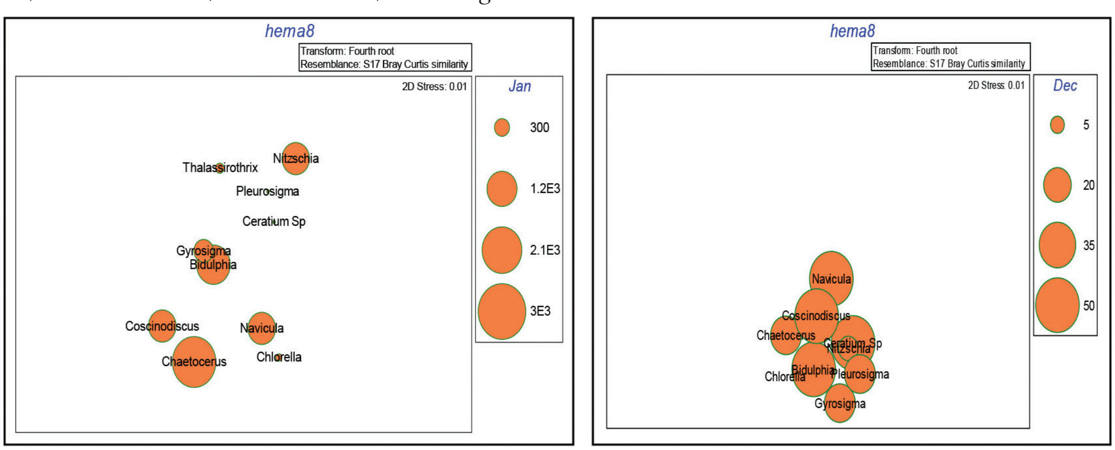

Fig. 3. Species distribution for the month of Jan'11 and Dec'11 in the Bray Curtis similarity

rophyll a (0.03), *Thalassirothrix* with primary productivity, gross (0.06). *Chaetoerus* with temperature (0.23), *Chaetocerus* with salinity (0.32), *Chaetocerus* with total soluble solids(0.20), *Chaetocerus* with nutrient nitrate(0.08), *Coscinodiscus* with salinity (0.03), *Coscinodiscus* with dissolved oxygen (0.077), *Coscinodiscus* with chlorophyll b (0.00), *Coscinodiscus* with chlorophyll c (0.05), *Coscinodiscus* with nutrient nitrate (0.83).

Pleurosigma with temperature (0.09), *Pleurosigma* with salinity (0.29), *Pleurosigma* with dissolved oxygen (0.40), *Pleurosigma* with total soluble solids(0.20), *Pleurosigma* with primary productivity, gross (0.00) *Chlorella* with temperature (0.09), *Chlorella* with salinity (0.36), *Chlorella* with pH (0.44), *Chlorella* with dissolved oxygen (0.15), *Chlorella* with primary productivity, gross (0.06), *Chlorella* with primary productivity, net (0.01), *Chlorella* with nutrient nitrate (0.07) and *Chlorella* with nutrient ammonia (0.26). The environmental variables are correlated with the different species. The negative correlation exists between dispersed volume and temperature (0.39), dispersed volume and pH (-0.10), dispersion volume and tss (0.01), dispersed volume and chlorophyll b (-0.01), dispersed volume and chlorophyll c(-0.00), dispersed volume with primary productivity, net (-0.08), dispersed volume with nutrient, nitrate (-0.28), dispersed volume and nutrient ammonia (0.17). Ceratium species with temperature (0.00), *Ceratium* species with pH (-0.37), *Ceratium* species and chlorophyll b (-0.04), *Ceratium* species with chloro -phyll c (-0.05), *Ceratium* species with primary productivity, net (-0.15), *Ceratium* species with nutrient nitrate (-0.60), *Ceratium* species with nutrient ammonia (-0.17). *Navicula* with pH(-0.47), Navicula with dissolved oxygen (-0.04), *Navicula* with chlorophyll a (0.07), *Navicula* with chlorophyll b (-0.06), *Navicula* with chlorophyll b (-0.05), *Navicula* with chlorophyll c (-0.02), *Navicula* with primary productivity, gross (-0.27), *Navicula* with primary productivity, net(-0.27), *Navicula* with nutrient ammonia (-0.35). Bidulphia with temperature (-0.190), Bidulphia with salinity(0.06), Bidulphia with pH (-0.11), *Bidulphia* with chlorophyll a (-0.00), *Bidulphia* with primary productivity, gross(-0.12), *Bidulphia* with primary productivity, net(-0.09), *Bidulphia* with nutrient ammonia (-0.86). Nitzschia with temperature (-0.09), Nitzschia with pH (-0.30), *Nitzschia* with chlorophyll b (-0.05), *Nitzschia* with chlorophyll c (-0.02), *Nitzschia* with primary productivity, net (-0.12), Nitzschia with nutrient ammonia (-0.63), *Nitzschia* with nutrient ammonia (-0.33). *Gyrosigma* with pH (0.01), Gyrosigma with dissolved oxygen (-0.01), *Gyrosigma* with chlorophyll a (-0.09), *Gyrosigma* with chlorophyll b (-0.07), *Gyrosigma* with chlorophyll c(-0.05), *Gyrosigma* with primary productivity, gross (0.22), *Gyrosigma* with primary productivity, net(-0.23), *Gyrosigma* with nutrient ammonia(-0.18), Thalassirothrix with pH(0.31), *Thalassirothrix* with chlorophyll b (-0.11), *Thalassirothrix* with chlorophyll c (- 0.11), *Thalassirothrix* with primary productivity, net (-0.17), *Thalassirothrix* with nutrient ammonia (-0.18), *Chaetocerus* with pH (-0.52), *Chaetocerus* with dissolved oxygen (0.01), *Chaetocerus* with chlorophyll a (-0.10), *Chaetocerus* with chlorophyll b (-0.10), *Chaetocerus* with chlorophyll c (-0.08), *Chaetocerus* with primary productivity, gross(- 0.27), *Chaetocerus* with primary productivity, net(-0.29), *Chaetocerus* with nutrient ammonia (-0.37). *Coscinodiscus* with pH (0.02), *Coscinodiscus* with tss (0.06), *Coscino discus* with Chlorophyll a (-0.04), *Coscinodiscus* with primary productivity, gross(-0.19), *Coscinodiscus* with primary productivity, net (-0.16) and *Coscinodiscus* with nutrient ammonia (-0.75).*Pleurosigma* with pH (-0.55), Pleurosigma with chlorophyll a (0.134), *Pleurosigma* with chlorophyll b(-0.13), *Pleruosigma* with chlorophyll c (-0.14), *Pleuro sigma* with primary productivity, net(-0.21), Pleurosigma with nutrient nitrate (0.60), *Pleurosigma* with nutrient ammonia (-0.22), Chlorella with tss (0.08),*Chlorella* with chlorophyll a(-0.24), *Chlorella* with chlorophyll b (-0.18), *Chlorella* with chlorophyll c (- 0.21). All correlation are significantly different from each other. Species distribution of the correlation matrix of the species and the hydrographic variables, temperature and salinity in the primer graph (Fig. 4).

Correlation between diversity indices and hydrographic variables: The diversity indices include total species(S), total individuals (N), species richness(d), Shannon's index(H'), (Shannon. C.E. and Weaver, 1963), Simpson's dominance index, (1-ë) and Pielou's evenness index (J') (Omori and Ikeda, 1984). The total species and its correlation with the environmental parameters are as follows, S with Temperature (-0.17),S with salinity(-0.11),S with pH(0.14), S with dissolved oxygen(-0.19), S with tss(-0.18), S with chlorophyll a(0.12), S with chlorophyll b (0.18), S with chlorophyll c (0.19), S with primary productivity, gross (0.27), S with primary productivity, net(0.204), S with nutrient, nitrate(0.026) and S with nutrient, ammonia(0.12).N

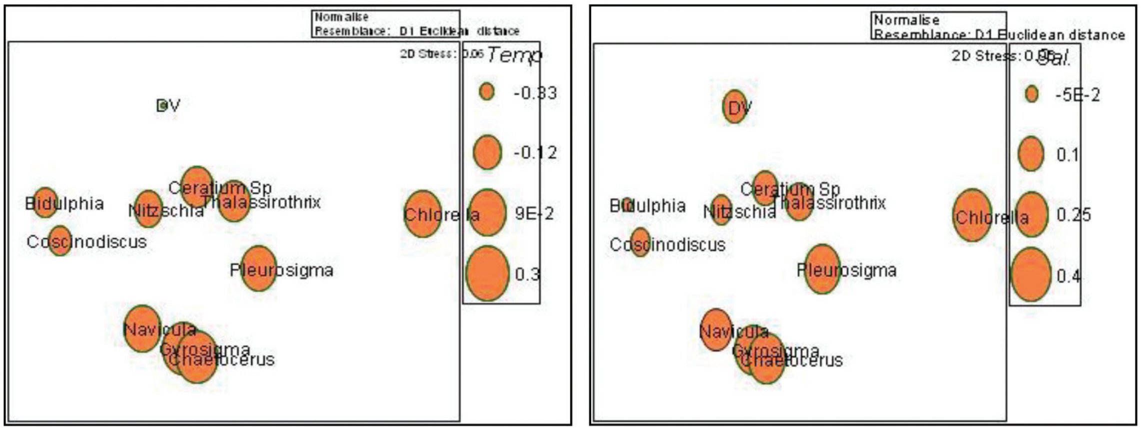

Fig. 4. Species distribution of the correlation matrix of species and hydrographic variables

with temperature (0.21), N with salinity (0.28), N with pH (0.14), N with dissolved oxygen (0.260), N with tss (0.25), N with chlorophyll a(-0.02), N with chlorophyll b(-0.06), N with chlorophyll c (-0.02), N with primary productivity, gross (-0.06), N with primary productivity, net(-0.20), N with nutrient nitrate (0.30), N with nutrient, ammonia (-0.26).d with temperature (-0.30), d with salinity (- 0.26), d with pH(0.043), d with dissolved oxygen (-0.34), d with tss(-0.31), d with chlorophyll a (0.13), d with chlorophyll b (0.20), d with chlorophyll c(0.20), d with primary productivity, gross(0.28), d with primary productivity, net (0.24), d with nutrient, nitrate(- 0.12) and d with nutrient ammonia (0.156). J′ with temperature (-0.24),J′ with salinity(- 0.16), J′ with pH (0.07), J′ with Dissolved oxygen(-0.19), J′ with tss(-0.21), J′ with chlorophyll a (0.12), J′ with chlorophyll b (0.13), J′ with chlorophyll c (0.14), J′ with primary productivity, gross (0.30), J′ with primary productivity, net (0.14), J′ with nutrient nitrate (-0.09) and J′ with nutrient ammonia(0.11). H′ with temperature (-0.23), H′ with salinity (-0.16),H′ with pH (0.10),H′ with dissolved oxygen (-0.22), H′ with tss (-0.22), H′ with chlorophyll a (0.13), H′ with chlorophyll b(0.17), H′ with chlorophyll c(0.18), H′ with primary productivity, gross(0.30), H′ with primary productivity, net (0.20), H′ with nutrient nitrate(-0.05) and H with nutrient ammonia (0.15). λ with temperature (-0.23), λ with salinity (-0.15), λ with pH(0.078), λ′ with dissolved oxygen(-0.20), λ with tss(- 0.20), λ′ with chlorophyll a (0.120), λ′ with chlorophyll b (0.13), λ′ with chlorophyll, c (0.14), λ′ with primary prod -uctivity, gross(0.28), λ′ with primary productivity, net (0.13), λ′ with nutrient nitrate (0.07) and λ with nutrient ammonia (0.09). Correlation between temperature, salinity, dissolved oxygen, total soluble solids, Primary productivity, net nutrient nitrate and nutrient ammonia with diversity indices are non significant and all other hydrographic variables with diversity indices are significant ($p \leq 0.05$). Euledian distance of the diversity indices for the month of Jan'11 and Feb'11 in the primer bubble plot graph. (Fig. 5).

Correlation among diversity indices and species: The correlation coefficient between diversity indices and the distribution of species were worked out. S with dispersed volume (0.32), S with *Ceratium* species (-0.27), S with *Navicula* (0.10), S with *Bidulphia* (0.18), S with *Nitzschia* (-0.16), S with *Gyrosigma* (0.07),S with *Thalassirothrix* (-0.28), S with *Chaetocerus* (0.02), S with *Coscinodiscus* (0.30), S with *Pleuro sigma* (-0.23) and S with *Chlorella* (0.24). N with Dispersed volume (0.65), N with *Ceratium* Species (0.28), N with *Navicula* (0.83), N with *Bidulphia* (0.62), N with *Nitzschia* (0.52), N with *Gyrosigma* (0.76), N with *Thalassirothrix* (0.26), N with *Chaetocerus* (0.73), N with *Coscinodiscus* (0.60), N with *Pleurosigma* (0.50) and N with *Chlorella* (0.12).D with dispersed volume(0.19), d with *Ceratium* species (-0.33), d with *Navicula* (-0.10), d with *Bidulphia* (0.00), d with *Nitzschia* (-0.30), d with *Gyrosigma* (-0.12), d with *Thalassirothrix* (- 0.35), d with *Chaetocerus* (-0.156), d with *Coscinodiscus* (0.12), d with *Pleurosigma* (- 0.35), d with *Chlorella*(0.16).J with dispersed volume(0.59), J with *Ceratium* species (0.07), J with *Navicula* (-0.00), J with *Bidulphia* (0.049), J with *Nitzschia* (0.05), J with *Gyrosigma* (-0.00), J with *Thalassirothrix* (0.05),J with *Chaetocerus* (-0.03), J with *Coscinodiscus* (0.11), J with *Pleurosigma* (0.05) and J with *Chlorella* (0.24). H with

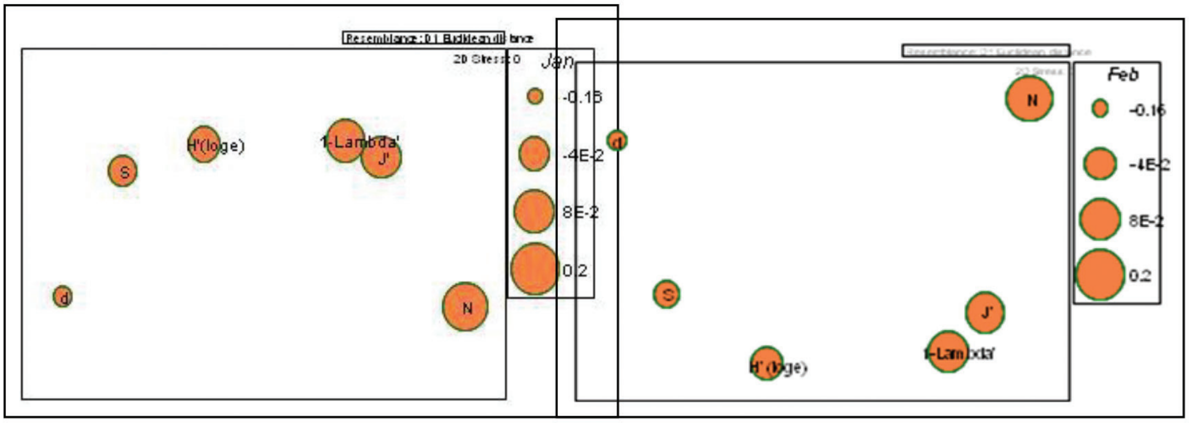

Fig. 5. Eucledian distance of the diversity indices for the months Jan'11 and Feb'11

dispersed volume (0.41), H with *Ceratium* species (-0.14), H with *Navicula* (0.01), H with *Bidulphiac* (0.07), H with *Nitzschia*(-0.11), H with *Gyrosigma*(-0.02), H with *Thalassir - othrix*(-0.16), H with *Chaetocerus* (-0.06) , H with *Coscinodiscus*(0.16), H with *Pleurosigma* (-0.15) and H with *Chlorella*(0.24). λ with dispersed volume (0.56), λ with *Ceratium* species(0.01), λ with *Navicula* (0.04), λ with *Bidulphia* (-0.10), λ with *Nitzschia* (0.04), λ with *Gyrosigma*(0.03), λ with *Thalassirothrix* (0.00), λ with C*haetocerus*(-0.00), λ with *Coscinodiscus* (0.17), λ with *Pleurosigma* (0.01) and λ with *Chlorella* (0.25). S, N, d, J, H and λ are significantly different among different species at 5% level of significance. *Chaetocerus* and *Coscinodiscus, Navicula* and *Bidulphia, Ceratium* species and *Pleuro sigma* are closely correlated, J, H and λ are significantly different at $p \leq 0.05$ and d with N and N with S are non significant $p \geq 0.05$. These diversity indices are shown in the similarity graph using Bray Curtis similarity graph in primer software. (Fig. 6)

Correlation among hydrographic variables and months with respect to species: Temperature with Jan(0.45), temp. with Feb(0.01), temp. with Mar(0.03) ,temp with May(- 0.08), temp. with June(-0.15), temp. with July(-0.45), temp. with Aug(-0.19), temp. with Sep(-0.18), temp. with Oct(0.02),temp. with Nov(0.35), temp. with Dec(0.51).Salinity with Jan(0.49), sal. with Feb(0.02), sal. with Mar(0.26), sal. with May(0.04), sal. with June(0.27), sal. with July(-0.10), sal. with Aug(-0.48), sal. with Sep(0.04), sal. with Oct(0.37), sal. with Nov. (0.04) and sal. with Dec.(0.47). pH with Jan(-0.13), pH with Feb(0.38), pH with Mar(0.09), pH with May(0.54), pH with June(-0.22), pH with July(- 0.40), pH with Aug(0.39), pH with Sept.(0.45), pH with Oct.(-0.00), pH with Nov(-0.59) and pH with Dec (-0.72). dissolved oxygen with Jan(0.21), dissolved oxygen with Feb(0.23),

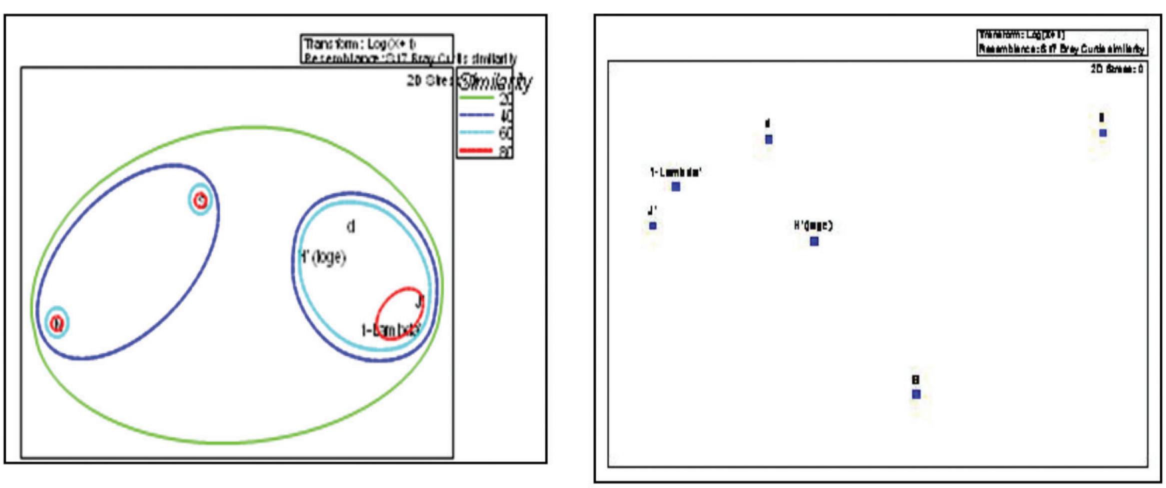

Fig. 6. Diversity indices in a similarity graph using Bray Curtis similarity

dissolved oxygen with Mar (0.18), dissolved oxygen with May(-0.23), dissolved oxygen with June(0.24), dissolved oxygen with July(-0.49), dissolved oxygen with Aug(0.30), dissolved oxygen with Sept.(0.13), dissolved oxygen with Oct(0.55), dissolved oxygen with Nov. (0.09), dissolved oxygen with Dec. (0.52), tss with Jan(0.52), tss with Feb(0.60), tss with Mar(0.18), tss with May(0.55), tss with June(0.21), tss with July(-0.41), tss with Aug(-0.31), tss with Sept.(-0.464), tss with Oct. (0.24), tss with Nov. (0.11) and tss with Dec. (0.57), chlorophyll a with Jan(0.37), chlorophyll a with Feb.(0.12), chlorophyll a with Mar.(0.13), chlorophyll a with May (0.34), chlorophyll a with June(0.04), chlorophyll a with July(0.12), chlorophyll a with Aug (0.36), chlorophyll a with Sept.(0.12), chlorophyll a with Oct.(0.00), chlorophyll a with Nov.(0.37), chlorophyll a with Dec.(-0.02).chlorophyll b with Jan(-0.34), chlorophyll b with Feb. (0.13), chlorophyll b with Mar.(-0.12), chlorophyll b with May(-0.30), chlorophyll b with June(- 0.01), chlorophyll b with July(-0.06), chlorophyll b with Aug(0.36), chlorophyll b with Sept.(-0.10), chlorophyll b with Oct.(-0.08), chlorophyll b with Nov.(0.34), chlorophyll b with Dec. (-0.08).chlorophyll c with Jan(-0.352), chlorophyll c with Feb.(0.09), chlorophyll c with Mar. (-0.12), chlorophyll c with May(-0.34), chlorophyll c with June(- 0.03), chlorophyll c with July(-0.09), chlorophyll c with Aug(0.33), chlorophyll c with Sept.(-0.15), chlorophyll c with Oct.(-0.11), chlorophyll c with Nov.(0.32) and chlorophyll c with Dec. (-0.10), primary productivity, gross with Jan(0.32), primary productivity, gross with Feb.(0.11), primary productivity, gross with Mar.(0.73), primary productivity, gross with May(-0.02), primary productivity, gross with June (0.30), primary productivity, gross with July(-0.02), primary productivity, gross with Aug.(0.65), primary productivity, gross with Sept.(0.066), primary productivity, gross with Oct. (0.33), primary productivity, gross with Nov.(-0.06) and primary productivity, gross with Dec.(-0.18), primary productivity, net with Jan(0.45), primary productivity, net with Feb(-0.15), primary productivity, net with Mar(0.49), primary productivity, net with May(-0.33), primary productivity, net with June(0.84), primary productivity, net with July(0.31), primary productivity, net with Aug(0.42), primary productivity, net with Sept.(0.15), primary productivity, net with Oct.(0.07), primary productivity, net with Nov.(0.04) and primary productivity, net with Dec.(0.16),nutrient nitrate with Jan(-0.14), nutrient nitrate with Feb.(-0.17), nutrient nitrate with Mar.(0.01), nutrient nitrate with May(-0.05), nutrient nitrate with June(-0.23), nutrient nitrate with July(-0.11), nutrient nitrate with Aug. (-0.32), nutrient nitrate with Sept.(- 0.44), nutrient nitrate with Oct.(-0.73), nutrient nitrate with Nov.(-0.53) and nutrient nitrate with Dec.(-0.69). Among the environmental variables, pH with temperature and salinity, dissolved oxygen with pH, total soluble solids with pH, Chlorophyll a, b & c with pH, primary productivity, gross and net with pH, nutrient nitrate with pH and nutrient ammonia with pH are $p \geq 0.05$ at 5% level of significance. With respect to species, pH and salinity, Chlorophyll a with temperature, salinity, pH, dissolved oxygen, total soluble solids, Chlorophyll a, Chlorophyll b with temperature, pH, dissolved oxygen, total soluble solids, Chlorophyll c with temperature, pH, dissolved oxygen, total soluble solids, primary productivity, gross with temperature, salinity, pH, dissolved oxygen, total soluble solids, Chlorophyll a, primary productivity, net with tempera-

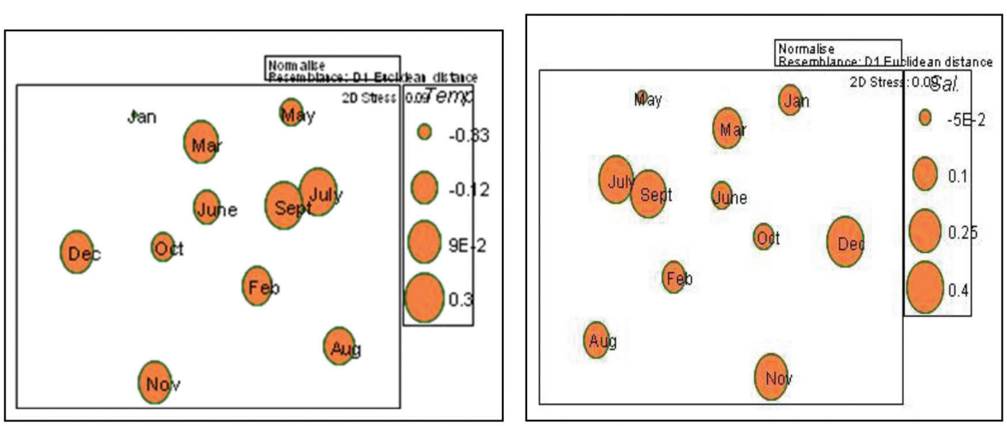

Fig. 7. Eucledian distance of the correlation among hydrographic variables and months with respect to species

ture, salinity, pH, dissolved oxygen, total soluble solids, and Chlorophyll a, nutrient nitrate with temperature, salinity, pH, dissolved oxygen, total soluble solids and Chlorophyll a, primary productivity, gross with Chlorophyll c, primary productivity, net with Chlorophyll b, c and primary productivity, gross, nutrient nitrate with Chlorophyll b, Chlorophyll c, primary productivity, gross and net are non significant at $p \geq 0.05$ level. Temperature, salinity, pH, DO, Tss, Chl-a, Chl-b, Chl-c are non significant and Pri-prod-gross, Pri-prod.-net, Nut.Nit and Nut. Amm are significant at 5% level of significance. Fig. 7 represents the eucledian distance of the correlation among the hydrographic variables and months with respect to species in the primer graph.

The overall correlation coefficient for Ennore is 0.18 and for CFH is 0.20 for environmental variables with marine phytoplankton. The primer graphs for eclidean distance of different months for different species of phytoplankton are drawn (Fig. 9).

Principal component analysis of the different species were done and eigen values were worked out (Table 2) Graphical representation for principal components were drawn to show the distribution of different species of phytoplankton (Fig. 14). The abundance and the biomass curves were drawn. (Fig. 11). The correlation between the environmental variables and the phytoplankton species distribution were drawn in primer 6 (Fig. 27). Bubble plots displays the individual species abundances in relation to the overall community pattern (Fig. 8). Funnel graphs are drawn for the number of phytoplankton (Fig. 10). The linkage between different sets of months, Jan-Mar, Aug-Sept, Nov-Dec and June-July were shown in similarity matrix. The months Sept, Oct, Nov and Dec are much different from Mar'11. The statistical significance at $p<0.05$ level was tested among the months and was non significant among the species tested. Bubble plot represents the volume/number of species distributed in every month in the form of bubble. The abundance and biomass curves for different kinds of phytoplankton are drawn and Weiner's index for all phytoplankton are worked out and ranges between 0.10-0.60. S, N, d, J and λ for different species of phytoplankton are given in Table 1. The species number in different months of 2011 along the Chennai coast are given in Fig.12, Ceratium species distribution during differ-

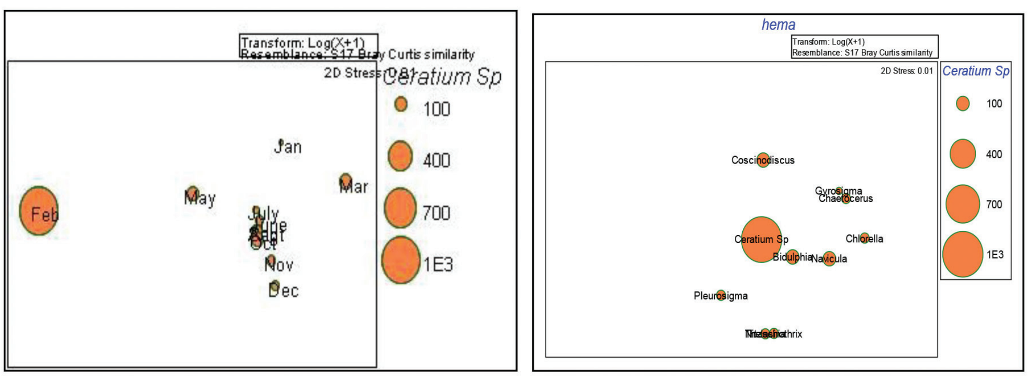

Fig. 8. Bubble plot distribution of *Ceratium* species of phytoplankton both monthwise and specieswise

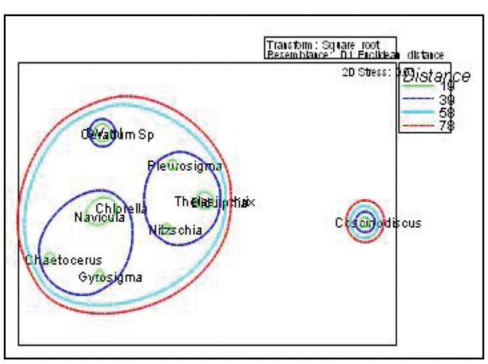

Fig. 9. Eclidean distance of Specieswise phytoplankton distribution at 4 intervals

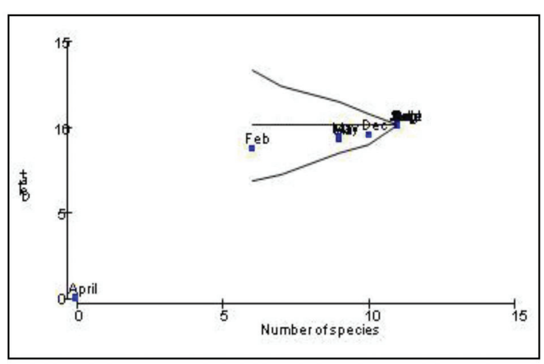

Fig. 10. Number of species distribution in funnel graph

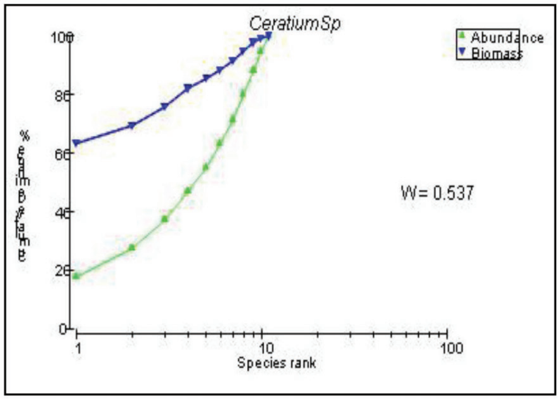

Fig. 11. Abundance and biomass curves for cumulative dominance and species rank

ent months (Fig. 13), species numbers during different months (Fig. 15), Diversity index for 12 months (Fig. 16), Number of individuals, N during different months (Fig. 17), Species richness, d during different months (Fig. 18), Evenness index, J during different months (Fig. 19), Simpson's dominance index, λ at different months (Fig. 20), species number, s of different species, (Fig. 21), Diversity index for 12 months (Fig. 22), Number of individuals, N during different months (Fig. 23), Species richness, d during different months (Fig. 24), Evenness index, J during different months (Fig. 25), Simpson's dominance index, λ at different months (Fig. 26).

Correlation among diversity indices and months with respect to hydrographic variables: S with Jan(-0.06), S with Feb.(-0.07), S with Mar. (-0.07), S with

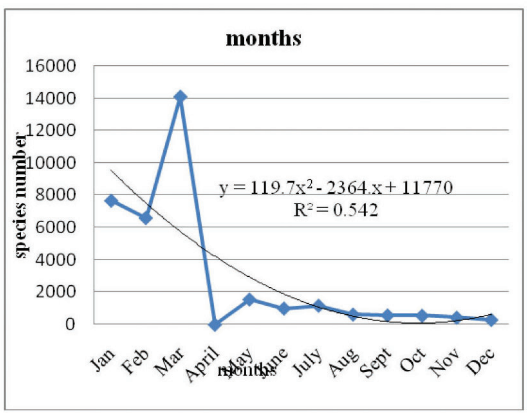

Fig. 12. Species number in different months of 2011 along Chennai coast

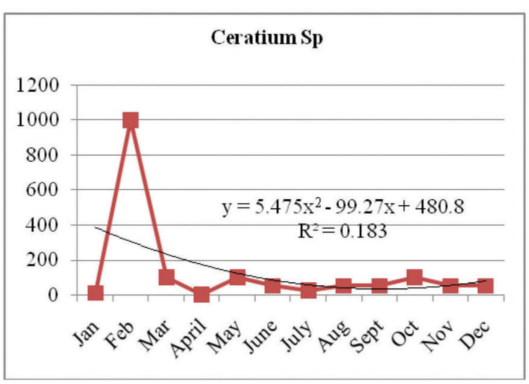

Fig. 13. *Ceratium* species distribution during and species different months

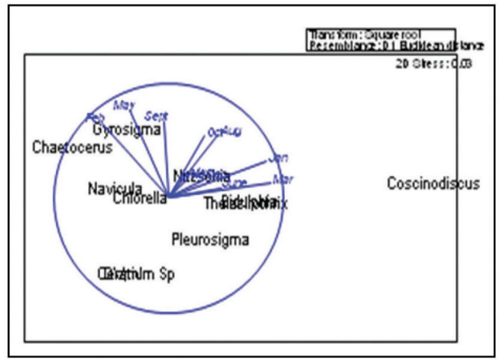

Fig. 14. PCA correlation graph for months

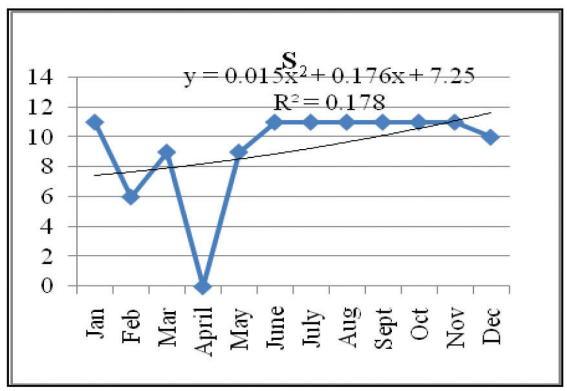

Fig. 15. S, species number during different months

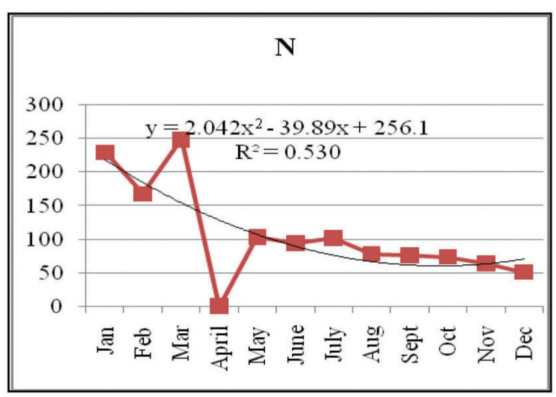

Fig. 16. Diversity index for 12 month

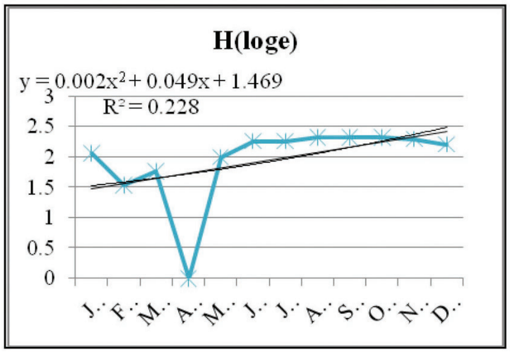

Fig. 17. Num. of indiv. N during diff. months

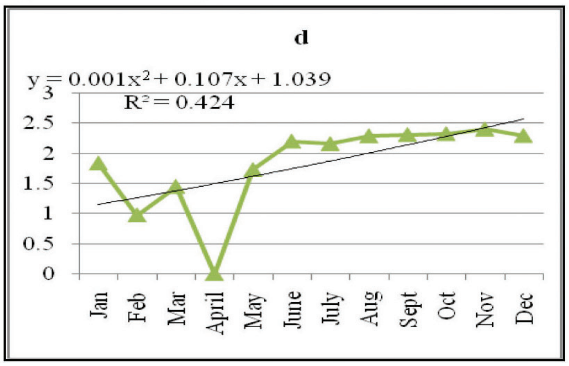

Fig. 18. Species richness, d during different

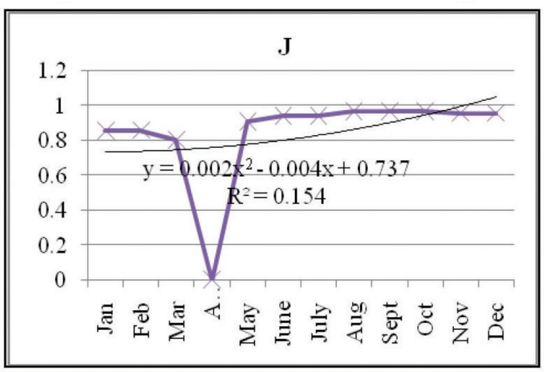

Fig. 19. Evenness index, J during different months

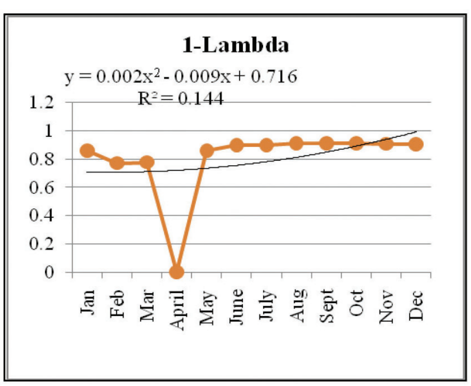

Fig. 20. Simpson's dominance index at different months

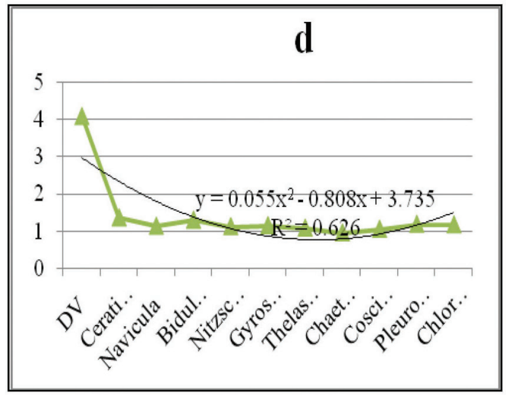

Fig. 21. S, species number of different species

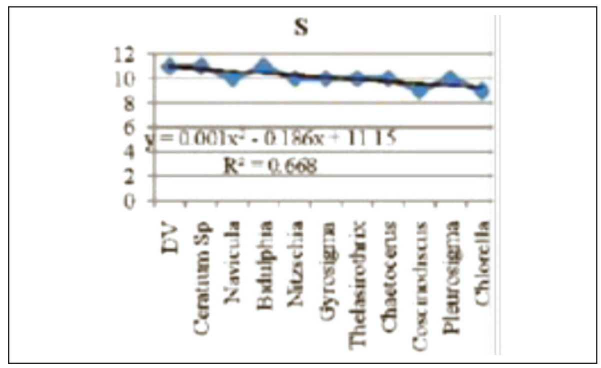

Fig. 22. d, species richness of different species

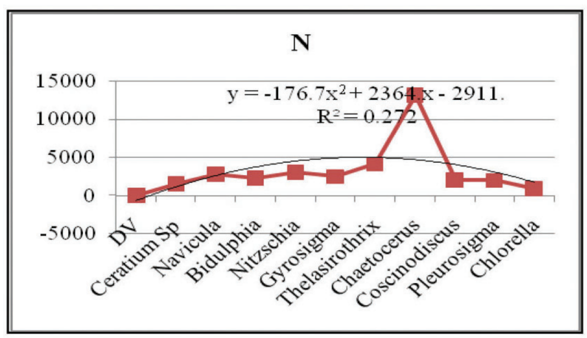

Fig. 23. Individual species, N of different species

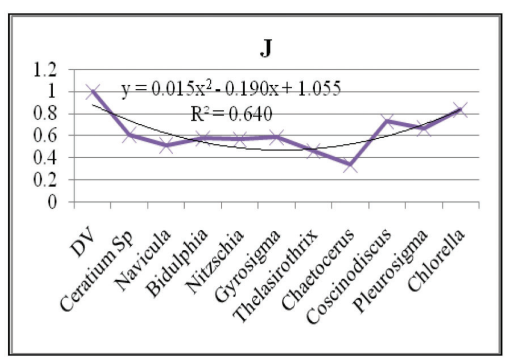

Fig. 24. Evenness index, J of different species

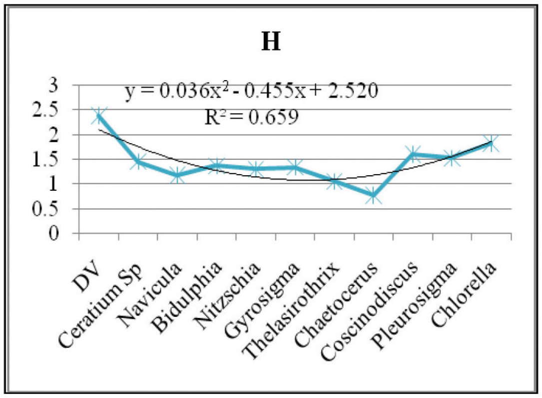

Fig. 25. Diversity index, H of different species

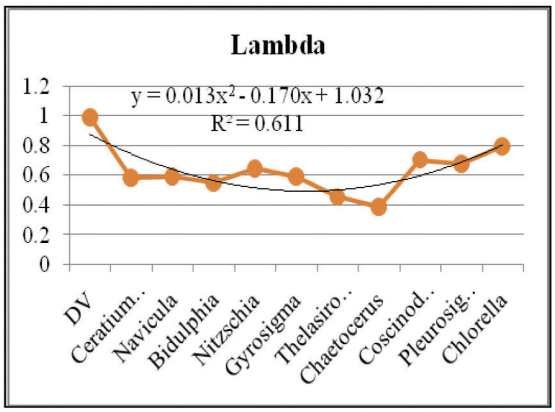

Fig. 26. Dominance index, λ of different species

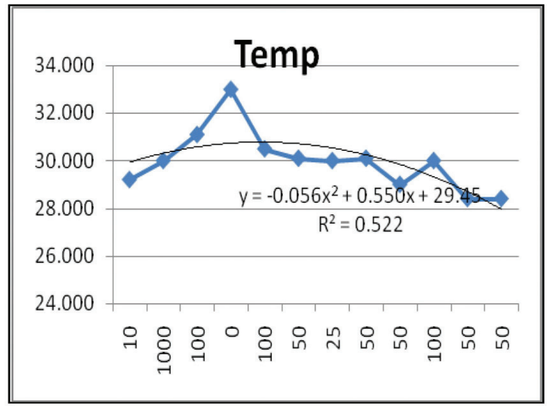

Fig. 27. Environmental variable, temp. and Ceratium species

Apr. (-0.07), S with May(-0.07), S with June(-0.07), S with July(-0.09), S with Aug.(0.07), S with Sept.(-0.07), S with Oct.(-0.03), S with Nov. (-0.06).S with Dec(-0.06), N with Jan(0.13), N with Feb.(0.13), N with Mar(0.13), N with Apr(0.13), N with May(0.13), N with June(0.13), N with July(0.19), N with Aug.(0.13), N with Sept.(0.12), N with Oct.(0.14), N with Nov. (0.15), N with Dec (0.15),d with Jan (-0.13), d with Feb.(0.14), d with Mar.(0.14), d with April(0.13), d with May(-0.13), d with June(-0.14), d with July(0.17), d with Aug.(-0.13), d with Sept.(-0.13), d with Oct. (-0.10) and d with Nov.(0.13), d with Dec(-0.13),J with Jan(0.06), J with Feb.(0.05), J with Mar.(0.06), J with April(0.06), J with May(0.06), J with June (0.60), J with July(0.05), J with Aug(0.62), J with Sept.(0.06), J with Oct. (0.08), J with Nov.(0.66), J with Dec (0.06). H with Jan (-0.02), H with Feb(- 0.02), H with Mar.(0.02), H with Apr.(-0.02), H with May (0.02), H with June(-0.02), H with July(-0.04), H with Aug(-0.02), H with Sept(0.02), H with Oct.(0.01) and H with Nov.(-0.020), H with Dec(0.02), λ with Jan (0.06), λ with Feb.(0.05), λ with Mar. (0.05), λ with Apr.(0.05), λ with May.(0.05), λ with June(0.05), λ with July(0.05), λ with Aug.(0.05), λ with Sep.(0.06), λ with Oct. (0.08) and λ with Nov.(0.06), λ with Dec(0.06), The differences between months and among indices are Jan, Feb and

Table 1. S, N, d, J',H' and ë for different species of phytoplankton

SNo.	species	S	N	d	J'	H'(loge)	1-Lambda'
1	DV	11	12	4.09	0.99	2.38	0.99
2	*Ceratium Sp*	11	158	1.35	0.60	1.45	0.58
3	*Navicula*	10	283	1.13	0.51	1.18	0.59
4	*Bidulphia*	11	227	1.29	0.57	1.37	0.55
5	*Nitzschia*	10	309	1.12	0.56	1.30	0.64
6	*Gyrosigma*	10	250	1.15	0.58	1.34	0.59
7	*Thalassirothrix*	10	413	1.08	0.45	1.05	0.45
8	*Chaetocerus*	10	131	0.94	0.33	0.77	0.38
9	*Coscinodiscus*	9	2025	1.05	0.73	1.60	0.70
10	*Pleurosigma*	10	2010	1.18	0.66	1.52	0.68
11	*Chlorella*	9	950	1.16	0.83	1.83	0.79
	s/ns	s	s	s	s	s	s

March are non significant at 5% level of significance and between months and among species, May, June, July, Aug, Sept, Oct, Nov and Dec are significant at 5% level of significance. S, N, d, J, H and λ are significantly different among different species at 5% level of significance.

Table 2. PCA

Principal Component Analysis
Data worksheet
Name: Data 7
Data type: Abundance
Sample selection: All
Variable selection: All
Eigenvalues

PC	Eigenvalues	%Variation	Cum.% Variation
1	15.9	55.5	55.5
2	5.58	19.5	75.0
3	3.35	11.7	86.7
4	2.01	7.0	93.7
5	1.26	4.4	98.1

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
Jan	-0.30	-0.53	-0.46	-0.52	-0.21
Feb	0.65	-0.55	0.40	0.02	-0.18
Mar	-0.67	-0.27	0.47	0.40	-0.2
April	0.00	0.00	0.00	0.00	0.00
May	0.11	-0.32	-0.57	0.65	-0.13
June	-0.06	-0.25	0.07	-0.15	0.36
July	-0.05	-0.15	-0.05	0.04	0.67
Aug	-0.02	-0.17	0.04	0.12	0.28
Sept	0.00	-0.17	-0.02	0.0	0.33
Oct	-0.02	-0.19	0.06	0.06	0.12
Nov	-0.04	-0.11	0.13	-0.04	0.19
Dec	-0.04	-0.18	0.19	-0.29	-0.15

Principal Component Scores

Sample	Score 1	Score 2	Score 3	Score 4	Score 5
DV,ml	2.06	5.69	-5.7E-2	-0.32	-1.51
Ceratium Sp	3.14	-0.54	1.90	1.23	-0.43
Navicula	-3.91	0.32	3.01E-2	-0.64	-0.77
Bidulphia	-0.24	-1.73	-0.96	-0.99	-0.58
Nitzschia	4.73	-2.07	-2.12	-1.02	-0.93
Gyrosigma	-3.51	8.96E-2	-0.49	0.9	1.67E-2
Thelasirothrix	6.16	-2.04	-0.72	0.55	0.77
Chaetocerus	-6.84	-2.49	0.27	1.11	-0.85
Coscinodiscus	-2.64	0.75	-0.10	-2.93	1.85
Pleurosigma	1.64	-0.17	4.38	-0.11	0.67
Chlorella	-0.58	2.18	-2.11	2.24	1.78

Correlation among diversity indices and months with respect to species: S with Jan(-0.04), S with Feb.(0.07), S with Mar. (-0.06), S with May(-0.20), S with June (-0.47), S with July(-0.89), S with Aug.(-0.47), S with Sept.(-0.55), S with Oct.(0.00), S with Nov. (-0.06). S with Dec (0.17), N with Jan(0.78), N with Feb.(0.00), N with Mar (0.94), N with May(0.08), N with June(0.45), N with July(0.02), N with Aug.(0.44), N with Sept.(0.14), N with Oct.(0.40), N with Nov. (0.09), N with Dec (0.02),d with Jan (-0.34), d with Feb.(- 0.20), d with Mar.(-0.21),d with May(-0.29), d with June(-0.40), d with July(-0.43), d with Aug.(-0.60), d with Sept.(-0.67), d with Oct.(-0.58) and d with Nov.(-0.40), d with Dec(-0.38), J with Jan(-0.61), J with Feb.(-0.32), J with Mar.(-0.57), J with May(-0.26), J with June (-0.29), J with July(0.04), J with Aug(-0.30), J with Sept.(-0.33), J with Oct. (-0.63), J with Nov.(-0.25), J with Dec(-0.34). H with Jan (-0.61), H with Feb (-0.30), H with Mar.(- 0.57), H with May(0.29), H with June (0.34), H with July(0.07), H with Aug(0.37), H with Sep t(0.41), H with Oct.(0.63) and H with Nov.(0.26), H with Dec(0.32), λ with Jan (0.56), λ with Feb.(-0.34), λ with Mar. (-0.53), λ with May.(-0.29), λ with June (0.35), λ with hema July (0.07), λ with Aug.(0.35), λ with Sep.(-0.46), λ with Oct. (0.65) and λ with Nov.(-0.23), λ with Dec(-0.38). The diversity indices and months with respect to species are significantly different from each other (p≤0.05).

Conclusion

Among the hydrographic variables tested, chlorophyll b and c are highly correlated (0.99) and tss and chlorophyll b are least correlated (-0.00). Among the species tested, *Gyrosigma* and *Chaetocerus* (0.99) are highly correlated, whereas *Chaetocerus* and *Chlorella* are least correlated (0.05). Among the correlation between species and hydrographic variables tested, primary productivity, gross and *Chlorella* (0.46) are closely correlated wheras chlorophyll a and *Bidulphia* are least correlated. (-0.00). Among the correlation between diversity indices and hydrographic variables, H' is highly correlated with primary productivity, gross (0.30) and S is least correlated with nutrient nitrate. Among the correlation among diversity indices and species, species richness, *Ceratium* is the highest (1.35) and the *Chaetocerus* is the lowest (0.94) in evenness index, *Chlorella* is the lowest (0.33) Among the correlation among hydrographic variables and months with respect to species, primary productivity, net with June (0.84) is highly correlated, chlorophyll b with June is least correlated. (-0.00) Among the correlation among diversity indices and months with respect to hydrographic variables, S with July is highly correlated (0.17), March with J'(0.00) is least correlated. Among the correlation among diversity indices and months with respect to species, N with Mar (0.94) and is highly correlated S with Jan is least correlated (-0.04). The primer graphs drawn for the distribution of different species of phytoplankton shows a diverse environment and is highly dependent on the prevailing environmental variables.

Acknowledgement

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