CHAPTER 4

ORDINATION OF ZOOPLANKTON COMMUNITY DATA: TRENDS IN THE COMMUNITY STRUCTURE OF MARINE ZOOPLANKTON AT SAURASHTRA

INTRODUCTION

All the marine and coastal biodiversity forms the foundation of natural ecosystem that produces and maintains the other biological resources. It is considered as the most ecologically and socio–economically vital resource on the planet. Unfortunately, marine and coastal biodiversity everywhere is increasingly threatened by land-based sources of pollution, such as the over exploitation of living resources, destructive harvesting techniques, coastal development, introduction to alien species and global climate change (May 1988). However, the more we learn of the working of the natural world, clearer it becomes that there is a limit to the intervention that environment can tolerate. Human activities also affect the environment in many ways from changes to the atmosphere and potentially the climate to directly polluting local habitats. In coastal zones, several activities pose threats to the marine biodiversity. Activities related to domestic and industrial waste disposal, waste from aquaculture, exploitation of minerals and accidents related to oil exploration and transportation can reduce local marine biodiversity and alter coastal habitats. Tourism also can change local habitats, thereby affecting the community structure and its biodiversity of the coastal waters. All these factors bring about species losses, and there comes a point when the whole ecosystem breaks down (SER 2004). Yet we are unable to envisage what proportion of species can be lost before this point of breakdown is reached. Hence, it can be rightly said that biodiversity is inevitable part of the very existence; its importance for perpetuation of life can never be overruled. Marine biodiversity is important for a number of reasons. It supports the life - sustaining systems of the aquatic biosphere, firstly, people rely on life in the seas for victuals, for medicines and for employment. Secondly, rich marine ecosystems attract tourists for its amazing beauty and speculate at the colors and multiplicity of marine organisms. Thirdly, marine ecosystems bestow protection from environmental extremes; for example, mangroves act as a buffer zone in coastal areas, protecting against the worst effects of storms. Finally, diverse and fascinating environments add to the quality of life; humans like to live in an exciting world surrounded by a variety of animals and plants. Therefore, it is an obligation to protect and care such colossal and vulnerable aquatic ecosystem as oceans and seas.

The sea's vastness and its enduring mysteries make it difficult for humanity to appreciate its vulnerability and the limits of its resources and resilience. It has also been suggested that we are on to the mass extinction of species (Myers, 1979; Wilson, 1985). Till to date, the terrestrial ecosystem has received a great deal of attention from many workers through out the world, covering its various aspects whereas aquatic habitat, together with marine and freshwater has been neglected to a certain level. The aquatic ecosystem especially the marine ecosystem is considered as the biologically most productive systems on the earth. Conversely, any harmful impact on the ecosystem will eventually affect the biodiversity of the marine resources.

Internationally however, many new findings have served as a new benchmark in the search for global biodiversity in marine ecosystem (Xabier, 2004). Marine ecosystem is home to myriad life forms with many known phyla and unknown number of species. Though ocean offers a fertile ground for the procreation and sustenance of innumerable life forms, they are also one of the most sensitive and susceptible ecosystems on the planet. Its productivity, community structure, stability and diversity are imbalanced by the unending manifestation of our own greed making this ecosystem most receptive to pollution. Ocean with its enormity and rich diversity hiding many untold secrets underneath is therefore impossible to explore and gather many unknown facts. Even a fraction of this huge aquatic body, if systematically investigated can throw light on its ecology and diversity. Further, it is well documented that the diversity of the coastal waters generally depends on the linkage between the productivity and its environment (Natahondi, 2001).

The environment itself is constituted by the abiotic and biotic factors of the water mass concerned. The abiotic factors, which comprises of the chemical and physical features underwent remarkable alteration in recent years. These extensive environmental variations had profound effect on the lives of scores of organisms living in aquatic bodies particularly marine water bodies. Among the most notable contributors to these environmental dissimilarities are the temperature and chemistry of water. This environmental change influences several elements of the habitat producing reflective implications on the plankton community to higher components of the trophic level, thereby affecting its diversity (Natahondi, 2001). Any changes in the physicochemical parameters ultimately bring alterations in the interrelationships among the various organisms at different trophic levels. The basis of this hypothesis is the changing hydrological factors directly influence the plankton community and its interrelationships and this will directly transfer to species level changes in abundance and distribution. The phytoplankton community is mainly influenced by the variations in the nutrient contents in the seawaters. This explains greater emphasis on the zooplankton population and its site-specific interactions. The zooplankton shows species level response either thriving or waning in its density, with alterations in the phytoplankton populations. These alterations owe to changing hydrochemical and hydrophysical features of marine ecosystem. This resultant changes in the marine ecosystem also affects the performance of marine organism at various stages in their life history cycle *via* changes in physiology, morphology and behavior (Hochackka and Somero, 2002). Thus, plankton community and its relation to physicochemical facet measure an essential part of the environment and when closely related with biological study greatly enhances its significance. Therefore, the physicochemical analysis of water is an important facet from the point of view of aquatic biology. The biological importance of physicochemical properties varies within and among the species. It has long been known that different ontogenetic stages are differently susceptible to hydro biological variations, as young benthic stages of many organisms are more vulnerable to these changes than the adults (Foster, 1971). The ecological response also depends upon the biotic environment, affecting population dynamics and community structure of the marine ecosystem.

However, recent work is totally emphasized to know about the unprecedented changes in the hydrological parameters of Oceans the world over, brining vulnerability among the species. Many speculations have been put forward to explain the probable raison d'être. Out of all, upwelling in the Oceans is considered to be of fundamental importance, producing changes in the atmospheric circulation (Bromerski *et al.,* 2003) disturbing the coastal salinity, turbidity, and inputs of terrestrial derived nutrients and pollutants (Pisias *et al.,* 2001). All these physical driven changes impart either positive or negative feedback to the plankton community. The plankton community with more diverse assemblages was less resistant to tolerate these variations but more resilient to disturbance imported by the extreme conditions (Allison, 2004). Since species responds individually to the residing environment, shifts in the community dynamics of the plankton population were noticed (Schiel *et al.,* 2004). This shift further affects the species abundance and diversity of an ecosystem. Yoshinaga *et al.* (2000) also stated that animal population lives in a diversity of environment and therefore a complex mixture of environmental factors regulates their population dynamics. Explaining, of large-scale pattern in population dynamics and its distribution due to changes in the environmental factors requires information on habitat extent and complexity (Magarran, 1988, Rosezweig, 1995), the rates and effects of disturbance and levels of productivity (Connell, 1978; Sousa, 1979; Petraites, Latham and Niesenbacum, 1989; Baltz, 1991).

Generally, aquatic disturbances have been qualitatively identified as starting from some meteorological event or quantitatively by measuring a specific physical event such as stratification differences in lakes or water discharge in rivers and estuarine ecosystems (Shipley *et al.,* 1991; Allison, 1992; de Madariaga *et al.,* 1992; Peterson and Stevenson, 1992; Moustaka-Gouni, 1993). Disturbance intensity can also be related to variations in water composition (Locke and Sprules, 1994; Locke *et al.,* 1994) or a specific biological component (Gerino, 1990; Brey, 1991). Many studies have been carried out in controlled conditions by manipulating the cause of disturbance (Hurlbert *et al.*, 1972; Jenkins *et al.*, 1992; Locke and Sprules, 1993; Flöder and Sommer, 1999). Disturbance intensity has also been measured by observing the response of a specific community to environmental change. This is calculated using the distance of the state of a community from a specific reference state, expressed either as a mean value or an ideal measurement of capacity towards which the community tends (Rojo and Alvarez Cobelas, 1993; Sommer, 1993). This technique is appropriate when disturbances are of different origins. Thus, predicting these dynamics of ecological system following perturbations or disturbances is a major goal of ecology. Therefore, there are many possible strategies for evaluating the relationship between the community composition and environmental variables. Four different variables were used to explain the complete community compositions, its complexity gradient and the variations in the community dynamics as result of hydrological changes in the costal waters of Saurashtra. The first variables are the similarity index measured using pair wise Euclidean distance. This showed that the sample plot could be clustered in to three distinct groups, indicating that the composition of zooplankton among habitat types showed similarities in the community. All the species showed individual response to the variant disturbance in the ecosystem, this attributes to different peak abundance at different spatial position. Thus, the community compositions were subjected to Principle Component Analysis. This measures the degree of faunistic difference between the communities. Moreover, the response of the zooplankton assemblages to the disturbances are thought to be more detected at higher taxonomic levels. This may be because of the confounding influence of abiotic factors. Further, it will affect the diversity at species level (Warwick and Clarke, 1993). To quantify such changes in taxonomic relatedness, Warwick and Clarke (1995) and Clarke and Warwick (1998 b) have defined biodiversity indices, which quantify the taxonomic diversity and taxonomic distinctness of faunal assemblages using the path length between zooplankton grouped by their taxonomic relationship. Hence, the data matrix was further subjected to Taxonomic Distinctness Analysis, to measure the taxonomic distance between any two individuals. To be more precise Taxonomic distinctness (Δ^*) is a form of taxonomic diversity that limits the influence pattern in species dominance by dividing Δ by a form of Simpson diversity, thus constructing a measure that nearly reflects pure taxonomic relatedness. However, over the study period, zooplankton was subjected to variability in habitat parameters (Temperature, pH, DO, Salinity, TSS etc) that merely affects their growth and survival. These changes further influences, the phytoplankton growth affecting the zooplankton–phytoplankton interrelationship. Consequently, to understand the affects of each individual factor on plankton community compositions, Draftsman's Correlation Analysis was performed. **Thus, objective was to characterize the community compositions at the three selected stations of the Saurashtra coast *viz* Alang, Diu and Veraval using multivariate analytical methods and to comprehend the interrelationship of plankton community amongst themselves and also with the varying physicochemical conditions to asses the dynamic state of the ecosystem.**

MATERIAL AND METHODS

HYDROPHYSICAL PARAMETERS ANALYSIS

The physicochemical analysis was carried out as per the treatise 'Standard Method for the Examination of Water and Waste Water' Published jointly by APHA and AWWA (1998). The detailed procedure is described elsewhere (chapter 2).

STATISTICAL ANALYSES

Statistical procedure employed a variety of multivariate technique. All statistical analyses were carried out using Primer Ver. 5 (Clark and Warwick, 1994).

RESULTS

HYDROLOGICAL CONDITIONS

TEMPERATURE

The mean annual temperature at all three stations did not show much variation. The minimum annual mean temperature of 28.8°C was recorded in Diu. Where as the highest mean temperature of 30.0°C was observed at Alang. Besides, Veraval showed a very slight difference in the mean temperature with 29.6°C. Not much difference was observed in the day and night temperatures at the surface waters of the three stations. An analysis of correlations with zooplankton abundance revealed a negative correlation. The increase in temperature caused an increase in the metabolic level of zooplankton species. Respiration rates measured in *C. pacifus* were twice as high as normal due to increase in temperature (Vidal, 1980). The pH and TSS g/L exhibits a positive relation with temperature (Table 4.3 and Figure 4.1)

pH

The pH of Seawater is quite buffered, and tends to have pH values above eight. Since all the three stations are relatively alkaline, the mean pH ranged from a minimum of 7.8 at Diu to maximum of 8.26 at Alang respectively. At Veraval the pH value was 8.23, which was almost similar to that of Alang. Regression correlation showed an inverse relation with zooplankton abundance. Thereby stating that with the increase in pH, the population may show decrease in trend (Table 4.3 and Figure 4.1). Changes in pH, with the decrease in pH of about 0.4 units inhibits oxygen uptake of Squids (Seibel and Fabry, 2003). Indeed, this also resulted in decrease in productivity (Seibel and Fabry, 2003) and ensued by 70 % decline in zooplankton abundance (Roemmich and McGawan, 1995).

DISSOLVED OXYGEN

The dissolved oxygen exhibited a consistent variation when studied annually. The minimum dissolved oxygen of 2.83 mg/L was recorded at Alang. Where as coastal waters of Diu showed the high oxygen concentration with mean values of 5.59mg/L. In Veraval, mean dissolved oxygen concentration of 4.67mg/L was noted during the entire study. Simple correlation coefficients were computed between DO and other parameters. However, DO exhibited a positive correlation with chlorophyll-a and zooplankton abundance (Table 4.3 and Figure 4.1). Dissolved oxygen and phytoplankton are two best indicators for the quality of water. There are phytoplankton species like *Chetoceros conacicornis*, simply surviving in anoxic waters. Thus, the presence of the bloom would indicate that low oxygen concentration in water have no detrimental effect on phytoplankton as a whole. Similarly, there remains zooplankton species with lower oxygen needs and higher surface area to volume ratio; they are less sensitive to the low oxygen waters (Anonymous).

SALINITY

Salinity varied negligibly as recorded annually. The concentration varied from minimum value of 31.6‰ at Alang to a meager increase up to 32.4‰ at Diu. Veraval though showed an annual salinity gradient of 32.0‰. The correlation analysis indicated positive relation with chlorophyll-a and zooplankton abundance (Table 4.3 and Figure 4.1). Arthur (1960) reported about the zooplankton tolerance capacity to constant changes as high and low salinities in the Caribbean Sea and South Atlantic Ocean. The majority of forms studied withstand salinity changes much greater than they would be expected to encounter, thus suggesting that salinity may not be a limiting factor in their distribution.

TOTAL SUSPENDED SOLIDS

It showed consistent variations at all the three stations. Diu recorded the minimum average of 0.32 mg/L to a maximum average of 0.45 mg/L at Alang. Veraval showed a mean value of 0.39mg/L. Regression correlation showed an inverse relation with zooplankton abundance and productivity in the coastal waters (Table 4.3 and Figure 4.1). The Secchi disk measurements for the TSS at Narragansett Bay showed a decrease in the total suspended solids with a concomitant increase in phytoplankton and zooplankton abundance (David and Theodore, 1998).

CHLROPHYLL – a

Another measure of productivity is the chlorophyll –a concentration of unfiltered water. The chlorophyll-a concentration through out the study was quite varied. The lowest mean concentration was in Alang (1.04 mg/m^3). Higher concentration was somewhat variable at different seasons over the course of the study. Moreover, higher concentration of chlorophyll-a up to 1.78 and 2.06 mg/m^3 were observed at Veraval and Diu respectively. Additionally, the analysis of correlation coefficients revealed a positive significant relation between chlorophyll-a and zooplankton abundance (Table 4.3 and Figure 4.1). Gyung and Harold (2000) noted statistically significant relation between phytoplankton bloom and zooplankton biomass. Within highly eutrophied water, the small oligotrichs (< 30µm) and rotifers dominated the total zooplankton biomass. However, tintinnids, copepods nauplii and meso zooplankton significantly decreased with the increases of eutrophication.

ZOOPLANKTON COMMUNITY FEATURES OF DIU, VERAVAL AND ALANG

Thirty eight species of zooplankton belonging to 9 class, 9 orders, 24 families and 38 genera were recorded through out the study period. The analysis of the numbers and identification of varied Zooplankton species revealed that Copepods were the most diversified group comprising of 18 species followed by Forminiferans 4 species, Appendicularians 1 species, Chetognaths 2 species, Siphonophora 1 species Harpacticoida 2 species, Cyclopoida 5 species, Decapods 2 species, Rotiferans 1 species, Gastropods 1 species, Pisces 1 fish egg and 1 post larva of fish. In spite of large number of species recorded, four species were perennial; *Rhincalanus, Paracalanus, Sagitta enflata and Sagitta sp.* In the open coast of Arabian Sea and Gulf of Khambatt *viz.* Diu, Veraval and Alang, Copepods appeared to be the most abundant group. Their average standing crop (whole season and sites) was 312598 ind.m^{-3} and occupied ~91.8 % of the total zooplankton. The meroplanktonic larvae, protozoan and other components, which comprised of *Foraminiferans Chaetognaths, Appendicularians, Harpacticoids, Cyclopoids, Decapods, Cladocerans, Bivalve, Rotifers, Gastropods, Siphonophors* all together constituted the subdominant group collectively contributing 36411 ind.m^{-3} ~10.6 %. The zooplankton was also characterized by community relationship by considering the average density recorded based on their occurrence in samples of three different stations. A highest average species density was characterized in Diu with 45566 ind.m^{-3}. While Alang exhibited minimum average density contributing to 13152 ind.m^{-3} of the total zooplankton community. Besides the average zooplankton, density between Veraval and Alang varied distinctively exhibiting 27267 ind.m^{-3} and 13152 ind.m^{-3} respectively (Table 4. 2)

Diu comprised of, *Cladocerans, Harpacticoids, Appendicularians, Cyclopoids, Foraminiferans* representing as dominant groups collectively adding up to 45. 53 %. The genus Copepod characterized by *Paracalanus sp* (14.69%), *Rhincalanus sp* (13.92%), *Isias tropica* (8.46 %), *Acrocalanus gracillis* (7.42%) relatively outsized other species at Diu (Table 4.4 and Figure 4.2).

Out of the 38 taxa identified among the three stations, only 25 species comprising of 33.45% fair the average abundance at the coastal waters of Veraval. Copepods like *Paracalanus* were highly dominant showing 25%. The other miscellaneous forms, fish eggs and post larva of fish were relatively common at Veraval. Each comprises of 15.2 and 1.3 % respectively. The other taxon exclusively found at Veraval were Rototarians (*Keratella*) making up to 2.45% of the total abundance. The other opportunistic species were *Mysis of P. indica* (2.21%), *Hippopodius sp* (0.52%), *Rosalina sp* (0.78%) and *Globigerina sp* (0.52%) (Table 4.5 and Figure 4.3)

Alang however, exhibited the lowest average zooplankton abundance comparative to the other two stations. The zooplankton community was dominated by copepods on average crustaceans; *Acrocalanus gracillis* (10.76%), *Calocalanus gracillis* (14.88%), *Euchaeta* (12.02%) and *Paracalnus* (9.33%) all dominated the community. Further, it includes Foraminiferans like *Rosalina sp* (9.04%) and Chetognaths comprising of *Sagitta enflata* (9.04%) and *Sagitta sp* (11.80%) of the total zooplankton abundance throughout the study. Alang also favored some exclusive species, which were present during some seasons of the year. They were *Oithona brevicornis* (1.63%), Foraminiferans that includes *Quinqueloculina sp* (1.17%), Chetognaths; *Sagitta enflata, Sagitta sp* and Decapoda: *Zoea larva* making up to 1.24% of the total community compositions (Table 4.6 and Figure 4.4)

Contrary to the average density, the diversity showed a different trend, maximum species richness of 0.28 was recorded in Alang. Richness progressively declined towards Diu with 0.26 recorded annually, mostly comprising of meroplanktonic forms with diverse array of other zooplankton species. Veraval exhibited a richness consisting of 0.26 annually (Table 4.1). Considering the number of species found in all the three stations, it could be observed that species richness decreased in the following sequence Foraminiferans → Cyclopoids → Copepods → Gastropod → Decapods. Annual distribution of zooplankton species as mean abundance value at the three stations were shown in figure 2, 3 and 4. Photomicrographs of few representative species are included in the figures, 4.14 - 4.17.

COMMUNITY ANALYSIS WITH MUTIVARIATE STATISTICAL TECHNIQUES

SIMILARITY IN ABUNDANCE MEASURED BY EUCLIDEAN DISTANCE

In the present study, the cluster dendrograms for the community similarity built from the none transformed data measured by the Euclidean distance exhibited spatial similarities in the abundance of zooplankton species between three stations.

General descriptions

The Diu and Veraval showed the closest linkage between species. In Diu Copepods, *Eucalanus* and *Temora discaudata* and *Acrocalanus* and *Parvocalanus sp* showed the closest linkage. Whereas in Veraval Foraminiferans; *Globegerina*, Siphonophoran; *Hippopodius sp* and Crustaceans; *Eucalanus* and *Parvocalanus* exhibited the closest linkage in the community similarity. The *Candacia sp* also formed the closest linkage in Veraval. The third station Alang showed the lowest distance from the rest of the two stations in the community compositions of zooplankton. In Alang, Copepods; *Centropages elongata* and Foraminifera; *Nannocalanus minor* showed the closest association. Similarly *Quinqueloculina sp* and Decapoda; Zoea larva were the closest groups. Results of the community similarities of plots located at all three stations were high. The plots can be divided into three groups, groups showing the lowest distance, moderate distance and highest distance. This grouping pattern suggests that whenever changes in the hydrological parameters occur, the assemblages of zooplankton species show alterations in community compositions.

Detailed descriptions

Forty species belonging to three stations have been clustered on the basis of similarity in abundance of species measured by Euclidean distance. Station one, Diu comprises of some dominant species; *Paracalanus, Rhincalanus, Isias tropica* and *Acrocalanus gracilli* and they shared the greatest distance within the community. However, *Oithona* and *Cyclopid* nauplius also shared the similar distance but they were not abundantly recorded in Diu. Among the crustaceans, *Paracalanus* are commonly found at all the three stations with Diu carrying (14.69 %), Veraval (25%) and Alang (9.33%) and few of the rare species;

Microsetella and *Oikopleura sp*, all exhibiting the closest distance among them. These species are generally not seen at the other two stations, Veraval and Alang. *Temora sp* showing, *Nonion* and *Calanus* showed moderate distance within the community (Figure 4.5).

The cluster dendrograms of Veraval reveal further groups of classification sequence existing among the similarity distribution of species. The most dominant species were *Paracalanus, Calanus*, and *Isias tropica,* which formed the cluster with the highest distance. Rotifer: *Karetella* an opportunistic species at Veraval, together with *Acrocalanus sp* and few scarce forms of siphonophores, gastropods and foraminiferan: *Globigerina, Oithona sp* and post larva of fish all together shared the shortest distance between themselves in the community. *Centropages sp* and *Parvocalanus sp* also shared the similar distribution pattern in the community. Mysis *of P. indica, T. discaudata, Candacia sp, Calocalanus gracillis, Eucalanus sp, Rhincalanus sp* and *R. cornutus* all showed similarity in the abundance of species compositions that were measured as moderate Euclidean distance in community composition (Figure 4.6).

The community analysis using Euclidean distance indicated that the Copepodite: *Acrocalanus gracillis* with the widest distance is the dominant and widely spread species over Alang. The zooplankton species, *Eucheata sp* and *Sagitta enflata*; *Calocalanus sp* and *Sagitta*; Zoea larva and *Oithona brevicornis* all together exhibited moderate distance. The chaetognaths species were exclusive as well as perennial, thus, comforting that these species can tolerate a wide range of environmental change. Among the other zooplankton species, some of the copepods: *Centropages sp* and *Nannocalanus sp*, gastropods and larvae of barnacle, foraminiferans and decapods indicated the lowest distance shared within the zooplankton community of the third station Alang (Figure 4.7)

PRINCIPLE COMPONENT ORDINATION ANLAYSES

The statistical data matrix of the cluster numbers at all the three dendrograms of the three different stations was randomized further and subjected to ordinations; Principle Component Analysis (PCA) which measures the degree of faunistic difference between the communities. The seasonal related hydrological variations, which brings variations in zooplankton community was summarized by PCA of non-transformed data. The Eigen values which are known as the latent root (Refer: Statistical analyses in Chapter 2) are ranked here from the highest to the lowest. In the present study, the Eigen values for the three axes are 1.52, 0.91 and 0.57 respectively. These are related to the amount of variations in a community, which are explained by the axis. Factor one, explains 50.7% of the total variations and are directly correlated to the species in a community, which are *Acrocalanus, A. gracillis, I. tropica*, *Paracalanus* and *Rhincalanus* species. This further is inversely correlated to *Oikopleura, Rosalina, Nonion, Microsetella, M. gracillis, Gyrosigma* and *Navicula.* Factor two, explains 30.4% of community difference which are directly correlated to *C. nauplius, Euchaeta, Sagitta enflata* and *Sagitta sp* and inversely to *Calanus* species. Factor three, reveals a trivial amount of community variation, which may not be worth interpreting. The factor indicates 18.9% of the total variations and correlates directly to copepods. The result further indicates that the axis (PCA1) as being positively related to the abundance of the zooplankton species. Axis 2 (PCA2) on the other hand is positively related to the abundance at Diu and negatively related to the species abundance at Veraval and Alang. Thus, the "gradient" reflected by axis, one which reflects the complete relation is something which benefits the species compositions in a community. Therefore, zooplankton species at Diu indicates the maximum abundance and significant composition throughout the study. Based on the relative distribution of groups of zooplankton species of the three study stations, the groups that are closer together correspond to composition, which are much similar and the groups that are far apart represents dissimilar compositions. The bubbler size represents the relative size of the group density of the zooplankton species (Table 4.7 and Figure 4.8).

TAXONOMIC DISTINCTNESS ANALYSES

Multivariate analysis revealed difference among areas and times, suggesting that communities had changed, perhaps because of changes in hydrological properties. Therefore, the data was subjected to further analysis using Taxonomic distinctness analysis Δ^* to examine whether there have been shifts in the taxonomic relatedness of the assemblage comparable to those observed by Warwick and Clarke (1995). The newly introduced diversity index TDS (Δ^*) measures the average taxonomic distance between any two individuals chosen at random belonging to separate species, which is calculated using the formula

$$=[\Sigma\Sigma_i <_j \omega_{ij} X_i X_j] | \ldots [N(N-1)/2]$$

The taxonomic distinctness test with aggregation of zooplankton data set comprising 37 species divided among 9 class, 9 orders, 24 families and 38 genera. The TDS (Δ^*) was also analyzed considering the species richness. The (Δ^*) displays a similar trend across all the three stations. The overall community compositions, which had the highest number of species of specific phylum and class, were subjected to distinct weights. The "distinctness weight" 100 and 16.6 are given to the path length that links species i and j in the hierarchical classification. This denotes that, all the three stations, zooplankton belonging to single phylum (Arthropoda) were the most dominant. This furthers reflects the taxonomic spread of species among the community (Clarke and Warwick, 1999).

Making use of the abundance table and the aggregation table, that gives the information about the taxonomy of the species, the funnel and ellipsoid plots were drawn. The funnel was drawn after total random selection of all the species identified from the three stations. This suggests that the two biodiversity indices on the funnel plots, Delta (+), that shows variations in the taxonomic distinctness and Lambda (+1) measures the degree to when the species are taxonomically related to each other. The sample from the three stations *viz* Diu, Veraval and Alang fell within 95% confidence funnel, for all the taxonomically related species in the community. This suggests that, probably all the species were drawn from the same regional species pool, whereas the taxonomic spread was concentrated in to few taxa (Genera & families). The variations, Lambda (+1) also fell inside the 95% confidence limits in the funnel plot, indicating the aforementioned reason. The test combining the average taxonomic distinctness with aggregation was even determined by taking in species richness. This reveals similar results, with taxonomic distinctness that falls below the 95 % probability contours (ellipsoid). This suggest that overall diversity pattern of the Saurashtra coast which includes the three study stations, located at the Gulf of Khambatt and the open coast of the Arabian Sea have very high diversity pattern showing lesser statistical deviations. The other point that has to be taken in is that lambda (+1) was significantly higher than expected from a random sample of the regional species pool and for the crustaceans; this was the case for all the stations. This also indicates an overall representation of some taxa and the under representation of other in the overall community composition of the Saurashtra coast. This includes both the dominant forms and the exclusive one showing the overall representations, and some trivial divisions like Rotiferans and Cnidarians that were under represented. Finally, the use of weighting to reflect the quantitative reduction in the taxon richness on moving up the hierarchy seems logical. In fact, the correlation between the abundance and diversity with weighting shows that they are highly correlated (Table 4.8 and Figure 4.11 and 4.12)

DRAFTSMAN'S PLOT CORRELATION ANALYSIS

In order to understand the interrelationship between the environmental and biological parameters such as zooplankton abundance, the data was subjected to regression analysis. Table 12 and Figure 13 gives the regression (r) values of various physical and biological parameters of the intertidal zone. It can be seen that dissolved oxygen, salinity and chlorophyll-a showed a significant positive relation with zooplankton abundance. This suggests that zooplankton diversity / density is not much affected by variations in these factors. However, the temperature showed a negative relation to the overall density of zooplankton species. This indicates, the temperature is an important factor that determines the growth and perpetuation of species. This further implies that low zooplankton density is associated with coastal waters having high temperature. Similarly, pH in the coastal waters of Saurashtra also exhibits a negative relation with zooplankton abundance, while the total suspended solids showed a positive relation with pH of the water. This reveals that, with the lowering of pH, it helped the growth of fish egg and Cyclopoid larvae. The higher turbidity in the coastal waters during this period, which is mainly anthropogenic in origin, increases the pH. This furthers contributes to drop in the DO (negative relation). The zooplankton abundance and chlorophyll – a was directly related to DO which are basic requirement for the survival of organisms. In Mumbai Harbor waters, it was observed that the tidal flow had largely influenced the polluted Bay waters, where at least one third of water is renewed at every tidal cycle. This helped to maintain normal dissolved oxygen level and reduce organic load for zooplankton to survive (Swane *et al.,* 2001).

The salinity also exhibited a direct relation with zooplankton abundance and chlorophyll-a, whereas it showed inverse relation with TSS. This indicates that increase in salinity favored zooplankton survival with increase in abundance of certain diatoms species. In the present study, total suspended solids exhibits a negative correlation with chlorophyll-a and zooplankton This is in agreement with the Dunton (1990) who described that variations caused in transparency of water due to highly turbid waters, can have significant effects on the annual production of different species in the marine waters. The increase in the turbidity of water may affect the chlorophyll – a concentration, which subsequently affects the zooplankton composition.

Chlorophyll – a and zooplankton abundance showed a direct relation. This suggest that zooplankton is directly associated with phytoplankton concentration. When the environmental factors become favorable, with well oxygenated water, increase in nutrients, lowering of pH offer a favorable environment for the proliferation of phytoplankton. This influences the zooplankton community, as it shows interactive effects on its predation source. Previous work has argued that nutrients and herbivores have interactive effects on the diversity of primary producers (Collins, *et al.,* 1998; Worm, *et al.,* 2002; Hillebrand, 2003). In the straits of Malacca, which has been classified as typical shallow Sea with partially mixed water of estuarine origin, Razai *et al.* (2003) observed that higher zooplankton density was associated with higher amount of chlorophyll – a, in the near coastal areas (Table 4.10 and Figure 4.13).

DIVERSITY OF ZOOPLANKTON

The faunistic component of aquatic biota is dominated Arthropoda, Sarcomastigophora, Cnidaria, Rotifera, Chaetognatha and Chordata. A checklist of the aquatic microfauna observed during the current study is presented as follows:

PHYLUM: SARCOMASTIGOPHORA

CLASS: GRANULORETICULOSEA

ORDER: FORAMINIRERIDA

FAMILY: NONIONIDAE

1. *Nonion sp.*

FAMILY: ROSALINIDAE

2. *Rosalina sp.*

FAMILY: MILIOLIDAE

1. *Quinquloculina sp.*

FAMILY: GLOBOROTAIIDAE

2. *Globigerina sp.*

PHYLUM: CNIDARIA

CLASS: HYDROZOA

ORDER: SIPHONOPHORA

FAMILY: HIPPODODIIDAE

3. *Hippopodius sp.*

PHYLUM: ROTIFERA

CLASS: MONOGONONTA

ORDER: PLOIMA

FAMILY: BRACHIONIDAE

4. *Keratella sp*

PHYLUM: CHAETOGNATHA

CLASS: SAGITTOIDEA

ORDER:APHRAGMOPHORA

FAMILY: SAGITTIDAE

5. *Sagitta enflata*
6. Sag*itta sp.*

PHYLUM: MOLLUSCA

CLASS: GASTROPODA

7. Unidentified sp.

PHYLUM: ARTHROPODA

CLASS: CRUSTACEA

SUBCLASS: COPEPODA

ORDER: CALANOIDA

FAMILY: EUCHAETIDAE

10. *Euchaeta sp.*

FAMILY: PARACALANIDAE

11.*Acrocalanus sp.*

12. *Acrocalanus gracillis*

13. *Calocalanus gracillis*

FAMILY: METRIDINIDAE

14. *Pleuromamma gracillis*

15. *Pleuromamma sp.*

FAMILY: CALANIDAE

16. *Calanus sp.*

FAMILY: EUCALANIDAE

17. *Rhincalanus sp.*
18. *Rhincalanus cornutus*

FAMILY: CANDACIIDAE

19. *Canadacia sp.*

FAMILY: PARACALANIDAE

20. *Paracalanus sp.*
21. *Parvocalanus sp.*

FAMILY: CENTROPAGIDAE

22. *Centropages elongata*
23. *Centropages sp.*

FAMILY: EUCHAETIDAE

24. *Isias tropica*

FAMILY: EUCALANIDAE

25. *Eucalanus sp.*

FAMILY: OITHONIDAE

26. *Oithona brevicornis*
27. *Oithona sp.*

ORDER: HARPACTICOIDA

FAMILY: ECTINOSOMATIDAE

28. *Microsetella sp.*
29. Microstella gracillis

ORDER : CYCLOPOIDA

FAMILY: CYCLOPIDAE

30. *Cyclopoid nauplius*
31. *Larvae of cyclopoid*

FAMILY: CALANIDAE

32. *Nannocalanus minor*

FAMILY: TEMORIDAE

33. *Temora discuadata*
34. *Temora sp.*

CLASS: MALACOSTRACTA

ORDER: DECAPODA

FAMILY: DROMIIDAE

35. *Zoea Larva*

PHYLUM: CHORDATA

CLASS: APPENDICULATA

ORDER: APPENDICULARIA

FAMILY: OIKOPLEURIDAE

36. *Oikopleura sp.*

CLASS: OSTEICHTHYES

37. Fish egg

38. Post larvae of fish

DISCUSSION

Zooplankton community compositions and its variations in response to various biotic and abiotic factors at the three stations *viz.* Diu, Veraval and Alang of the Saurashtra coast were studied using multivariate ordinations. The interaction between these biotic and abiotic factors is very important in structuring the biological communities of the marine environment together with complex community of plankton. Although the literature does not much clarify the magnitude that can be measured as reliable indicators for understanding the severity and intensity of variations in the community compositions. However, the community composition of plankton and the factors affecting its abundance and richness are very intricate, which will provoke substantial proximate and emergent responses in the biosphere. Therefore, report exists on various factors that could be affecting its periodicity at the community level in the plankton population. UnterÜberbacher, (1964) noted increase zooplankton abundance when there occurs a fall in temperature and reported a primary peak about two months after the period of lowest temperature. Christopher, (2006) from his observation concluded that community level are mediated by interacting species (e.g. Predators, Competitors etc) and variations in the abundance and per capita interactions among the species depend on the difference in the hydrographic and hydro biological features. Luci cajuero carneiro pereira *et al.* (2005) based on their study of affects of physicochemical properties on plankton composition and distribution in coastal areas of Brazil states that variation in the hydrological conditions of the coastal waters are responsible for the reduction in the biomass of the most opportunistic (strategist) species. Linden *et al.* (2002); Shushkina and Vinogardov, (1992); Fernandez *et al.* (1993) and Kokuirkina and Mikailyam, (1994) gave a similar conclusions that dynamic structure of plankton communities (diversity, abundance and distribution) depend on the local environmental conditions. Gomez-Erache, *et al.* (2000) studies supported the above observations, that environment variability was the principle factor influencing the lowest diversity values from Soles Grande estuary; and on the South Coast of Portugal (Villa *et al.*,1997) in phytoplankton and Zooplankton communities. Verheye *et al.* (1998) attributed that changes in the species and size spectra of plankton community are not only controlled by the environmental forcing mechanisms but also to predator prey interaction. During the present study a significant alteration in the plankton community was observed with concurrent variations in hydrological parameters. An annual data of the seasonal variations have been compiled and discussed. Overall zooplankton density was found to be highest in Diu followed by Veraval and the least values were observed in Alang. However, species richness was more pronounced in Alang followed by Veraval and Diu respectively. The increase in the density was essentially may be attributed to the lower turbidity in Diu waters. It is further comparable with the opinion of Reay and Kimaro, (1984) and Okemua, (1990) that there occurs increase in plankton density in the coastal waters due to high amount of nutrients washed into the sea. However, there are contradictory reports available about zooplankton exhibiting a different distribution pattern of multiple peaks when the temperature usually goes up with a drop in the nutrient contents in the water temperature and a secondary peak was observed during seasons when the temperature increases. This peak generally corresponds to periods of maximum phytoplankton concentration. (kollmer, 1962, 1963) from his experiments argued that some genuine factors like chemical, physical and biological interference, competition, heterogeneity and predation all together regulates a plankton community and its succession. Several studies have been conducted to understand and characterize the plankton community of the marine ecosystem with respect to magnitude and variety of changes in the hydrological conditions

In the present study considering the range of variations in the hydrological properties of the water, which subjects to alterations in the community compositions of zooplankton species, the data was subjected to specific ordinations that focus on intra and inter annual variations in the zooplankton community at the three selected stations of the Saurashtra Coast. This also focuses on the ecological functioning of marine zooplankton assemblages, it incorporates information on species distribution and the biological characteristics they exhibited, to produce a summary of biological composition of assemblage. The approach provides a link between species, environments and ecosystem process. This is potentially useful for understanding the hydrological changes, including the anthropogenic impacts on ecological function.

In the present study, in order to determine whether seasonal hydrological changes explains a significant amount of variations in the numbers of species in a community, three multivariate ordination tools were used. They include Euclidean distance for measuring community similarity, Principle Component Analysis for measuring the faunistic variation. The Taxonomic distinctness which is a univariate biodiversity index, which in its simplest form calculates the average distance between all pairs of species in a community sample, where this distance is defined as the path length through a standard Linnean or phylogenetic tree connecting these species.

All, ordinations portrayed different compositional structure of zooplankton assemblage and discriminated between assemblages up to its taxonomic classification. The overall, multivariate approaches allows for monitoring community compositions to determine whether stations are improving or degrading over time. Thus, the basic approach was to study the comparison between the compositional differences in a community and the relative similarity existing between these communities among the three stations that may have been induced by the perturbations in the physicochemical variables throughout the year. The multivariate ordinations (clustering using Euclidean distance, Principle component analysis and Taxonomic distinctness test, Regression correlation) exhibited that the whole zooplankton community structure, especially the copepod community was influenced primarily by variations in the hydrological variables. Amongst that, the temperature, pH and total suspended solids affected the community structure that comprises of zooplankton and chlorophyll-a. The dynamics of zooplankton communities and assemblages as well as the influence of environmental factors on them were studied using different multivariate ordinations. These ordinations revealed importance of some environmental factors on the zooplankton community compositions (Ioanna siokou *et al.,* 1998). Sterling *et al.* (2006) suggested similar observations through multivariate methods studied for the inequity the zooplankton assemblages of the Bar-built estuaries near Visakhapatnam.

The similarity analysis using Euclidean distance seems to be very powerful tool in understanding the relationship existing within zooplankton species assemblages. In the present study, among the forty zooplankton species clustered on the basis of community compositions using Euclidean distances; all the three stations exhibited fairly similar linkages indicating similarity in compositions. The copepods were most dominant group within the three stations. The *Paracalanus* was the most common and dominating species within these three stations Diu, Veraval and Alang. Copepods comprised >80% of the zooplankton enumerated from oceanic regions of the Arabian Sea (Madhupratap and Haridas, 1990). Calanoid copepods were mostly typical subtropical (and small) copepods of the genera *Paracalanus*, common in upwelling areas Indian Ocean (de Decker, 1973) and northwestern Indian Ocean (Smith, 1982 1984), and observed off Oman (S. L. Smith, unpublished). In upwelling areas of the South west coast of India and coast of Pakistan, the dominant copepods were species of *Eucalanus*, *Paracalanus*, and *Temora*, and *Acrocalanus* (Haq *et al.,* 1973; Stephen *et al.,* 1976). In Diu, *Oithona* and *Cyclopoids* shared the greater distance but not abundantly found. However, Denburg (1998) recorded high abundance of *Oithona sp* and *Calanoids sp* in the stratified North Sea. In Veraval, some opportunistic species like *Keretella* and few forms like *Siphonophores*, Foraminiferans; *Globegerina* etc also shared the shortest distance, indicating their smaller distribution in the community. Tiwari (1993) recorded small percentage of *Siphonophores,* though its presence was sporadic at the Dharamtar creek adjoining Bombay harbor. The highest abundance of *Globigerina* for instance is found in Arabian Sea waters as warm as 24°C. This species is also found in very abundance in regions with very high productivity caused by coastal upwelling (William and Dorinda, 1997). Similarly, in Alang, species *S. infalta* and *Sagitta, Barnacles* all exhibited moderate distance showing to be exclusive forms, some being perennial. Thus, indicating that species can tolerate a wide range of environmental change. The distribution of *Sagitta sp* is limited to specific areas. *Sagitta inflata* and other three species of *Chetoganathas* occur in the Pacific Equatorial and Central water masses. The Peru and California currents are inhabited by Sagitta and they are also found in the coastal waters of Japan (Robert, 1959). Barnacles, are considered as the best bio- indicators species, *Mytilus edulis* in particular as bio-indicators is in vogue since 1939 (Moore and Kitching, 1939; Southward and Crisp, 1954, 1956). *Chetoganaths* are also known as good bio-indicator species, which are present in the Andaman Sea. Barnacles are also biofouling agents. In comparison to *Mytilus edulis*, *(Lepas* sp) were found to be dominant macrofoulers on buoys deployed in the oceanic regions off Kavartti, Mangalore and Goa coast (Syed *et al.,* 2004). The biological data matrix of the three stations was further subjected to Principle community analysis (PCA), to identify the degree of floristic variation between the three stations. That further shows which species are directly or inversely related in bringing the community difference. In the present study Eigen values (mathematical concept) determine the total variations which relates to species in a community. Together, in the whole community, species are directly or indirectly related that brings in 50% variations in the community. These species are *Acrocalanus, A. gracillis, I. tropica, Oiklopluera, Micro setella* etc. There are other set of zooplankton species that commemorate 30% of community variations either directly or indirectly in an ecosystem. They are *C. nauplius, Euchaeta and Sagitta* etc. The last set of 18 % shows a trivial variation, which are non- significant to indicate in a community. The distribution of zooplankton was described in order to separate ecological areas in terms of specific community compositions. This was studied by Jean (1994). PCA was performed for most of the zooplankton taxa, explaining different percentage of variation in the community. The three sets of species were observed which exhibited different degree of complexity in the marine ecosystem. The highest was shown by *copepods* and *calanoids*. Intermediate by *appendicualrians*, poor though diversified with typical copepods from warm waters e.g. *Oithiona, Calacalanus* and *Clausocalanus furcatus* etc. Considering the station wise gradient, community compositions showed more positive relatedness towards Diu, indicating a maximum abundance and significant composition, which furthers reflects a pristine environment of the ecosystem. The PCA suggested community compositions at various degree of percentage caused by the direct and indirect species gradient at community level.

However, to understand further the shift in the community at the taxonomic level, precisely to evaluate the taxonomic distinctness between two different species in a community, the data matrixes are subjected to Taxonomic distinctness analyses. In the present study, analyses shows that the Phylum Arthropoda are the most diversified and dominant phylum, with class Crustacea showing the maximum species. Further, the graphical representation using funnel plots; lambda and delta shows that total species of the Saursashtra coast from phylum to species level of classification fall within 95% probability contour, indicating that the coastal belt of Saurashtra are very rich carrying high diversity. This includes both the dominant forms and exclusive ones showing the overall representation. This also includes lesser division (result from the present study) like *Rotatorians* and *Protozoans* are under represented. The taxonomic distinctness is a new suite of multivariate indices. The variations in taxonomic distinctness (also called lambda and delta) (Clarke and Warwick, 2001b) emphasizes how similar the upper levels (e.g. Order, Classes) are between samples. Andrew *et al.* (2005) studied about marine benthic invertebrate from Irish Sea, Hong Kong and Seychelles. The estimation from the taxonomic distinctness, results showed that taxonomically (considering bivalves alone) Irish Sea being the richest with high diversity. Honk-Kong generally has the poorest fauna and least for Seychelles with very low diversity. Warwick and Turk (2002) studied about the assemblages of mollusk (gastropods and bivalves) from the sandy beach at Harly Bay, North Cornwell. The biodiversity measures used for the taxonomic distinctness delta and lambda also showed that they are significantly different in biodiversity. They belong to same regional species pool. The changes in the environmental factors e.g. climate had tremendous changes by the end of this century, but the biodiversity, the compositions did not show remarkable changes (Warwick and Turk, 2002). These were factors that determined the community structure, what exactly prompted these variations in the community structure are environmental factors e.g. hydrological conditions of the water.

The hydrological changes in the marine waters have significant affects on the compositions of zooplankton communities studied. Makas Rachel *et al.* (2002) found comparable results of ordinations among the zooplankton community at the surface waters of the Atlantic Ocean. This observation supports that perturbation in the hydrological parameters makes some of the core species, to dominate the habitat at all the volumes (Unpublished data). Besides, Rosenberg, (1973); Hoare and Hiscock, (1974); Pearson and Rosenberg, (1978); Cross and Eills, (1981) in their observation have stated that there occurs a reduction in zooplankton communities under the influence of the variations in the hydrological parameters of the marine waters. Rezai *et al.* (2004) made a quantitative approach to explain in his studies distinctiveness among the zooplankton distribution that was mainly attributed to the variations in the physical, chemical and biological parameters of the marine ecosystem. In the present study it was indicated that any perturbations in the hydrological environment are mainly responsible for the variations in the compositions of the zooplankton community. Therefore, in order to understand the existing relationship between the variables and plankton compositions, the data was subjected to regression correlation using Draftsman's correlation.

Moreover, it was observed that temperature and salinity and to a certain extent pH were three main factors that were influencing the compositions of the zooplankton community at all the three stations of the Saurasathra coast. Marta, *et al.* (2006) suggested salinity to be the most important environmental factor determining the structure of the invertebrate community along a spatial gradient, noted from a related observation using Darftmans plot. However, the strong affect of salinity is a limiting factor on primary producers and many of the invertebrates including zooplankton (Hart *et al.,* 1998; López–González *et al.,* 1998; Thiéry and Puente, 2002; Tripp and Collazo, 2003). However, it's often unclear whether the distribution of plankton communities is limited directly by the salinity and temperature itself or their associations with the other factors like pH and DO are also responsible. Moreover, many of the activities that occur in the coastal areas have strong environmental impact, brining variations in the physicochemical parameters further influencing the community structure. This includes many factors, which controls the ecology and diversity of a plankton community. Amongst various hydrological features, temperature is one such factor, which is considered most imperative in determining the population dynamics of plankton community. In the present study, temperature shows a negative correlation with zooplankton abundance. The plankton abundance was maximum at Diu when temperature falls down. However, decline in plankton density was observed when the temperature increases at all the three selected stations of the Saurashtra coast. It may be alleged that plankton population, zooplankton and phytoplankton needs an optimum temperature for survival and growth and when variation happens in temperature, decline in population density occurs. The importance of temperature for the continued existence of any life forms can never be overruled. It's the one among the most vital parameters for all the physiological and biochemical reactions to be activated in all living organisms. Hochakka and Somero (2002) stated that temperature affects all physiological process ranging from protein damage to membrane fluidity to organ function. Because many organisms live close to their thermal tolerance (Somero, 2002; Hughes *et al.,* 2003) as increase in temperature can produce negative impact on the performance and survival of marine organisms including plankton population.

The biological importance of rising temperature varies within and among the species. However, temperature is positively correlated with zooplankton birth rates and mortality in laboratory experiments (Wolfinbarger, 1999). Plankton can reproduce and flourish and even commute to 'blooms' depending upon the temperature variations provided other factors are not limited. Pechenik (1989) opined that different ontogenetic stages are differentially susceptible to environmental stress. For e.g. certain plankton larvae stages are particularly susceptible to thermal effects. It is however, difficult to determine the effect of temperature on an individual or population, as temperature persuades other processes that in turn affect the plankton community. Consequently, the rate of biological process is seldom influenced by temperature alone but by a number of other factors too. Nevertheless, with increase in sea surface temperature biogeographical range shift had occurred as abundant fossil evidence suggests that marine fauna had shifted pole words as Sea surface temperature rose (reviewed in Fields *et al.,* 1993). However, it can be said that temperature does not solely decide when and where a species will thrive. Its influence is mainly indirect in enhancing or retarding the development and association with other biotic and abiotic factors.

The pH is another environmental factor of aquatic ecosystem at the interface of physicochemical and biological processes. It is regulated by carbonate equilibrium, both in the oceans and in the inland waters and is imported by biological process such as photosynthesis and respiration. The composition of plankton community could be affected by pH of water in which they live. According to Schindler, (1988); Battarkee, (1990); and Charles,(1991), effects of hydrogen ion activity on aquatic biota have received the most attention across the globe, In particular, the impact of lowered pH in poorly buffered water, which was formed as result of acidic disposition of devious activities performed in the aquatic medium. In the present study it was observed that the pH values ranged between a minimum of 7.8 to a maximum of 8.26 showing the pH was alkaline. This observation was compatible with the study of Lalli and Parson (1993) who sated that pH is relatively constant in the ocean 8 ± 0.5. The lowest annual mean pH value of 7.8 was recorded in Diu, which coincided with maximum plankton density. With the increase in pH the plankton density showed lowest productivity. When pH and zooplankton abundance were correlated, it exhibited an inverse relationship affecting the zooplankton density and diversity of the community. However, the significance of pH for the occurrence and competitiveness for many of the planktonic species is virtually still unknown. This may result from the assumption that daily and seasonal fluctuations in pH are minor, relative to those of temperature and biological interactions in the marine ecosystem. However, pH fluctuations by 1-2 units imply 10 to 100 fold changes in free hydrogen ion activity. It is well known that hydrogen ion concentration gradients affect many transport process across cellular membranes and metabolic functions in the cytoplasm and cellular organelles of the many of the aquatic organisms (Anderson, 1988 and Prescots *et al.,* 2002). Further, pH has a strong impact on solubility, bioavailability and toxicity of some heavy metals (Anderson, 1988 and Wetzel, 2001). Michaclidis *et al.* (2005) from their study observed that 0.7 unit pH reduction lowers the metabolic rate and growth of mussels. According to Shirayama and Thornton, (2005) when mere 0.03 units lower pH, reduction in the growth and continued existence of gastropods and sea urchin are seen. In fact, the acidification of the Oceans all over the world, could severely impact the many marine invertebrates and algae that build carbonates structures. Freely *et al.* (2004) stated that if Ocean water becomes more acidic, it reduces the calcification in corals and coralline red algae. Therefore, impacts of such overwhelming changes in the world's oceans that affect the population and its community in the marine ecosystem are largely unknown. Considering that the expected pH drop may be unprecedented over the last several hundred million years. Hence, the study for the ecological implications of pH change in marine ecosystem is desperately needed.

Similar to temperature and pH, the concentration of dissolved oxygen is also considered to be a very important factor for the subsistence of all the marine life forms. Although oxygen exists in gaseous state in nature, they dissolve to a certain extent in aquatic medium. All the living species, whether terrestrial and aquatic need oxygen to keep their cells alive. Michael *et al.* (1993) has shown that dissolved oxygen can influence the survival of planktons. In the present study, dissolved oxygen showed a positive correlation with zooplankton abundance. It was observed that plankton population was maximum when the dissolved oxygen level was high. However, zooplankton showed reasonably fair density, when the dissolved oxygen was at its upper limits with the relative drop in temperature. The increase in temperature showed relatively moderate concentration of dissolved oxygen at Veraval and Diu though it showed a drop in oxygen concentration in Alang of the Saurashra coast. In view of the fact that, Diu carried the highest plankton density with high dissolved oxygen concentration, suggesting that there exists a direct correlation between dissolved oxygen level and plankton population. However, Kamykowski and Zintra (1990) observed that, oxygen minimum zones are also found throughout through out the Worlds Ocean. And the zooplankton abundance is recurrently reduced in these oxygen minimum layers (Sewell and Fage, 1948; Vinogradov and Oronina, 1961; Longhurst, 1967). Where as Judkins (1980) suggested that oxygen minimum zones appear to be inhabited by particular zooplankton species that can tolerate low oxygen but not true anoxybionts.

Furthermore, the turbidity in Seawater is considered as an essential factor affecting the community structure in the marine ecosystem. Turbidity in Sea includes all suspended materials like slit, clay and sediments, the phytoplankton community and detritus (decaying organic materials). High turbidity in natural Seawater may affect the species composition, community structure, biomass availability, and growth rate. There is a lack of information from many part of the world including India, on impact of highly turbid Seawater on the ecology and diversity of Marine biota (Ragunathan *et al.,* 2003). In the present study it was observed TSS exhibited a negative relation with zooplankton abundance. Scott (2006) observed a negative correlation between total suspended solids and zooplankton distribution estuarine turbidity zone (ETZ) zone of the Chesapeake Bay. This is characterized by high total suspended solids, high light attenuation and high densities of few omnivorous copepods e.g. *Eurytemora affinis*. Whereas Mysids and Copepods e.g. *Acartia tonsa* were found to be trivially distributed. Amongst the three stations, the Alang carried the highest suspended solid level. This is in agreement with Tiwari, *et al.* (2001) that seawater in the Gulf of Khambatt of Arab Sea is very turbid, mainly by sand, silt and clay brought by the perennial rivers of South Gujarat. Nair *et al.* (1983) reported related observations that maximum production occurs in surface waters during monsoon because of the increase in turbidity of Seawater thus carrying maximum essential nutrients along with it. Similarly, maximum productions were seen in bottom waters due to greater penetration of light. This ephemeral distinction has been given equal importance in plankton ecology. Verma *et al.* (1975) suggested that increased turbidly in coastal waters from the land run off prevent many larvae from entering the estuary or caused newly settled larvae to be flushed out. Increased turbidity alters predator efficiency, which might indirectly affect zooplankton community dynamics. However, it can be seen that Diu, which has highest plankton density have low suspended solids in compare to the other two sites *viz* Veraval and Alang. However, Pereira, *et al.* (2003 b) gave a different statement from his observation that with increase in freshwater inflow and river discharge causes elevations in turbidity. These conditions caused an increase in the phytoplankton density and vice-versa.

Amongst, all the factors described salinity of the Seawaters is the most vital factor to be measured. Salinity always shows constant values but reasonable variations occur in the Ocean salinity due to several factors. Salinity fluctuates with variations in temperature (Emelia, 1978). In the present study, Salinity showed a positive relation with zooplankton average density. During period of reduced salinity, densities of copepods, Uca Zoeae and barnacle nauplii decreased and densities of Uca megalopae and Penaus postlarvae increased in the intertidal Salt Marsh Basin at North Inlet Estuary, South Carolina (Dorian and Dennis, 1996). However, among the stations, Alang showed the low salinity value comparative to Diu and Veraval. In spite of this, Alang showed the maximum species richness. There appears to be species–specific salinity preference in the zooplankton community especially among copepods. Hansen *et al.* (2005) observed from their studies that high abundance of *C. cairinatus* and *R. nasutus* were associated with cold (<13.0 °C) low salinity water. Similarly *M. lucens* was abundantly seen in much wider ranges of salinity. The variations occurring in diversity of zooplankton could be explained to some extent based on the salinity fluctuation. Gario-soto *et al.* (1990) and Kelly *et al.* (2000) from their observation explained that the diminution of diversity index values indicated a less explored biotope due to gradient developed in salinity incursion. During the present study, annual increase in salinity was noticed in Diu and Veraval with high density of plankton. This was in uniformity with the studies made from the estuarine areas of the Mandovi–Zuari (Goswami, 1982) and in the coastal waters of Trivandrum (Haridas *et al.*, 1980).

In addition to the affect of physicochemical variants on the community structure of the plankton in marine ecosystem, there are other features responsible for brining changes in the abundance and compositions of the plankton community and its interrelationships. These factors are food, predators and nutrients that are considered responsible for plankton abundance and composition. The competition for food may be as vital as competition for space. Peter *et al.* (1977) specified that feeding habits rather than quantity of food are responsible for co existence among plankton organism. Havens (1991) gave conclusions that selectivity of food depends on the zooplankton composition, since the nature of the food selection varies among the zooplankton taxa. In coastal waters, apart from the effects of physicochemical aspects on the plankton population, grazing by herbivores also brings changes in the producer (phytoplankton) population. In the study, cholorophyll - a was positively related to zooplankton abundance, showing there interrelationship. Moreover, Sommer *et al.* (2000) and Sommer *et al.* (2001) suggested that the feeding behavior of the zooplankton might change with the season; where as grazing, stress appeared to be different during different seasons. Any changes in the composition of the phytoplankton would lead to subsequent changes in the zooplankton community. However, phytoplankton showed proportionately high numbers than zooplankton in Alang and Veraval. The reason for the low zooplankton diversity is attributed to presence of high proportion of Chrysophyceae and Cynosophyceae in the seawaters of Alang and Veraval. Abdul (2004) conferred these observations that Chlorophyceae, Cyanophycea and Crysophyceae were less palatable food for many of the zooplankters, particularly copepods and rotifers that depend mainly on Bacillariophyceae more than Chlorophyceae and Cyanophycea as food. In present study Diu, Veraval and Alang showed presence of Carnivores' species like *Temora, Acrocalanus, Rhincalanus,* and *Centropages* that were more prominent considerably during some seasons. However, there is a virtual increase in herbivores species like *Paracalanus Calanus, Nannocalanus, Parvocalanus and Copepod naupli* that feed upon different phytoplankton making a noticeable drop in their counts. Besides, it is perhaps difficult to identify the exact factors responsible for overall community variations with respect to time and species coexistence within space Thus, exhibiting a consistent pattern in the seasonal succession. Smith, (1979); Bradley, (1990); Hoffmeyer, (1994) and Calbert, *et al.* (2001) specified that available food production, grazing, competition and predation are essential factors to be observed for plankton compositions. However, Madhupratap *et al.* (2001) suggested that there exists a relationship between highly transient phytoplankton community diversity in the pelagic ecosystem that is translated into the higher tropic levels of the food web. Phytoplankton exhibits different groups thus displaying species-specific preferences for diet by organisms at higher tropic level (Schnetzer and Steinberg, 2002). Hence, it would be envisaged that preference for various phytoplankton as food might be different thus causing a steady decrease in the overall phytoplankton population. Behn and Bocemans, *et al.* (2001) from their related observations explained that herbivores have been shown to alter phytoplankton productivity, distribution and overall community structure in a marine ecosystem. Among the assorted factors, competition for food may not be as vital as competition for space as the feeding habits rather than quantity of food are responsible for existence among plankton organisms (Petel, *et al.*, 1977). Nevertheless, during the study period, time component of the total variance among the plankton community was predominant.

In the present study most of the recorded zooplankton populations are herbivores or detrivores suggesting that the phytoplankton constitutes the major source of food. Any variations in the composition of phytoplankton would lead to subsequent changes in the plankton community. Diu recorded the maximum chlorophyll – a with a subsequent increase in the zooplankton density. However, from Veraval to Alang annual chlorophyll – a concentration exhibited a descending trend with a consequent decline in zooplankton population. Goswami and Devassy (1991) found cladoceran abundance to be positively correlated with chlorophyll-a level. Besides, all the factors nutrient levels are also an important determinant of marine biodiversity, influencing the process of competition and community structure in the marine environment.

In the present study, the lowest concentration of nutrients was observed with gradually increase (Refer Chapter one). Consequently, this supported the increase in the hetrotrophs: zooplankton population as there occurred a steady growth in the phytoplankton count at Diu. Krishanamurthy, (1961) and Santhakumari (1971) have attributed to the raise in phytoplankton count with the increase in the nutrient content and this influences the zooplankton diversity and abundance to a large extent (Ramaiah and Nair, 1997). 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 considerably concurred with the maximum zooplankton population. A comparable observation by Unterüberbacher (1964) noted highest zooplankton abundance during some season, taking inter annual variability into account. Kollmer, (1962, 1963) reported a substantial raise in zooplankton abundance with a periodic increase in phytoplankton concentration. However, Timonin, *et al.* (1992) studied the tropho-ecological characteristics of zooplankton species and observed that in addition to their general distribution, all are closely linked to hydrological conditions in the marine environment. Although, this contradicts with observations 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. As nutrients increase the environment becomes mesotrophic. This results in the increase in phytoplankton productivity, thus reducing the transparency of the water and thereby reducing the penetration of light. This promotes the eutrophication in the marine waters and the community becomes dominated by precise species that have high fecundity, early maturity and fast growth. The occupation of several niches by a few generalist species thereby reduces the diversity (Lalli and Parsons, 1997). Among, all the factors grazing are always considered as an essential process in limiting the amplitude of phytoplankton concentration during both bloom and oligotrophic conditions. Godhantaraman (2001) has attributed that the biological variables i.e. chlorophyll – a values can be positively correlated with variations in zooplankton populations. Contrary to the expectations Xabies *et al.,* (2004) noted that there exists a lack of relation between phytoplankton and zooplankton diversity: with the inclusion of mesozooplankton. However, along with the hydrological factors many biotic causes may also play a consequent role in controlling the plankton community structure. The community structure also depends to a great extent on the factors affecting the recruitment pattern, presence or absence of predators along with many other complex biological interactions. Macrophytes play a role in increasing the hetrogenicity in the aquatic ecosystem. Urale, (1990) indicated that spatial variation in the macropytes regulates the abundance of zooplankton. Therefore, presence of predators brings dramatic changes in abundance, community, composition and phenology of plankton at lower tropic levels (Edward *et al.,* 2002; Beaugarnd, 2004; Edward and Richardson, 2002). Some zooplankton taxa were observed to occur exclusively at a particular sampling site showing compartmentalization of the habitat in terms of the resource availability and/or pollution level as envisaged by Sheshagiri and Anil (2003). Thus, it can be concluded that both the abiotic and biotic factors work conjointly producing an inclusive environment responsible for the possible selectiveness of the plankton population. Hence, it can be concluded that, each site shows its own diversity pattern with respect to the varying abiotic and biotic features. However, the more adaptive species possibly outgrows the less efficient one reducing the overall diversity and affecting the interrelationship among the plankton community. Further, these multivariate analysis, provide evidence on the overall distribution and community dynamics of plankton population. This could greatly help in understanding the integration with behavioral studies and characterization of oceanographic features of each study station. The other central aspect for the interpretation of the multivariate ordination, which remains to be fully acknowledged, is the role of Crustaceans, its behavior and its interaction with the physical features of the marine environment at different geographic areas and oceanographic conditions. Hence, this is probably a fruitful direction for the future studies of near shore plankton distribution, its community dynamics and behavioral pattern using Multivariate Ordinations.

Table 4.1. Annual composition of zooplankton community at Diu, Veraval and Alang of the Saurashtra Coast.

STATIONS	S	N (ind/m^3)	J	d	H'
Diu	4	182264 ± 8762[@]	0.25	0.8782	1.217
Veraval	4	109067 ± 6492	0.26	0.8932	1.238
Alang	4	52609 ± 3208	0.28	0.856	1.187

[@] Mean ± Standard Deviation; n = 3

S = Number of species, N = Average Annual Density, d = Species richness, j = Evenness, H' = Diversity

Table 4.2. Zooplankton density during different seasons at the three stations of the Saurashtra Coast.

STATIONS	Winter ind/m^3	Pre monsoon ind/m^3	Monsoon ind/m^3	Post monsoon ind/m^3	Annual ind/m^3
Diu	6072 ± 744[@]	1677 ± 486	7619 ± 486	8400 ± 675	45566 ± 5936
Veraval	3606 ± 890	1057 ± 332	3161 ± 684	4678 ± 913	27267 ± 1918
Alang	2632 ± 217	579 ± 121	2850 ± 316	2127 ± 664	13152 ± 793

[@]Mean ± Standard Deviation; n = 3

Table 4.3. Annual mean physicochemical characteristics of the study sites - Diu, Veraval and Alang

DIU

PARAMETERS	
Temperature (Water) (°C)	28.8 ± 1.18[@]
pH	7.8 ± 0.20
DO (mg/L)	5.59 ± 0.70
Salinity (‰)	32.4 ± 1.70
TSS (g/L)	0.32 ± 0.50
Chlorophyll – a (mg/m^3)	2.06 ± 0.66

VERAVAL

PARAMETERS	
Temperature (Water) (°C)	29.6 ± 1.57[@]
pH	8.23 ± 0.10
DO (mg/L)	4.67 ± 0.69
Salinity (‰)	32.0 ± 1.14
TSS (g/L)	0.39 ± 0.10
Chlorophyll – a (mg/m^3)	1.78 ± 0.55

ALANG

PARAMETERS	
Temperature (Water) (°C)	30.0 ± 1.18[@]
pH	8.26 ± 0.04
DO (mg/L)	2.83 ± 0.46
Salinity (‰)	31.6 ± 1.8
TSS (g/L)	0.45 ± 0.10
Chlorophyll – a (mg/m^3)	1.04 ± 0.29

[@]Mean ± Standard Error (SE); n = 3

Table 4.4. Seasonal variation in individual density (ind/m^3) and percentage of occurrence of zooplankton species at Diu

Species	Winter	%	Pre monsoon	%	Monsoon	%	Post monsoon	%	Annual density	%
Acrocalanus gracillis	0$^@$	0.0	1700$^@$	16.90	0$^@$	0.00	13526$^@$	20.13	13526$^@$	7.42
Acrocalanus	10684	29.3	0	0.00	0	0.00	0	0.00	12384	6.79
Calanus sp	0	0.0	0	0.00	8004	11.67	0	0.00	8004	4.39
Calocalanus garcilis	0	0.0	0	0.00	3256	4.75	0	0.00	3256	1.79
Candacia Sp	5634	15.5	0	0.00	0	0.00	0	0.00	5634	3.09
Centropages elongata	0	0.0	0	0.00	0	0.00	8605	12.81	8605	4.72
Centropages Sp	0	0.0	3456	34.35	0	0.00	0	0.00	3456	1.90
Cyclopoid nauplius	0	0.0	0	0.00	9568	13.95	0	0.00	9568	5.25
Eucalanus Sp	4567	12.5	0	0.00	0	0.00	0	0.00	4567	2.51
Isias tropica	0	0.0	0	0.00	0	0.00	15426	22.96	15426	8.46
Larvae of cyclopoid	3328	9.1	0	0.00	0	0.00	0	0.00	3328	1.83
Microsetella Sp	0	0.0	845	8.40	0	0.00	0	0.00	845	0.46
Microsetella gracillis	0	0.0	0	0.00	0	0.00	1200	1.79	1200	0.66
Nannocalanus minor	0	0.0	0	0.00	0	0.00	5894	8.77	5894	3.23
Nonion Sp	0	0.0	384	3.82	0	0.00	0	0.00	384	0.21
Oikopleura Sp	0	0.0	986	9.80	0	0.00	0	0.00	986	0.54
Oithona Sp	0	0.0	0	0.00	2135	3.11	0	0.00	2135	1.17
Paracalanus Sp	7896	21.7	2689	26.73	9658	14.08	6524	9.71	26767	14.69
Parvocalanus Sp	0	0.0	0	0.00	12365	18.03	0	0.00	12365	6.78
Pleuronamma sp	0	0.0	0	0.00	8745	12.75	0	0.00	8745	4.80
Rhincalanus Sp	4325	11.9	0	0.00	10258	14.96	10785	16.05	25368	13.92
Temora discaudata	0	0.0	0	0.00	4581	6.68	0	0.00	4581	2.51
Temora Sp	0	0.0	0	0.00	0	0.00	5240	7.79	5240	2.87

$^@$ Median value; n = 3

Table 4.5. Seasonal variation in individual density (ind/m^3) and percentage of occurrence of zooplankton species at Veraval

Species	Winter	%	Pre monsoon	%	Monsoon	%	Post monsoon	%	Annual density	%
Keratella sp	$2675^{@}$	12.36	$0^{@}$	0	$0^{@}$	0	$0^{@}$	0	$2675^{@}$	2.45
Acrocalanus gracillis	0.0	0.00	0	0	0	0	5002	11.88	5002	4.59
Acrocalanus Sp	2659	12.29	0	0	8523	22.47	0	0.00	2659	2.44
Calocalanus gracillis	0	0	0	0	2584	3.71	0	0	8523	7.81
Calanus sp	0	0.00	0	0	2584	6.81	0	0.00	2584	2.37
Candacia Sp	1502	6.94	0	0	0	0.00	0	0.00	1502	1.38
Centropages elongata	0.0	0.00	0	0	0	0.00	5864	13.93	5864	5.38
Centropages Sp	0	0.00	675	9.12	0	0.00	0	0.00	675	0.62
Cyclopid nauplius	0	0.00	0	0.00	1025	2.70	0	0.00	1025	0.94
Eucalanus Sp	3562	16.46	0	0.00	0	0.00	1004	2.38	4566	4.19
Euchaeta Sp	0	0.00	0	0.00	4512	11.89	0	0.00	4512	4.14
Fish egg	0	0.00	1089	14.72	0	0.00	7895	18.75	8984	8.24
Gastropod	0	0.00	540	7.30	0	0.00	0	0.00	540	0.50
Globigerina Sp	0	0.00	567	7.66	0	0.00	0	0.00	567	0.52
Hippopodius Sp	0	0.00	0	0.00	569	1.50	0	0.00	569	0.52
Isias tropica	4285	19.80	0	0.00	0	0.00	4852	11.53	9137	8.38
Mysis of *P.Indica*	0	0.00	0	0.00	0	0.00	2415	5.74	2415	2.21
Oithona Sp	0	0.00	0	0.00	1458	3.84	0	0.00	1458	1.34
Paracalanus Sp	6953	32.14	2895	39.13	7895	20.81	9562	22.71	27305	25.04
Parvocalanus Sp	0	0.00	0	0.00	3564	9.40	0	0.00	3564	3.27
Pleuronamma gracillis	0	0.00	0	0.00	4003	10.55	0	0.00	4003	3.67
Post larva of fish	0	0.00	0	0.00	1500	3.95	0	0.00	1500	1.38
Rhincalanus cornutus	0	0.00	786	10.62	1095	2.89	4501	10.69	6382	5.85
Rosalina Sp	0	0.00	847	11.45	1205	3.18	0	0.00	847	0.78
Temora discaudata	0	0.00	0	0.00	0	0.00	1004	2.38	2209	2.03

@ Median value; n = 3

Table 4.6: Seasonal variation in individual density (ind/m^3) and percentage of occurrence of zooplankton species at Alang

Species	Winter	%	Pre monsoon	%	Monsoon	%	Post monsoon	%	Annual density	%
Acrocalanus gracillis	0[@]	0	0[@]	0	0[@]	0	5662[@]	33.37	5662[@]	10.76
Acrocalanus sp	2600	24.69	256	11.06	0	0	0	0.00	2856	5.43
Calocalanus garcilis	3265	31.01	0	0.00	4562	20.01	0	0.00	7827	14.88
Centropages elongata	0	0.00	0	0.00	0	0.00	2514	14.82	2514	4.78
Cyclopoid nauplius	0	0.00	0	0.00	2351	10.31	2025	11.94	4376	8.32
Euchaeta sp	0	0.00	0	0.00	6321	27.72	0	0.00	6321	12.02
Gastropod	0	0.00	0	0.00	700	3.07	0	0.00	700	1.33
Larva of barnacle	0	0.00	0	0.00	752	3.30	0	0.00	752	1.43
Mysis of *P.Indica*	0	0.00	0	0.00	0	0.00	502	2.96	502	0.95
Nannocalanus minor	0	0.00	0	0.00	0	0.00	2546	15.01	2546	4.84
Oithona brevicornis	0	0.00	0	0.00	0	0.00	857	5.05	857	1.63
Paracalanus Sp	2664	25.30	0	0.00	0	0.00	2245	13.23	4909	9.33
Quinqueloculina sp	0	0.00	0	0.00	0	0.00	615	3.62	615	1.17
Sagitta enflata	0	0.00	758	32.76	4000	17.54	0	0.00	4758	9.04
Sagitta sp	2000	19.00	650	28.09	3560	15.61	0	0.00	6210	11.80
Temora discaudata	0	0.00	0	0.00	554	2.43	0	0.00	554	1.05
Zoea larva	0	0.00	650	28.09	0	0.00	0	0.00	650	1.24

Median value; n = 3

Table 4.7. The Principal component scores showing the degree of correlation of zooplankton communities at the three different sampling stations.

Eigen values

PC	Eigen values	% Variations	Cum.% Variations
1. (Diu)	1.52	50.7	50.7
2 (Veraval)	0.91	30.4	81.1
3 (Alang)	0.57	18.9	100

Variable	PCA 1	PCA 2	PCA 3
Diu	0.665	0.184	0.724
Veraval	0.636	-0.369	-0.678
Alang	0.392	-0.911	-0.128

Principal Component Scores

Sample	Score 1	Score 2	Score 3
Keratella sp	-0.21	-0.739	-1.019
Acrocalanus gracillis	1.305	1.736	1.098
Acrocalanus Sp	1.015	0.435	0.797
Calanus sp	0.777	-1.018	-0.259
Calocalanus garcilis	0.972	2.726	-0.468
Candacia Sp	-0.297	-0.468	0.377
Centropages elongata	0.961	0.178	0.000
Centropges Sp	-0.493	-0.420	0.118
Cyclopid nauplius	0.807	1.248	0.612
Eucalanus Sp	-0.157	-0.581	-0.001
Euchaeta Sp	0.613	2.066	-0.980
Fish egg	1.107	-1.451	2.327
Gastropod	-0.761	0.246	-0.181
Globegerina Sp	-0.969	-0.248	-0.115
Hippopodius Sp	-0.969	-0.248	-0.116
Isias tropica	1.5888	-1.265	0.467
Larva of barncle	-0.905	0.099	-0.086
Larvae of cyclopoid	-0.706	-0.300	0.317
Microsetella Sp	-0.953	-0.232	0.048
Microstella gracillis	-0.918	-0.242	0.087
Mysis of *P.Indica*	-0.749	-0.376	-0.350
Nannocalanus minor	-0.003	0.671	0.449
Nonion Sp	-0.999	-0.219	-0.002
Oikilopleura Sp	-0.939	-0.236	0.064
Oithona brevicornis	-0.886	0.142	-0.093
Oithona Sp	-0.651	-0.368	0.003
Paracalanus Sp	5.749	-0.825	-0.894
Parvocalanus Sp	0.619	-0.796	0.844
Pleuronamma gracillis	-0.559	-0.485	-0.552
Pleuronamma sp	-0.167	-0.450	0.905
Post larva of fish	-0.858	-0.312	-0.234
Quinqueloculina Sp	-0.929	0.043	-0.079
Rhincalanus cornutus	-0.275	-0.650	-0.855
Rhincalanus Sp	1.487	-0.908	2.707
Rosalina Sp	-0.936	-0.267	-0.151
Sagitta enflata	-0.200	1.739	-0.316
Sagitta Sp	0.055	2.333	-0.400
Temora discaudata	-0.220	-0.261	0.141
Temora Sp	-0.516	0.353	0.525
Zoea larva	-0.923	0.057	-0.081

Table 4.8. Result of taxonomic distinctness tests (TAX D TEST) shows the level of classification used for the zooplankton taxonomy of the intertidal zone. Brach shows the series of classification from the phylum to species level. Weight depicts the total length between i & j species in the taxonomic classification of the hierarchical order.

Taxon	Branch	Weight
Species	1	16.667
Genus	1	33.333
Family	1	50
Order	1	66.667
Class	1	83.333
Phylum	1	100

Table 4.9. The level of classification used for the zooplankton taxonomy of the intertidal zone using species richness aggregation data. Weight depicts the total length between i & j species in the taxonomic classification of the hierarchical order.

Taxon	Branch	Weight
Species	1	-92.739
Genus	1	-77.452
Family	1	-15.032
Order	1	-15.032
Class	1	6.3694
Phylum	1	100

Table4.10: Correlation between mean physicochemical parameters and zooplankton abundance.

Variable 1*	Variable 2*	Correlation Coefficient (r)
Temp (Water)	pH	0.962
Temp (Water)	DO	-0.929
Temp (Water)	Salinity	-0.982
Temp (Water)	TSS	0.989
Temp (Water)	Chlorophyll-a	-0.903
Temp (Water)	Zooplankton abundance	-0.993
pH	DO	-0.793
pH	Salinity	-0.894
pH	TSS	0.913
pH	Chlorophyll-a	-0.752
pH	Zooplankton abundance	-0.925
DO	Salinity	0.982
DO	TSS	-0.973
DO	Chlorophyll-a	0.998
DO	Zooplankton abundance	0.965
Salinity	TSS	-0.999
Salinity	Chlorophyll-a	0.968
Salinity	Zooplankton abundance	0.997
TSS	Chlorophyll-a	-0.956
TSS	Zooplankton abundance	-1.000
Chlorophyll-a	Zooplankton abundance	0.946

Variable 1* = Independent Variable 2* = Dependent

Figure 4.1 Annual hydrological profiles at the three stations of the Saurashtra (Diu, Veraval and Alang).

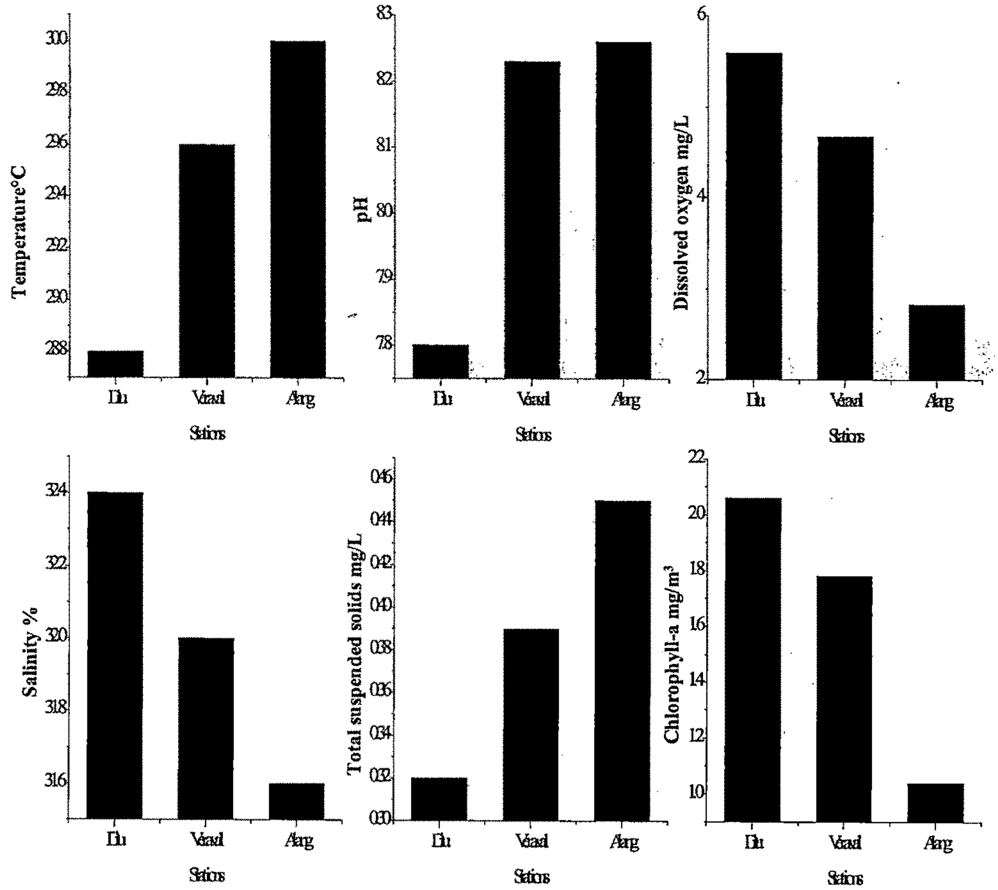
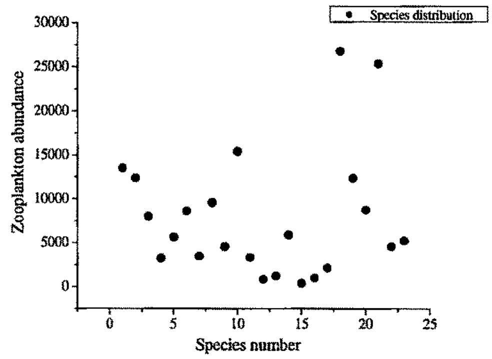
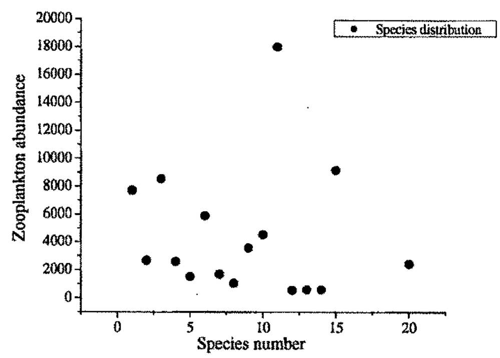


Figure 4.2-4.4 Annual distribution of zooplankton species as mean abundance value at various study sites

4.2 DIU



4.3 VERAVAL



4.4 ALANG

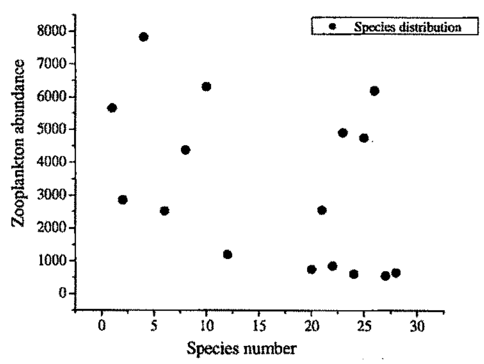
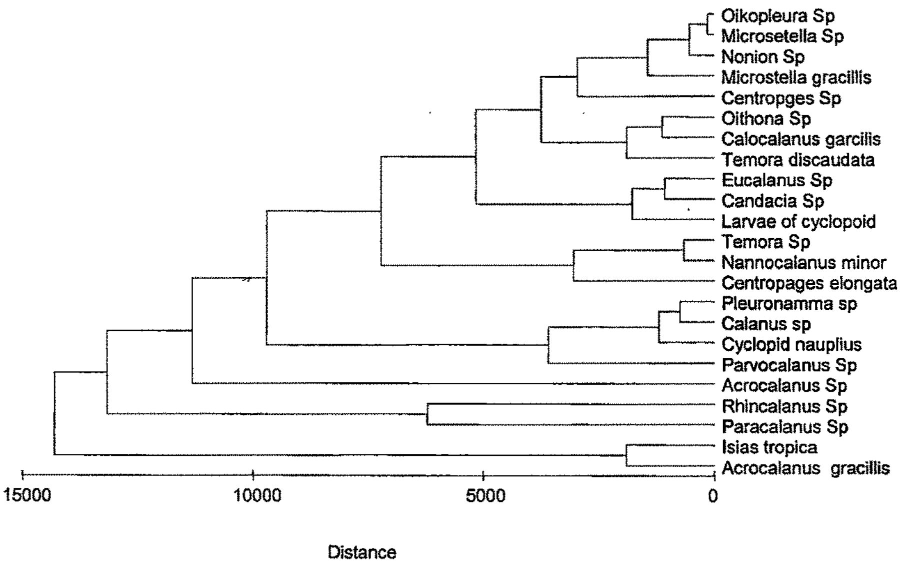


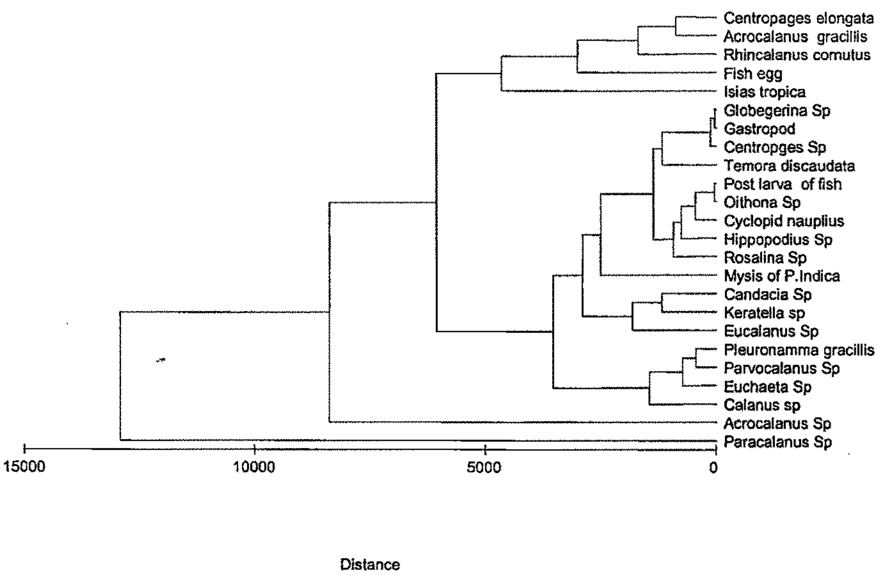
Figure4.5: Cluster analysis results in a Dendrogram showing linkages between zooplankton at Diu



Result

1. *Acrocalanus gracillis*	12+16 -> 24 at 141.
2. *Acrocalanus Sp*	15+24 -> 25 at 531.5
3. *Calanus sp*	14+23 -> 26 at 654.
4. *Calocalanus garcilis*	3+20 -> 27 at 741.
5. *Candacia Sp*	5+9 -> 28 at 1067.
6. *Centropages elongata*	4+17 -> 29 at 1121.
7. *Centropges Sp*	8+27 -> 30 at 1193.5
8. *Cyclopid nauplius*	13+25 -> 31 at 1426.91
9. *Eucalanus Sp*	11+28 -> 32 at 1772.5
10. *Isias tropica*	22+29 -> 33 at 1885.5
11. *Larvae of cyclopoid*	1+10 -> 34 at 1900.
12. *Microsetella Sp*	7+31 -> 35 at 2952.85
13. *Microstella gracillis*	6+26 -> 36 at 3038.
14. *Nannocalanus minor*	19+30 -> 37 at 3592.67
15. *Nonion Sp*	33+35 -> 38 at 3733.77
16. *Oikilopleura Sp*	32+38 -> 39 at 5148.23
17. *Oithona Sp*	18+21 -> 40 at 6204.75
18. *Paracalanus Sp*	36+39 -> 41 at 7203.86
19. *Parvocalanus Sp*	37+41 -> 42 at 9694.54
20. *Pleuronamma sp*	2+42 -> 43 at 11311.51
21. *Rhincalanus Sp*	40+43 -> 44 at 13164.92
22. *Temora discaudata*	34+44 -> 45 at 14302.47
23. *Temora Sp*	

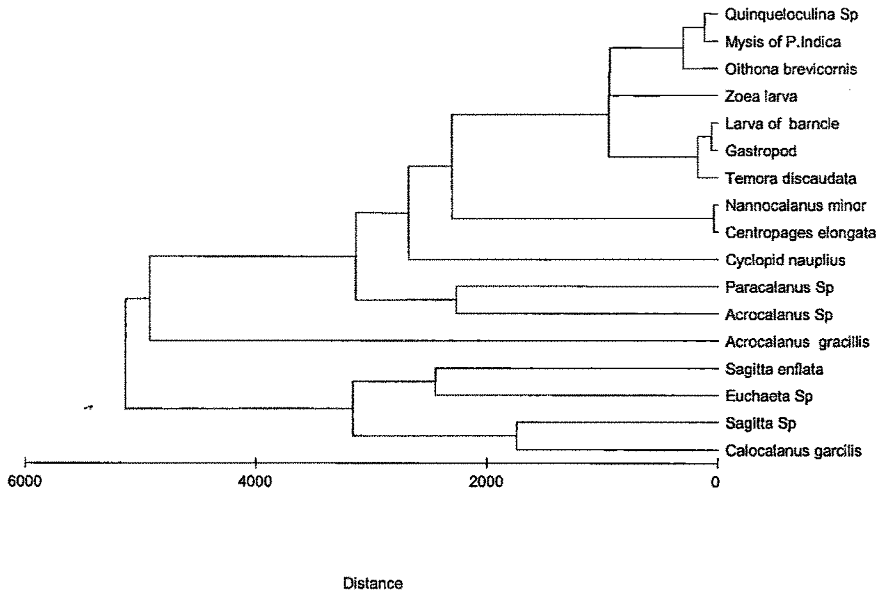
Figure 4.6 Cluster analysis results in a Dendrogram showing linkages between zooplankton at Veraval



Result

1. *Keratella sp*	1+3 -> 26 at 16.
2. *Acrocalanus Sp*	13+14 -> 27 at 27.
3. *Calanus sp*	18+22 -> 28 at 42.
4. *Calocalanus garcilis*	8+27 -> 29 at 121.5
5. *Candacia Sp*	24+29 -> 30 at 253.
6. *Centropages elongata*	20+21 -> 31 at 439.
7. *Centropges Sp*	9+28 -> 32 at 454.
8. Cyclopoid nauplius	11+31 -> 33 at 728.5
9. *Eucalanus Sp*	15+32 -> 34 at 758.67
10. *Euchaeta Sp*	2+7 -> 35 at 862.
11. Fish egg	25+34 -> 36 at 1072.58
12. Gastropod	6+26 -> 37 at 1165.
13. *Globegerina Sp*	30+36 -> 38 at 1408.59
14. *Hippopodius Sp*	5+33 -> 39 at 1442.33
15. *Isias tropica*	10+37 -> 40 at 1660.56
16. Mysis of *P.Indica*	23+35 -> 41 at 1677.46
17. *Oithona Sp*	17+38 -> 42 at 2516.24
18. *Paracalanus Sp*	40+42 -> 43 at 2904.08
19. *Parvocalanus Sp*	12+41 -> 44 at 2991.61
20. *Pleuronamma gracillis*	39+43 -> 45 at 3601.66
21. Post larva of fish	16+44 -> 46 at 4640.85
22. *Rhincalanus cornutus*	45+46 -> 47 at 6059.04
23. *Rosalina Sp*	4+47 -> 48 at 8110.34
24. *Temora discaudata*	19+48 -> 49 at 2993.26

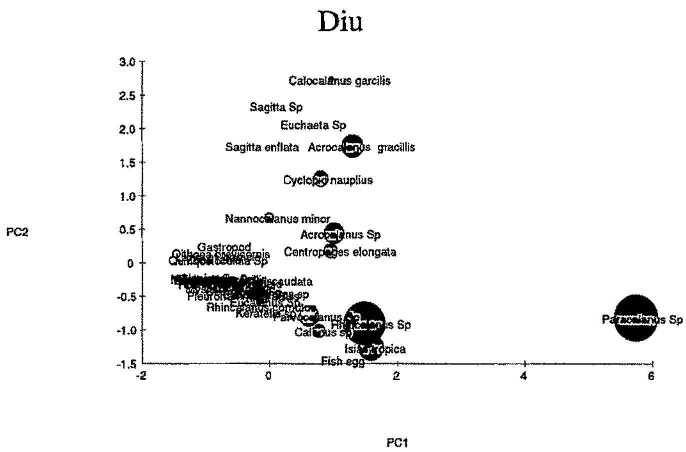
Figure 4.7. Cluster analysis results in a Dendrogram showing linkages between zooplankton at Alang.

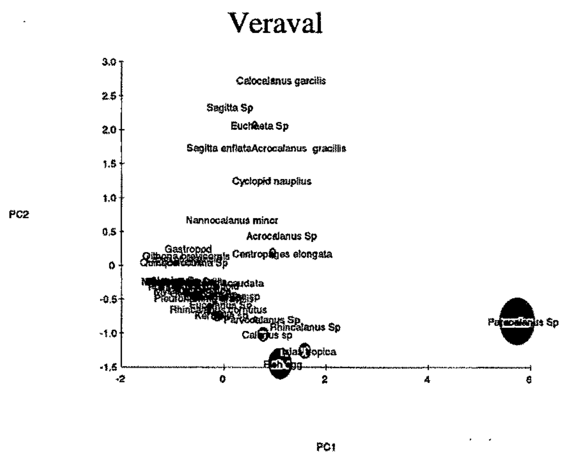


Result

1. *Acrocalanus gracillis*	4+10 -> 18 at 32.
2. *Acrocalanus Sp*	7+8 -> 19 at 52.
3. *Calocalanus garcilis*	9+13 -> 20 at 113.
4. *Centropages elongata*	16+19 -> 21 at 172.
5. Cyclopoid nauplius	11+20 -> 22 at 298.5
6. *Euchaeta Sp*	17+22 -> 23 at 930.58
7. Gastropod	21+23 -> 24 at 942.88
8. *Larva of barncle*	3+15 -> 25 at 1739.75
9. *Nannocalanus minor*	2+12 -> 26 at 2260.46
10. *Oithona brevicornis*	18+24 -> 27 at 2297.51
11. *Paracalanus Sp*	6+14 -> 28 at 2441.64
12. *Quinqueloculina Sp*	5+27 -> 29 at 2671.96
13. *Sagitta enflata*	26+29 -> 30 at 3128.27
14. *Sagitta Sp*	25+28 -> 31 at 3157.16
15. *Temora discaudata*	1+30 -> 32 at 4915.02
16. Zoea larva	31+32 -> 33 at 5125.8

Figure 4.8. PCA ordination plot showing the distribution of zooplankton species and the extent of relationship between them. The bubble represents the abundance value of each species in a community at the sampling stations





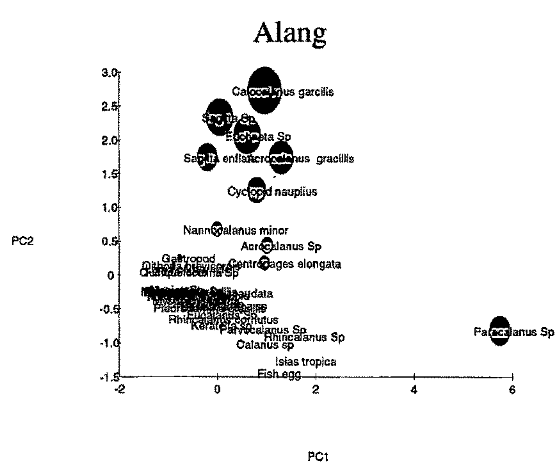
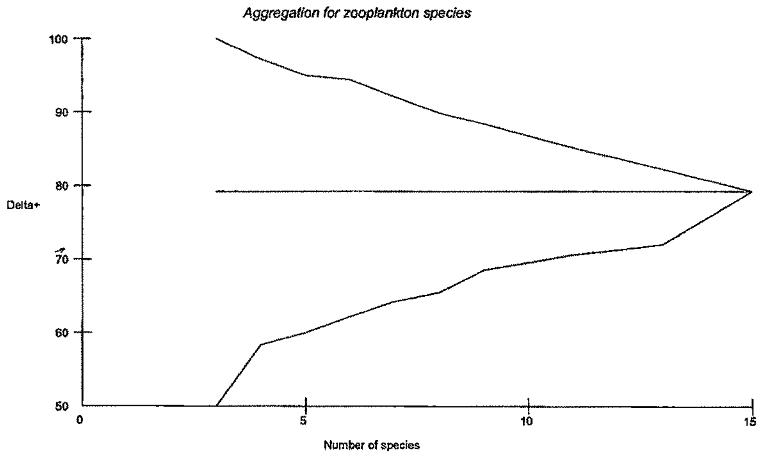


Figure 4.11. The distribution of zooplankton population using mean taxonomic distribution Δ* and within 95% confidence funnel, calculated using none transformed data. All the values of Δ* should fall within the confidence funnel assuming the null hypotheses that each station contains species randomly selected from the total species list.

Delta (+): denotes variations in the taxonomic distinctness



Lambda (+): measures the degree to when the species are taxonomically related to each other

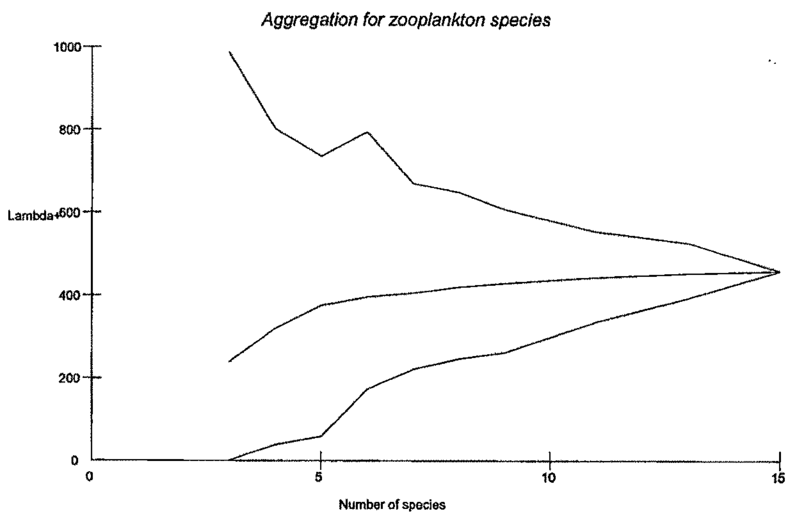


Figure 4.12. The distribution of zooplankton population using mean taxonomic distribution of Δ* and within 95% of ellipsoid graph, calculated using species richness aggregation data. All the values of Δ* should fall within the confidence limits assuming the null hypotheses that each station contains species randomly selected from the total species list.

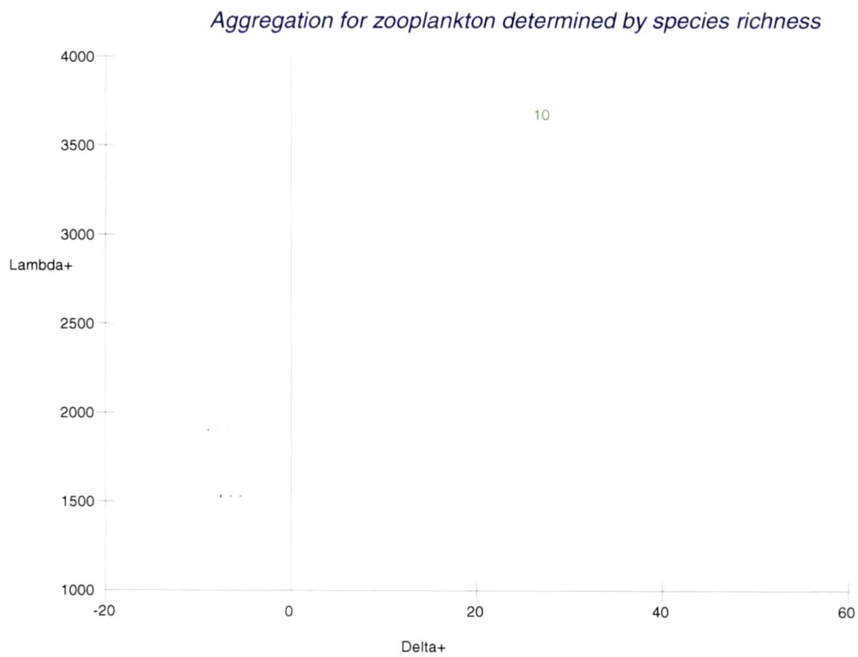
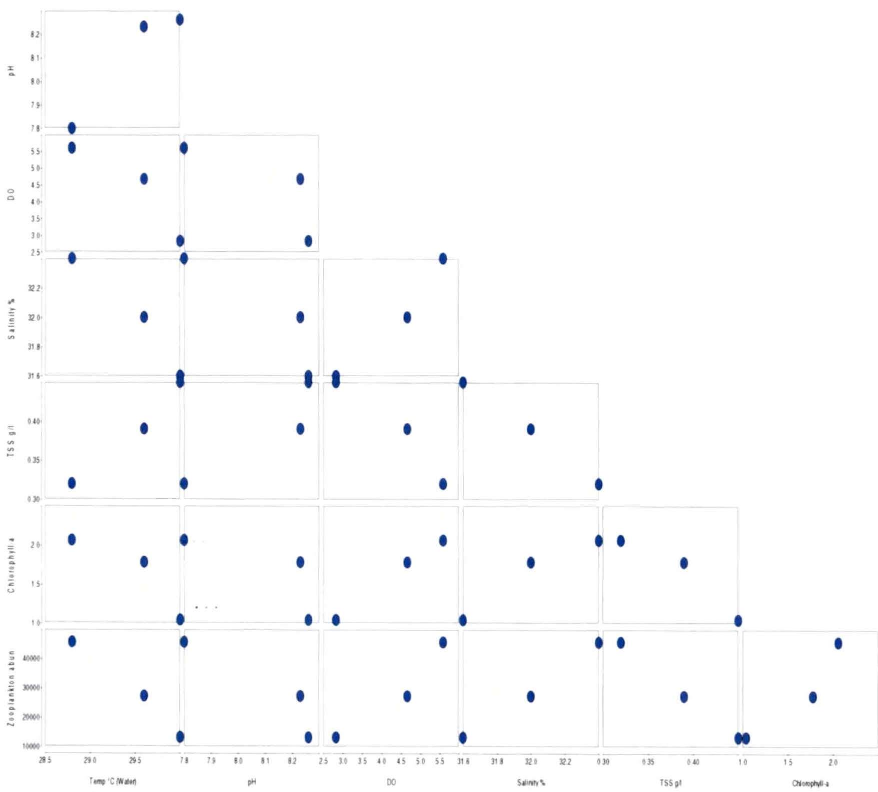


Figure 4.13. Relation between the annual hydrological parameters and the abundance of zooplankton at the three stations *viz* Diu, Veraval and Alang

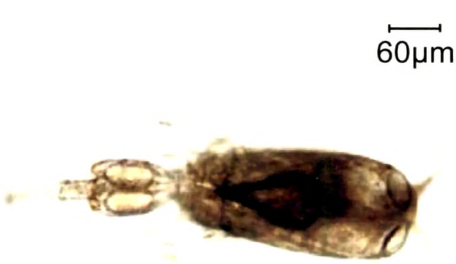


Acartia sp.

Copepod naupli

Rhincalnus rostifrons

Oncaea sp.



Coryceus sp.

Brachyuran zoea

Figure 4.12 Few representatives of zooplankton species recorded at Saurashtra coast

Temora sp.

Eucalanus sp.

Acartia sp.

Paracalanus sp.

Nannocalanus sp.

Centropages sp.

Figure 4.13 Few representatives of zooplankton species recorded at Saurashtra coast

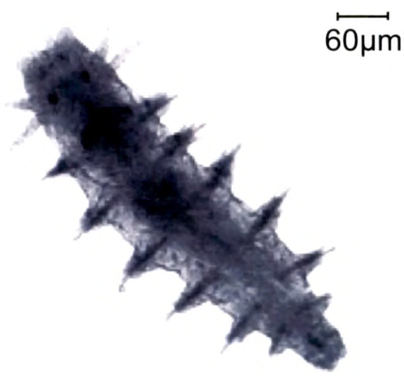
Setiger larvae.

Fish larvae

Ophiopluteus larvae

Brachyuran Zoea

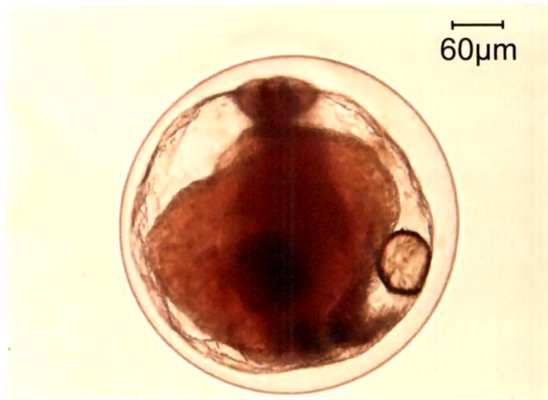
Protozoea of Lucifer



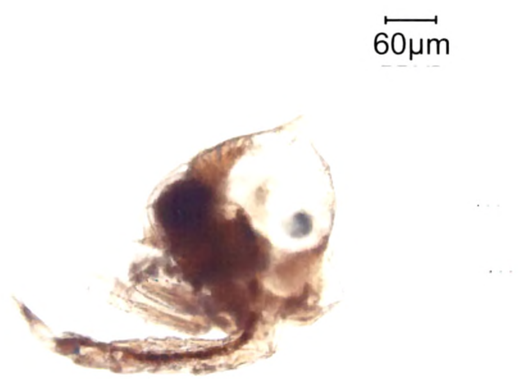
Polychaete larvae

Figure 4.14 Few representatives of zooplankton species recorded at Saurashtra coast

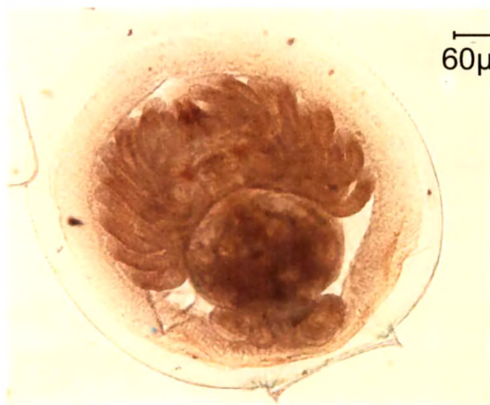
Peneiad larvae



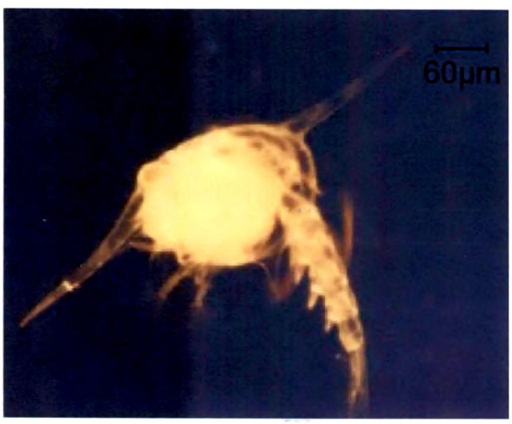
Fish egg



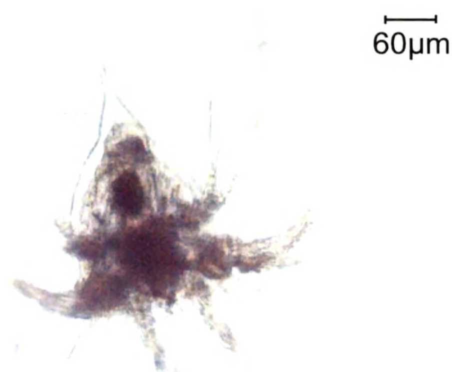
Zoea larvae



Brachiopod larvae



Brachyuran zoea of the crab



Copepod nauplea

Figure 4.15 Few representatives of zooplankton species recorded at Saurashtra coast