

**DISTRIBUTION OF INTERTIDAL PHYTOBENTHOS
OF POLLUTED AND COMPARATIVELY
UNPOLLUTED REGIONS ALONG MUMBAI.**

A

THESIS

**SUBMITTED TO THE
UNIVERSITY OF MUMBAI**

**FOR THE
DOCTOR OF PHILOSOPHY (SCIENCE)**

**DEGREE IN
APPLIED BIOLOGY**

**SUBMITTED BY
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March – 2012

STATEMENT BY THE CANDIDATE

As required by the University ordinances 770, I wish to state that the work embodied in this thesis entitled '**Distribution Of Intertidal Phytobenthos Of Polluted And Comparatively Unpolluted Regions Along Mumbai**' forms my own contribution to the research work carried out under the guidance of **Dr. JIYALAL RAM M. JAISWAR** at the **Regional Centre, National Institute of Oceanography, Mumbai – 400 053**. This work has not been submitted for any other degree of this or any other University. Whenever, references have been made to previous works of others, it has been clearly indicated as such and inducted in the bibliography.

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It is certified that the above statement made by the candidate is correct.

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*Dedicated
To
'My Loving
Grandparents'*

ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to my guide and advisor Dr. Jiyalal Ram M Jaiswar for his continuous support in my Ph.D study and research, and his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in research and writing of this thesis. Equally, I am thankful to his family who have been friendly and welcoming and always inspired me to achieve the goal.

Besides my advisor, I would like to thank Dr. S. R. Shetey, the Director of National Institute of Oceanography, Goa for his support and the team of Regional Center Mumbai, especially Dr. M D Zingde, Dr. K Govindan, Dr. S N Gajbhiye and Dr. Anirudh Ram Jaiswar for their encouragement.

My sincere thanks also goes to Department of Ocean Development, for offering me the Project Traniee III post which turned as a opportunity for me to work on diverse exciting projects.

I thank my fellow lab mates in National Institute of Oceanography: Dr. Shilpa Kamath, Dr. Meghana Nair, Mr. Sibu Nair, Late Mr. Anil Rai, Dr. Sushant Mane, Dr. Seema Khot, Ms. Sugandha Thakur, Mr. Siddesh Karangutkar, Mr. Nitin Walmiki, Mr. Somnath Vedpathak, Mr. Bhaskar Yengal and Ms. Reshma Kadam for being as a cordial friends working together during years. In addition, I would like to thank Mr. Mohhamad Illyas for his help during the field work. I would like to thank Mrs. Desouza, Mr. P B Nair and Mrs. Geeta Subramanyam for their support.

My thanks are due to Mrs. Bharati Joshi, Mrs. Archana Vithal Kamath, and Mrs. Deepa Rege for their assistance and support made available to me. Also I thank to Dr. Pradnya Bedeker, Dr. Moreshwar Pendse, Mrs. Mrinal George, Mrs. Manisha Kulkarni their continuous encouragement.

In particular, I am grateful to late Mr. Balaram Sakharam Kalyankar and late Mrs. Ratan Balaram kalyankar for they enlightened in me the first glance of the process of learning. Thank you doesn't seem sufficient but it is said with appreciation and respect; and to Mr. and Mrs. Rajas Vilas Raote who inculcated love towards education.

I would like to thank my grandparents: late Mr. Vasant Rambhau Paralkar and late Mrs. Sarojini Vasant Paralkar, as they made them selves available and their blessings are always with me. I would like to thank my parents Mr. Nagesh Vasant Paralkar and Mrs. Varsha Nagesh Paralkar, for their continuous efforts as well as hard work in their life which helped me in not losing a thread of my thesis and supporting throughout my life. And special thanks to my aunts (Suma, Sudha, Neena and Subodh) and my brother Mr. Tanuj Paralkar who's extended support stand still behind me throughout the work.

I would like to thank my in-laws: Mr. Suresh Jaywant Hule and Mrs. Rekha Suresh Hule, for support and encouragement.

On a personal note I would like to express my profound gratitude and gratefulness to Rege, Paralkar and Hule family members, whose blessings, boundless affection and encouragement made me to achieve this task.

I would like to give my special thanks to my husband Dr. Abhay Hule whose patient love enabled me to complete this work. And my daughter, "Purva" for her absolute adoring support in my absence while completing my work.

Above all, I am thankful to 'God' for his supreme wish.

Mugdha Nagesh Paralkar

Explanatory Note

AT	Air temperature
Av	Average
Chl <i>a</i>	Chlorophyll <i>a</i>
MPB	Microphytobenthos
Phaeo	Phaeophytin
DO	Dissolved oxygen
BOD	Biochemical oxygen demand
C _{org}	Organic carbon
SPOM	Suspended particulate organic matter.
LWL	Low level
HWL	High level
EPS	Extra-cellular polymeric substances
P	Phosphorus
N	Nitrogen
FI	Flood
Eb	Ebb
ND	Not detected

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- e: *Coscinodiscus granii* ;
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1 Introduction

Phytoplankters are generally defined as aquatic micro-autotrophs which are basic components of food chain whereas phytoplankton dwelling in sediment is known as phytobenthos. Phytobenthos is also referred as microphytobenthos (Mac Intyre *et al.*, 1996, de Jonge & Van Beusekom, 1992) which is a descriptive term used for the diverse assemblage of photosynthetic diatoms, cyanobacteria, dinoflagellates and microalgae that inhabit the surface layers of intertidal sediment. Both phytoplankton and microphytobenthos use light energy to fix CO₂, into organic matter (Mac Intyre *et al.*, 1996).

Phytoplanktons are the floating microscopic plants in the water column, drifting along with the water mass aided by winds and currents. They are predominantly autotrophic and produce the energy by photosynthesis process in presence of sunlight, water and carbon dioxide. Phytoplankton, primary producers play an important role in the energy cycle of an ecosystem and hence considered as an important part for the assessment of organic production in an aquatic ecosystem. During photosynthesis, the conversion of light to chemical energy depends upon the phytopigments, hence, the assessment of these pigments will determine the biomass (standing crop) of phytoplankton and similarly the qualitative and quantitative estimation of phytoplankton cell reflect their population (Strickland and Parsons, 1972; Raymont, 1980, Jiyalal 1985). There are different types of phytoplankton pigment viz. chlorophyll *a*, *b*, *c*, xanthophyll, carotenoids and phaeophytins in the algae. Among these chlorophyll *a* is the most active one and denotes the standing crop by taking major part in the photosynthesis process and also helps to know the condition of phytoplankton cells in an ecosystem (Jiyalal, 1985). The rate of photosynthesis can give an estimation of primary production potential of an

aquatic body. Chlorophyll *a* in combination with phaeophytin is a good index to evaluate the health of an ecosystem (Jiyalal *et al.*, 2011).

Phytoplankton are widely involved in pollution assessment studies, since pollutants may enhance or retard the growth of the phytoplankton, affecting the other organisms indirectly or directly and cause an imbalance in an ecosystem. Thus, the qualitative and quantitative studies of marine phytoplankton become imperative to understand the status of an ecosystem. Marine coastal environment of Mumbai with pockets of polluted regions offers an excellent opportunity to the study impact of anthropogenic pollutants on the phytoplankton in overlying water and microphytobenthos in sediment of intertidal area.

Studies on phytoplankton along Mumbai coast are limited to a few 1980's (Nair *et. al.*, 1980; Zingde and Desai, 1980; Abidi, *et. al.*, 1982; Jiyalal, 1984 and Jiyalal, 1985) which have established the basis for later studies to assess the environmental impact due to the settlement of a near by local population, different industries and other human activities. Information on microphytobenthos along Indian Coast is completely absent since there is no study carried out on this aspect.

Microphytobenthic communities are often thriving in surface sediments of inertidal regions (Dawes, 1998; Graham and Wilcox, 2000) and provide energy for mat growth and gelling activities (Paerl and Pinckney, 1996). The role of blue-green algae in stabilizing loose sediments has been recognized in studies of microbial mats (Golubic *et al.*, 2000). The gliding motility of their filaments in conjunction with a copious excretion of a polysaccharide sheath enables these organisms to spread rapidly over newly deposited sediments. But particularly diatoms play an important role in the sediment dynamics of mudflats and intertidal marshes, due to their mucilage secretion which increases consolidation of the particles and reduces erosion (Paterson, 1995 and Wilson and Holmes, 1981).

Marine microphytobenthos studied by Colijn and Dijkema (1981); Amspoker and McIntyre (1986); Alongi (1987); Delgado (1989); Cariou-Le Gall and Blanchard (1995); Peletier (1996); and Brotas and Plantae-Cuny (1998) have explained the process of life of microphytobenthos which are responsible to play a major role in regulating global warming by means of trapping carbon dioxide from atmosphere and transporting the carbon to the sediments. Although, there are number of works abroad [Colijn and Dijkema (1981) ; Amspoker and McIntyre (1986) ; Alongi (1987) ; Delgado (1989) ; Cariou-Le Gall and Blanchard (1995) ; Peletier (1996) ; and Brotas and Plantae-Cuny (1998) ; Varela & Penas, 1985 ; Plante-Cuny & Bodoy, (1987) ; Charpy Roubaud, (1988)] which have also explained the importance of microphytobenthos playing a role in maintaining the balance of carbon in the atmosphere.

Due to modernization and extensive development we face the challenge of the growing demand for land and water to meet the needs of our growing populations. At the same time we face the increasing uncertainty of the impacts of climate change and loss of resource capacity due to loss of water quality. Our ability to secure adequate clean water is a function of our ability to manage both water and land and to manage our activities so that the water secured is clean and used in the most efficient way. In addition to human need for water there is the need for water to support the ecosystem and maintain natural functions, including biodiversity and productivity with healthy environment (Vitousek *et al.*, 1997). Humans for a long time have been using aquatic resources to provide a number of services and functions such as supplying drinking water, fishery and transportation and for recreational purposes. Human-induced impacts on ecosystems are at the same reaching at an alarming rate resulting in a substantial loss of biodiversity (Vitousek *et al.*, 1997). There is also a growing concern that not only species diversity is lost, but also that ecosystem services may become lost due to anthropogenic stress (Daily *et al.*, 2000). There is a long tradition in ecology of considering the effect of

abiotic factors on biodiversity and water management based on physical, chemical or biological data (Loreau *et al.*, 2000). Many of the ecosystem functions such as species and habitat diversity, species interaction and mineralization of organic matter are connected to water quality and therefore a more integrated approach to water management is needed (Knoben *et al.*, 1995). The relationship between biodiversity, ecosystem and environmental processes has become a central issue and challenge in the last decade (Cardinale *et al.*, 2000, Loreau *et al.*, 2000, Loreau, 2001). These interests have spurred research to determine how species loss alters the rates of ecological processes that are vital to retain inherent ecosystem functioning. Although the contribution that species diversity has on ecosystem function is currently debated. Several studies have, nonetheless illustrated that biological communities regulate important ecological processes such as productivity, decomposition and elemental cycling and that species loss can alter the structure and functioning of ecosystems (Naeem *et al.*, 1994, Loreau *et al.*, 2000, Petchey *et al.*, 2004). Some modelling studies indicate, however, that there may be no single, general relationship between diversity and production. The relationships between species diversity and ecosystem processes are seen to be complex (Cardinale *et al.*, 2000, and Petchey *et al.*, 2004).

The studies on microphytobenthos in India, has been given less emphasis except a few viz., Ansari *et al.*, (1993); Ansari and Parulekar (1993); Sivadasan and Joseph (1995, 1998a and 1998b); and Ingole and Parulekar (1998). Impact of pollution on microphytobenthos is not yet well understood due to lack of information on this aspect. Mumbai coast is subjected to various threats of anthropogenic pollution and the area like Versova is highly under pressure of both domestic and industrial pollution. The intertidal area of Gorai is comparatively less polluted. Hence, it was decided to study the fate of microphytobenthos in the intertidal area of Versova and Gorai.

1.1 Role of microphytobenthos in pelagic food chain

As discussed before sediment habitats represent complex aquatic ecosystems and apart from the sediment microflora, they are also inhabited by innumerable invertebrate species. The sediment dwellers can be classified according to their size into microfauna (ciliates), meiofauna (harpacticoid copepods, nematodes, ostracods) and macrofauna (mainly amphipods, isopods, gastropods, polychaetes, mussels) by Plante-Cuny & Plante (1984). Most of these taxa can be defined as deposit and suspension feeders that consume, obligatory or optionally, herbivorous food items. Furthermore, smaller benthic organisms may also play a governing role as trophic linkages to macrofaunal consumers or other predators (demersal fish, birds). Apart from detritus and bacteria, the secondary production in shallow aquatic systems can be supported largely by the primary productivity of benthic microalgae (Daehnick *et al.*, 1992; Moncreiff *et al.*, 1992; Miller *et al.*, 1996; Moncreiff & Sullivan, 2001). Past studies on grazer-microalgae interactions have stated the relative importance of the microflora as food source for benthic consumers (Fenchel, 1968; Fenchel, 1975 a; Sumner & McIntyre, 1982; Plante-Cuny & Plante, 1984; Hillebrand *et al.*, 2002; McCormick & Stevenson, 1991). Consequently, there is now a consensus of opinion that the microphytobenthos can be considered as the major food source for herbivore invertebrates in the euphotic zone.

Benthic microalgae play an important role in the energy budgets of coastal ecosystems, particularly in low intertidal mud flats where they are usually the only primary producers. At low tide, they can reach at high production rates (Pomeroy *et al.*, 1981; Colijn and de Jonge, 1984; Knox, 1986; McLusky, 1989); whereas during high tide, photosynthesis is strongly reduced because of unfavourable light conditions and the downward migration of microphytobenthos at the end of low tide (Cailame & Debyser, 1954; Hopkins, 1963; Palmer & Round, 1965; Round & Palmer, 1966), but

microphytobenthos can potentially enrich coastal waters by means of resuspension that enhances microalgal biomass in the water column (Baillie & Welsh, 1980; Shaffer & Sullivan, 1987; de Jonge & van Beusekom, 1992). Despite the quantitative importance of microphytobenthos very little is known about its photosynthetic characteristics and the photophysiological processes that regulate primary production in sediments.

A particular point of interest seems to be photoinhibition as several studies agree about the good resistance of microphytobenthos to strong illuminations (Burkholder *et al.*, 1965; Gargas, 1971; Rasmussen *et al.*, 1983; Blanchard & Montagna, 1992), which is teleologically consistent since primary production of microphytobenthos can be restricted to the emersion period because of physical constraints. However, there are very few studies dealing with the photophysiological processes involved in primary production on intertidal mudflats.

In intertidal sediments, microbenthic algae are regularly mixed by the action of currents and tides (de Jonge, 1985). An important fraction of the biomass will be resuspended or buried. This phenomenon must be taken into account to understand the fate and recycling of organic matter in intertidal systems. Examining the quality and quantity of the chlorophyll, the pigments help in the understanding of the main degradation pathways (diagenesis by microbial activity or grazing) (Bianchi and Findlay, 1991), and the quantification of organic matter turnover in sediments (Bianchi *et al.*, 1993). The degree of exposure and the nature of sediments (grain size, silt content) also play a role in the retention and burial of the algae.

Additional support to these findings has been given by recent stable nitrogen, carbon and sulphur isotope studies which have demonstrated very convincingly that benthic microalgae are the basis for secondary production at the bottom of shallow freshwater and marine aquatic systems (Sullivan & Moncreiff, 1990; Hecky & Hesslein, 1995; Moncreiff & Sullivan, 2001;

Herman *et al.*, 2000; James *et al.*, 2000). Due to its high abundance and productivity, the microphytobenthos is considered to be a reliable and, furthermore, a highly nutritious food source (Fry & Sherr, 1984; Kitting *et al.*, 1984; Plante-Cuny & Plante, 1984; Decho & Fleeger, 1988; Jernakoff *et al.*, 1996; James *et al.*, 2000; Moncreiff & Sullivan, 2001) for benthic organisms. The diversity and functional role of microphytobenthic communities has become a major topic in benthic research for the last two decades (Blanchard, 1990; Blanchard, 1991; Sundbaeck & Joensson, 1988; Montagna *et al.*, 1995; Plante-Cuny & Plante, 1984).

The role of microphytobenthos in intertidal habitats is diverse. They are important primary producers and can contribute significantly to the total primary production (Heip *et al.*, 1995, Underwood & Kromkamp 1999, Middelburg *et al.*, 2000). Microphytobenthos also play an important role in sediment stabilisation, by the excretion of extracellular polymeric substances (Paterson 1989, Underwood *et al.*, 1995, Smith & Underwood, 1998), and thus play an important role in coastal morphology.

Kelly *et al.*, (1998) stated that diatoms are 'sub cosmopolitan', i.e. they occur anywhere when certain environmental conditions are fulfilled. This concept suggests that the composition and geographic distribution of diatom communities is influenced by specific environmental conditions at any particular site and time. According to Kwandrans *et al.*, (1998) diatom indices may be used to overcome problems relating to the monitoring of rivers for the inorganic nutrients that cause eutrophication, organic loading, ionic composition and dissolved oxygen.

Microphytobenthos not only constitute an important carbon source for local benthic food webs, but also provide an essential link to organic matter inorganic compounds which are available to top predators and higher trophic levels (Miller *et al.*, 1996; Mortazavi *et al.*, 2000). They are also an important food source in estuaries because they are available all year round and the periodic re-suspension of large numbers of cells that are

present in the water column as food for benthic grazers (Adams and Bate *et al.*, 1999). The microphytobenthic community forms a highly active bio film at the sediment water interface and as a result it has a significant impact on the exchange of dissolved and particulate matter between the water column and sediment, therefore influencing processes such as nutrient fluxes (Rizzo *et al.*, 1992; Reay *et al.*, 1995) and also the stabilization of the sediment (Yallop *et al.*, 1994).

Stevenson *et al.*, (1996) states that microphytobenthos can act as a biological indicator of pollution and is also useful in the monitoring of water quality as these organisms are autotrophic and are found at the interface of biotic, chemical and physical components of the food web. Therefore, the importance of benthic micro algae in intertidal systems as food sources, oxygen producers and carbon fixers has been well documented and fully recognized (Heip *et al.*, 1995; Barranguet *et al.*, 1998; Van Dam *et al.*, 1994; Watt, 1998; Adams and Bate, 1999; Guarini *et al.*, 1998, de Jonge and van Beusekom, 1995 and Lucas *et al.*, 2000).

The primary production of benthic micro algae that live in the upper few millimetres of sediment can account for approximately 30 percent of an estuaries annual carbon budget (de Jonge and Colijn, 1994). In turbid water, production of microphytobenthos is restricted to the emersion period due to light limitation during a flood tide (Colijn, 1982; Barranguet *et al.*, 1998). According to MacIntyre *et al.*, (1996), "The total primary productivity of microphytobenthos is usually higher in sheltered muddy habitats than in that of sandy ones". However in a temperate estuary the microphytobenthic biomass is constant throughout the entire year."

Though there are number of works as cited above, the knowledge on microphytobenthic pigment structure in relation to phaeophytin is totally absent. Therefore, the present thesis is aimed to have an understanding on community structure, cell health and pigment status of microphytobenthos with relation to depth of sediments. Considering these aspects of

microphytobenthic algae and their significant role in benthic and pelagic food web and carbon cycle, the present study is conducted in the selected intertidal areas of Mumbai.

1.2 Aim of study

Following were the aim of the study:

1. To investigate vertical distribution of microphytobenthic biomass, population and community structure in sediment.
2. To understand the pigment status and role of phaeophytin in relation to health of microphytobenthos in sediment.
3. To determine the hardy species of microphytobenthos with relation to depth of sediment.
4. To estimate the carbon sinks into intertidal sediment through microphytobenthic population.

Thus approach was applied to conduct comparative study of two intertidal areas along Mumbai coast. This work addresses the characterisation of the migratory response of natural microphytobenthic biofilms whereas primary objective is to investigate the spatial variability, vertical distribution and a spatial alternation due to pollution in Microphytobenthos community.

2 Literature Review

The distribution of benthic fauna in intertidal sediments is much less well known world wide than the distribution of vegetation. Generally mollusks – bivalves as well as gastropods – occurs in all intertidal areas, but burrowing bivalves are much more common where vegetation is absent or sparse, so they tend to dominate at higher latitudes in temperate or cold climates. This is also the case with burrowing worms, which also occur mostly in intertidal deposits that are bare. Burrowing crabs mostly dominate in intertidal sediments in tropical and subtropical climate as well as in some areas with a dry Mediterranean climate. In addition to crabs, a burrowing fish (the mudskipper) is also common on tropical and subtropical intertidal mud. The effects on the sediment of burrowing by benthic fauna vary. Benthic fauna may fix bottom sediment by building tubes and producing mucus, even may build low reefs, or may form banks that protect the sediment and induce deposition. Other benthic organism however, loosens the sediment through burrowing or through crawling over the surface and thus enhances resuspension or bottom transport.

The sediment on the supratidal flats are laminated fine silt or mud with pellets and skeletal grains (foraminifera, gastropods) with stromatoliths of blue – green algae, mud cracks, animal burrows, and other desiccation marks such as upcurling algal mats. Lenses of *Halimeda debris* (a calcareous alga, which lives in the shallow waters around the islands) are probably storm deposits. During a storm up to 5 cm thick sheets of pelleted lime mud and skeletal particles can be deposited. With time, a deposit of dense mud layers is formed and separated by organically rich concentration as algal mats.

In analogy to the distinction made by Woodroffe (1992) in the occurrence of mangroves based on the classification proposed by Roy *et al.*, (1980) for bedrock embayment, intertidal areas can be:

Some organisms stay their whole life in the plankton (holoplankton), but more switch during life. Some phytoplankton algae such as *Biddulphia aurita* spend part of their lifecycle on the bottom (tychoplankton), while others, such as most planktonic dinoflagellates, have benthic resting stages, or cysts.

Biological Effects on the sediments in a number of ways can be described as follows:

1. Biodeposition : Suspension feeders catch suspended matter while collecting their food and produce fecal and pseudo-fecal material containing the inedible fraction of the suspended matter. The pseudofeces are formed out of particles that are rejected before ingestion. Both feces and pseudofeces are added to the sediment.
2. Bioturbation : Burrowing organisms disrupt original sedimentary structure by bioturbation (sediment reworking): new structures may result due to biogenic sorting.
3. Traces : Organism may leave dwelling, feeding resting and escape traces in the sediment on its surface. In ancient sediments these may be the only marks of biological activity (and may give important paleological information). They are often difficult to relate to their producer except in recent environments.
4. Shear strength (internal cohesion) of the sediment : Many intertidal organisms produce mucus (mucopolysaccharides). Phytoplankton traps suspended particles and may enhance floc formation and sedimentation; mucus produced by diatoms, meio- or macrofauna living on soft bottoms makes sediments sticky. This influences shear strength.

5. Erosion / sedimentation : Mucus production also increases the critical erosion velocity of the sediment and vegetation and tube structures above the sediment, thus reduces erosion and enhances sedimentation.
6. Permeability: Burrowing organisms and their burrows increases the permeability of the sediment. This enlarges the water content. By pumping respiratory water through their burrows these organisms aerate the sediment and enhance sediment water exchange, e.g., of nutrients (P, N). Bioirrigation also increases meio- and microfauna : around burrows more oxygen is available.
7. Biogenic particles : Some consider only particulate organic matter as biological particles (Heip *et al.*,1995), but organism also produce other types of particles , e.g., siliceous or carbonate exoskeleton. Intertidal areas mollusks are particularly important. In addition, mussels, oyster, and polychaete may form reef-like structures on soft sediments. Coral reefs are mainly restricted to hard substances and will not be dealt with here. Predators may crush shells, producing shell fragments that are added to the sediment.
8. Influence of Man: Tidal flats have not only been used for reclamation, but also for the extraction of sediment (sand, mud), fishing (bottom fish, shellfish) and collecting mollusks or worms for food. Salt marshes are used for grazing cattle, sheep and geese for the cutting of turf for raising salt-tolerant crops. Minor use of salt marshes includes cutting and collecting grasses for hay, and several plants species for vegetable medicine, for flavouring and perfumes. Mangrove are being cut for the wood to use as timber for burning or for charcoal fabrication.
9. Sustainable use: Point source of nutrient may result in increased benthic algal productivity benthic and algal biomass because of rapid transfer of organic matter to grazers. The types of top-down forces that mask benthic algal responses have been well documented in several

aquatic ecosystem (Peterson *et al.*, 1985; Colletti *et al.*, 1987, Marks and Lowe, 1989). Thus, benthic algal information on community with physical and chemical properties is most valuable to understand the ecosystem of any region.

2.1 National level studies

Nair *et al.*, in 1968, calculated the potential production of phytoplankton in terms of carbon for the westcoast as 46×10^6 tons and for east coast of India as 15×10^6 tons. Sankaranarayanan and Qasim (1969) studied the nutrients of the Cochin estuary in relation to environmental characteristics.

Gopinathan, in 1972, studied the qualitative and quantitative analysis on phytoplankton of the Cochin estuary and described 120 species.

Nair *et al.*, in 1975, studied primary production in the Vembanad Lake. They observed that the annual gross production ranged from 150-650 gC/m²/day and the total organic production in the Vembanad Lake has been estimated as 100,000 tons of carbon.

Vijayalakshmi and Venugopalan (1975) studied the diversity of phytoplankton species, pigments and succession with a note on primary production at a tidal zone in the Velar estuary, East coast of India.

Pillai *et al.*, in 1975 studied the plankton production in relation to the environmental parameters in Vembanad Lake. Seasonal fluctuations in the abundance of phytoplankton in the Cochin backwaters were studied by Kumaran and Rao (1975).

Gopinathan (1975a), described an account of the estuarine diatoms present in various estuarine systems in India, their occurrence, seasonal fluctuations and distribution in the various estuaries particularly from Cochin backwater.

Gopinathan, (1975b), described some new distributional records of plankton diatoms from the Indian Seas.

In 1978, Qasim *et al.*, examined the biological productivity of the coastal waters of India upto 50m depth and proved that the larger phytoplankton species contributed to greater spatial variation in the primary production than the smaller forms.

Nair and Gopinathan investigated the primary productivity of the Exclusive Economic Zone (EEZ) of India and the factors governing phytoplankton production in 1981. The annual carbon production of the EEZ of India, comprising 2.02 million square kilometres has been estimated to be 283 million tons and the exploitable yield of living resources of the EEZ is estimated to be 5.5 million tons based on primary production.

Gopinathan (1984) studied the littoral diatoms of South West Coast of India and described 105 species of diatoms. Desikachary *et al.*, (1987a) investigated the diatom flora of sediments from Indian Ocean.

Desikachary and his colleagues, (1986, 1987a, b and c, 1988, 1989) made massive contribution to the field of algology in India. Their Atlases of diatoms are considered as the most valuable reference books world wide.

Jayalakshmy *et al.*, in 1986, studied the seasonal distribution of phytoplankton in Cochin backwaters. In 1989, Santra *et al.*, 1989 studied the seasonal fluctuations of phytoplankton in Bhagirathi-Hoogly estuary, in West Bengal.

Sarupria and Bhargava (1993) recorded 109 species of phytoplankton during cruise of R.V.Gaveshini.

Jiyalal and Goswami in 1993, observed the distribution of chlorophyll *a*, phaeopigments, zooplankton and physicochemical parameters in the surface waters from Southern Indian Ocean were carried out during 9th Indian Antarctic Expedition (1989-1990).

Gopinathan *et al.*, in 1994 recorded the peak periods of primary production and chlorophyll *a* of the inshore area at Tuticorin.

Sivadasan (1996) and Sivadasan and Joseph, (1995 1997, 1998a, 1998b) made a comprehensive study on the benthic microalgae of Cochin Estuary. Whereas Sreekumar (1996) and Sreekumar and Joseph (1995a, 1995b, 1996, 1997) studied the periphytic flora and their community structure in Cochin estuary.

Gowda *et al.*, (2001), recorded the abundance and distribution of phytoplankton in the Nethravathy estuary. Diatoms were the dominant components of phytoplankton followed by green algae, dinoflagellates, blue green algae and silicoflagellates.

Seasonal variation of phytoplankton abundance and productivity were studied in the surf zone of the sea at Cochin backwaters with reference to cell counts, chlorophyll *a*, photosynthesis and hydrographic parameters by Selvaraj *et al.*, (2003).

Sheeba and Ramanujan in 2003 identified 38 genera of phytoplankton together with physicochemical parameters of water at monthly intervals in the estuarine environment of Ithikkara River, southern Kerala.

Alkershi *et al.*, in 2003, studied the contribution of size fractions of planktonic algae to the primary organic productivity in the coastal waters off Cochin. They found that the productivity in the coastal waters of Cochin was inversely proportional to the size of the planktonic algae except in the case of the size groups of <53-25 μ m and <25-10 μ m. During the pre and post monsoon seasons, the major contribution was that of planktonic algae <25 μ m in size.

Benthic microalgal motility is known to be affected by various environmental factors; one of them is water cover (Mitbavkar and Anil, 2004).

In 2004, Geetha and Kondalarao carried out the qualitative and quantitative distribution of phytoplankton with regional and seasonal variations in the coastal waters of east coast of India. The study revealed that the dinoflagellates were the dominant taxa with 131 species, followed by 111 species of diatoms and 7 species of cyanophytes.

Renjith *et al.*, (2004) studied the primary production at selected stations in Cochin Estuary and showed a trimodal annual variation with peaks during April, July and November. Maximum production was in November and minimum in June.

Roy *et al.*, in 2006, investigated the spatial variation of phytoplankton pigments along the south west coast of India. Phytoplankton composition and abundance were studied along the southwest coast of India towards the end of upwelling season.

Madhu *et al.*, (2006) investigated the distribution of phytoplankton in western Bay of Bengal during summer, winter and spring inter monsoon period and found that there is a lack of pronounced seasonal variation in the phytoplankton standing stock (chlorophyll *a*) and primary production.

Mitbavkar and Anil (2002, 2004) investigated on the vertical migratory rhythms and community structure of microphytobenthos of Goan mud flat.

Mitbavkar and Anil (2006) monitored on thawing to track the mechanical injuries and their post-preservation recovery of two pennate microphytobenthic diatoms, *Amphora coffeaeformis* (Agardh) Kutzing and *Navicula transitans* var. *derasa* f. *delicatula* Heimdal, were cryopreserved

Anil *et al.*, 2007 presented a comparison of viable benthic diatom propagules based on the observations recorded immediately and after 5 years of ageing at 5 °C.

Mitbavkar and Anil (2008) studied seasonal variations in the fouling diatom community structure from a monsoon influenced tropical estuary.

Patil and Arga (2008) studied temporal variations in the diatom benthic propagule (DBP) community and their role in the phytoplankton community in a monsoon-affected tropical estuary, Zuari estuary, Goa (India).

Sanilkumar *et al.*, (2009a) reported the algal blooms along the coastal waters of southwest India during the period 2005-08 and prepared a probable 'fingerprint' of *Coscinodiscus asteromphalus* var. *centralis*. Sanilkumar *et al.*, (2009b) reported vertical distribution of microphytobenthos in Cochin estuary.

2.2 International level studies

Cadee and Hegeman, (1977) used chlorophyll *a* in sediment x 20 to estimate cell carbon content. Results indicated that living algal carbon represents from 7 to 24 % of the total sediment organic carbon.

Anderson *et al.*, (1981) followed Chlorophyll values can be used to give an approximate estimate of the amount of living carbon contained in algae.

de Jonge, and Colijn, (1994) to calculate the total biomass of the microphytobenthos expressed as organic carbon.

Taylor *et al.*, (1997) studied a acclimation of the growth rate and carbon-to-chlorophyll *a* ratio (C: chl *a*) of phytoplankton to irradiance, nitrate concentration and temperature was incorporated into a 1-dimensional model of phytoplankton production dynamics.

Underwood *et al.*, (1998) found that on smaller spatial scale, though there were no significant patterns in microalgal biomass in relation to nutrient enrichment, there were significant differences in the population densities of different epipelagic species along a multivariate nutrient gradient (decreasing concentrations of ammonium, nitrite, silicate, organic content, and increasing salinity and pore-water nitrate concentrations) away from a sewage outfall along a saltmarsh creek.

Bennett *et al.*, in 1999 did a microcosm experiment was conducted to examine the effects of polycyclic aromatic hydrocarbon (PAHs) contamination on the abundance and composition of microphytobenthos in surface (0–10 cm) sediments collected from a salt marsh in Pass Fourchon, LA. Plant pigment biomarkers were used to monitor changes in the microphytobenthos in sediments (over 60 days) with treatments containing high and low concentrations of PAHs.

Azovsky *et al.*, (2000) studied the spatial distribution of intertidal macrozoobenthos, microphytobenthos (diatom algae) and sediments at scales from decimeters to kilometers using an index of spatial homogeneity. At larger scales, microalgae showed a combination of patchy structure with pronounced gradient along the shoreline from brackish-water to marine flora.

Seuront and Spilmont (2002) studied a 2D distribution of microphytobenthic biomass is determined from a superficial sediment sampling on an exposed sandy shore.

Facca *et al.*, (2002) observed that the microalgal populations recorded in the water column differed significantly from those monitored in the surface sediment only at the one station, populated by the seagrass *Zostera marina* in Venice Lagoon, Italy. In this area sediment resuspension and settlement were lower than in the areas B, C and D which did not show any macrophyte coverage and had dense populations of bivalves. Both the phytoplankton and microphytobenthos communities exhibited strong relationships with the underwater light transmission and the suspended (FSPM) and deposited particulate matter (DSPM) amounts.

The Chlo *a*/Phaeo ratios of these intertidal sediments were always high (2 to 8), while the vertical distribution of pigments in sediments was highly variable (not illustrated) by Riaux-Gobin and Bourgoin in 2002 at Kerguelen's Land.

Apparently living MPB can be found throughout the top 10 cm of sediments as indicated by de Jong and de Jonge (1995), Welker *et al.*, (2002).

Montani *et al.*, (2003) noticed marked seasonal patterns were also recognizable, with primary production of Microphytobenthos significantly higher both in spring and summer than in winter and fall.

Grall *et al.*, (2006) found that the major potential sources of energy were identified to originate either from epiphytic macroalgae and microphytobenthos both growing, together with sedimenting (sedimentary) particulate organic matter (POM) originating from the water column.

The rhythmic vertical migration of large numbers of microalgae causes the periodic accumulation of large amounts of microalgal biomass in the photic zone of the sediment. The migratory photoresponse of microphytobenthos was characterised on the basis of variations in surface biomass of microphytobenthos by Sero^odio *et al.*, (2006).

Jesus *et al.*, (2006), stated that the distribution of microphytobenthic biomass in the vertical plane has been observed to be highly dependent on sediment type. In muddy sediments there is a strong accumulation of cells at the surface due to strong light attenuation and low re-suspension rates. In sandy sediments (2 mm) there tends to be a more homogeneous distribution due to deeper light penetration and to regular remixing by tidal re-suspension (Taylor and Paterson, 1998; Kelly *et al.*, 2001). As sampling depth increases the chlorophyll depth distribution in sandy sediments will eventually converge to a negative exponential decay, since burial rate and chlorophyll decay become the structuring parameters (Brotas and Sero^odio, 1995). However, at depths up to 2 mm the light penetration becomes the most important factor in structuring the vertical biomass distribution. Several sediment parameters are known to influence the photic zone depth causing an increase in the light attenuation coefficient. These parameters include:

organic content, water content, microphytobenthos biomass and sediment type (e.g. De Boer, 1981; Kelly *et al.*, 2001; Blanchard *et al.*, 2000; Paterson, and Hagerthey, 2001; Sero^o dio, 2004; Forster and Kromkamp, 2004). However, the majority of these variables are highly correlated to the fine particle content of the sediment (Paterson *et al.*, 2000; Flemming and Delafontaine, 2000).

Koh *et al.*, (2007) found a clear temporal pattern in within-day sediment Chlorophyll *a* indicating net increase of microphytobenthos biomass in surface sediment during a single-daytime exposure.

Cibic *et al.*, (2007a) analysed benthic microalgal composition, abundance (ABU) and biomass (BIOM). Temperature and photosynthetically available radiation (PAR) at the bottom were recorded during sampling. Throughout the 2-year study the microphytobenthic community was mainly composed of Bacillariophyceae. The statistically significant relation between diatom ABU and PAR confirmed that benthic microalgal ABU was mainly controlled by light availability at the bottom. The clear inverse relation between nitrite, nitrate and microphytobenthic biomass was emphasised both by the moving average and the Principle Component Analysis. Cibic *et al.*, 2007b, confirmed that benthic microalgal community was adapted to low light.

Meurer & Netto, 2007 found that sediment chlorophyll *a* and phaeopigments followed a similar seasonal trend, with low biomass in the winter, higher in the summer and intermediate values in spring and autumn.

Tang & Kristensen, (2007) stated that total carbon oxidation was fuelled primarily by microphytobenthic biomass, while EPS only contributed by 1–4%.

Longphuir *et al.*, (2007) studied the primary production and the spatial and temporal distribution of the subtidal microphytobenthic community in a temperate coastal ecosystem.

The trophic importance of marsh vascular plants, microphytobenthos, and riverine and channel particulate organic matter to macroinvertebrate and fish production was studied using stable carbon and nitrogen isotope tracers by Choy *et al.*, (2008).

Krumme *et al.*, (2008) indicated the importance of intertidal microphytobenthos production during low tide being made available to transient planktivorous fish at high tide by tidal resuspension.

Shang *et al.*, (2008) stated that the trophic importance of microphytobenthos, phytoplankton, C3 vascular plants and invasive *Spartina alterniflora* in benthic and pelagic food webs was studied in Jiuduansha, a newly formed salt marsh in the Yangtze River estuary, using natural stable carbon and nitrogen isotopic analyses and IsoSource evaluation. Microphytobenthos was found to be the major food source of meiofauna and important in the diets of macrofaunal consumers. Carbon derived from C3 vascular plants significantly contributed to the nutrition of all planktonic copepods and supported planktivorous nekton, but played a minor role in the benthic food web.

Brito *et al.*, (2009) found that there were no significant correlations between microphytobenthos chlorophyll and tidal range, wind speed, solar irradiance, water temperature and salinity and water nutrient concentrations. Sediment type was once more confirmed to be a key factor to microphytobenthos spatial variability.

Jesus *et al.*, (2009) studied adaptations of microphytobenthos assemblages to sediment type and tidal positions.

Pascal *et al.*, (2009) observed that accordance with stable isotopic analysis suggesting that microphytobenthos dominates the diet of the Brouage nematode community.

Williams *et al.*, (2009) recorded ten fold greater microphytobenthic chlorophyll *a*, than epiphytic chlorophyll *a*, suggesting that microphytobenthos is also an important primary producing component.

Fourqurean James *et al.*, (2010) suggest that epiphyte and microphytobenthos abundance are not unambiguous indicators of nutrient availability in relatively pristine seagrass environments, and therefore would make poor candidates for indicators of the status and trends of seagrass ecosystems in relatively low nutrient environments like the Florida Keys.

Du G Ying *et al.*, (2010) found that generally, the microphytobenthos surface biomass was an important factor in structuring the microphytobenthos vertical distribution. The vertical distribution to depths of 10 cm was closely related to the sediment composition over the long term, while the microphytobenthos migration influenced the vertical distribution over the short term in the top 1 cm of the sediment.

Chevalier *et al.*, 2010 found that photosynthetic responses of microalgae at a given light level differed for one emersion period to the other.

Lebretona *et al.*, (2011) found that the microphytobenthos was slightly more than ^{13}C and had high levels of diatom markers. Low mean $\delta^{13}\text{C}$ and large amounts of diatom and bacteria markers indicated that (suspended particulate organic matter) SPOM was mainly composed of a mixture of fresh and decayed pelagic diatoms.

3 Material and Method

To understand the dynamics of microphytobenthos, two sampling locations viz Versova (Figure 3.1-a) and Gorai (Figure 3.1-b) were selected. Sampling was carried out every month from August, 2000 to September, 2001.

Standard methods were employed for sample collection, analysis and data processing (Grasshoff *et al.*, 1983; Holmes & McIntyre, 1984; APHA.1998). Analysis and data processing were carried out in the laboratory of National Institute of Oceanography, Regional Center, Mumbai.

3.1 Physicochemical parameter

3.1.1 Sampling

At each intertidal station, the samples from overlying water were obtained during both flood and ebb periods to study physicochemical parameter viz., Temperature, pH, Suspended Solids (SS), Salinity (S ‰), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Reactive Phosphate (PO_4P), Nitrate - Nitrogen (NO_3N), Nitrite – Nitrogen (NO_2N), Ammonium – Nitrogen (NH_4N).

Surface water samples were collected manually using clean plastic bucket. The standard DO and BOD bottles were used to collect the samples. Care was taken to avoid air bubble while filling the DO and BOD bottles. DO samples were fixed immediately by using Winkler A (1.0 ml) and Winkler B (1.0 ml). The samples for determination of nutrients were collected in 500 ml polyethylene bottles.

3.1.2 Analysis

i) Temperature :

Air and water temperatures were measured by mercury bulb thermometer.

ii) pH :

pH was measured on a microprocessor controlled pH meter (Scan-2, Evlech-Cybermetics). The instrument was calibrated with standard buffers (7.0 and 9.4) just before use.

iii) Suspended Solids (SS) :

A known volume of seawater (500 ml) was filtered through a preweighed 0.45 μm (Millipore) membrane filter paper, which was dried and weighed again. The difference in the weights gave suspended solid content.

iv) Salinity:

A suitable volume of the sample was titrated against silver nitrate (25 g/l) with potassium chromate as an indicator. The salinity was calculated using standard tables. The standardization of silver nitrate was done using standard seawater. Standard seawater (5.0 ml) was pipetted out into a conical flask and potassium chromate (6 drops) was added as the indicator. The solution was titrated against silver nitrate solution (app. 0.15 N) under constant stirring using magnetic stirrer till the end point of dirty orange colour was obtained. The mean of three readings was used to determine the factor. Same procedure was followed with sample to obtain the burette reading [BR(s) (ml)]. The salinity was calculated as follows:

19.371

Factor (F) = _____

Burette reading of standard seawater (ml)

$$\text{Salinity (ppt)} = \text{BR(s) (ml)} \times F \times 1.80655$$

Where, 1.80655 is a constant factor for conversion of chlorinity to salinity.

v) Dissolved Oxygen (DO) :

The DO was determined by Winkler method. Sea water (50.0 ml) was pipetted out in a 150 ml conical flask. HCl (50%, 3 ml) was added to it and mixed well. Winkler A (1.0 ml) and Winkler B (1.0 ml) solutions were added to it and shaken well. Starch solution (1.0 ml) was added as the indicator. The solution was titrated against Sodium Thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) solution till the blue colour disappears. Experiment was repeated three times and the mean burette reading [BR(s)] was used for further calculation. Experiment was repeated with distilled water (Reagent blank) and the mean burette reading [BR (b)] was obtained.

The amount of DO in one litre of sample was calculated by following formula:

$$\text{DO (ml/l)} = 5.6 \times N \times [\text{BR(s)} - \text{BR(b)}] \times \frac{V}{a} \times \frac{1000}{V-1}$$

V-1 a

$$\text{DO (mg/l)} = \text{DO (ml/l)} / 0.7$$

Where,

N=Normality of sodium thiosulphate,

BR(s)=titre value of the sample (mean),

BR(b)= titre value of the blanks (mean),

V=Volume of the sampling bottle (125 ml),

a=volume of the sample titrated (50 ml).

The factor $(V / V-1)$ is included to correct for the volume of reagents added to the sample.

vi) Biochemical Oxygen Demand (BOD) :

The BOD samples were incubated for five days at 27°C. The DO was analyzed generally by Winkler method, both initially and after 5 days as described in section 3.1.2 (v) above. The difference of initial DO and the DO after 5 days was calculated and termed as BOD.

vii) Reactive Phosphate:

Acidified molybdate reagent was added to the seawater sample (25 ml) to yield a phosphomolybdate complex that was then reduced with ascorbic acid to a highly colored blue compound and absorbance was measured at 882 nm. In a blank solution (distilled water, 25 ml), standard phosphate (1µmol/l, 25.0 ml) solution, ascorbic acid (0.5 ml) and mixed reagent (0.5 ml) were added in sequence and mixed well. Their absorbance was measured at 882 nm after 10 min. Excess of absorbance due to turbidity was measured before adding reagent, and was subtracted from sample absorbance. Factor (F) was calculated from the following relation.

$$F = \frac{1\mu\text{mol/l (std)}}{\text{Abs}_{\text{std}} - \text{Abs}_{\text{blk}}}$$

Where,

Abs_{std} = Absorbance of standard solution,

Abs_{blk} = Absorbance of blank solution.

The $\text{PO}_4^{3-}\text{-P}$ concentration was calculated as follows:

$$\text{PO}_4^{3-}\text{-P } (\mu\text{mol/l}) = F \times (\text{Abs}_{\text{sample}} - \text{Abs}_{\text{blk}})$$

viii) Nitrite - Nitrogen ($\text{NO}_2^- \text{-N}$) :

Nitrite in the sample (25.0 ml), was allowed to react with sulphanilamide in acid solution. The resulting diazo compound was reacted with N-1- Naphthyl-ethylenediamine dihydrochloride to form a highly colored azodye. In standard nitrite solution (2 $\mu\text{mol/l}$, 25 ml), sulphanilamide solution (0.5 ml) and the diamine solution (0.5 ml) were added with 5 min interval and mixed thoroughly by shaking. The absorbance (Abs_{std}) of the solution was measured at 543 nm after 10 min using distilled water as the reagent blank (Abs_{blk}). The concentration factor (F) was calculated as follows:

$$F = \frac{2\mu\text{mol/l (std)}}{\text{Abs}_{\text{std}} - \text{Abs}_{\text{blk}}}$$

Where,

Abs_{std} = Absorbance of standard solution,

Abs_{blk} = Absorbance of blank solution.

Excess of absorbance due to turbidity was measured before adding diamine reagent, and was subtracted from sample absorbance. The concentration of NO₂⁻-N in the sample was calculated as follows:

$$\text{NO}_2^- \text{-N } (\mu\text{mol/l}) = F \times (\text{Abs}_{\text{sample}} - \text{Abs}_{\text{blk}})$$

ix) Nitrate - Nitrogen (NO₃⁻.N):

Nitrate was determined as nitrite as above after its reduction by passing the sample through a column packed with amalgamated cadmium.

Cadmium pieces (thickness 0.5 - 1.0 mm) were washed with acetone (100 ml) to remove oil and grease then with HCl (2N, 100 ml) to remove iron oxides and finally with distilled water to remove chlorides till the washings did not give any precipitate with silver nitrate solution. Then they were treated with HgCl₂ solution (1%, 100 ml) in a stoppered 125 ml glass bottle. The bottle was shaken well till the Hg-amalgamation was complete which was indicated by the colorless supernatant solution.

Excess mercuric chloride solution was removed by washing with distilled water. Care was taken for avoiding the contact of air with amalgamated metal. The column and reservoirs were filled with distilled water and cadmium fillings. Rate of elute was adjusted to 50 ml/min, then column was washed with distilled water till elute was free of chloride. In standard nitrate solution (4 μmol/l, 500 ml) prepared from KNO₃, buffer (Ammonium chloride, 10 ml) was added. The resultant solution (500ml) was allowed to pass through the column at the rate of 50ml / 8min. The initial

elute (400 ml) was rejected. Next elutes (25 ml x 3) were collected in three test tubes and analysed as described in section 3.1.2 (viii) above.

Seawater (50 ml) mixed with buffer solution (1 ml) was allowed to pass through the column. First elute (25 ml) was rejected and next elute (25 ml) was analysed as described in section 3.1.2 (viii) above.

x) Ammonium - Nitrogen ($\text{NH}_4^+\text{.N}$) :

Ammonium compounds ($\text{NH}_3+\text{NH}_4^+$) in water were reacted with phenol in presence of hypochlorite to give a blue color of indophenol. The absorbance was measured at 630 nm.

The buffer solution (Trisodium citrate, 1.5 ml) was added in a standard ($1\mu\text{mol/l}$, 25 ml) $\text{NH}_4^+\text{-N}$ solution prepared from NH_4Cl in a stoppered test tube, and mixed well, then phenol solution (0.5 ml) and hypochlorite reagent (0.5 ml) were added with 5 min interval and mixed well. The samples were kept overnight in cool dark place. Their absorbance (Abs_{std}) was measured at 630 nm against reagent blank (Abs_{blk}). Excess of absorbance due to turbidity was measured before adding trion reagent, and was subtracted from sample absorbance. The concentration factor (F) was calculated as follows:

$$F = \frac{2}{\text{Abs}_{\text{std}} - \text{Abs}_{\text{blk}}}$$

Where,

Abs_{std} = Absorbance of standard solution,

Abs_{blk} = Absorbance of blank solution.

The NH_4^+ -N concentration was calculated as follows:

$$\text{NH}_4^+\text{-N } (\mu\text{mol/l}) = F \times [\text{Abs}_{\text{sample}} - \{ \text{Abs}_t - \text{Abs}_{\text{blk}} \}]$$

Where,

$\text{Abs}_{\text{sample}}$ = Absorbance of seawater sample,

$\text{Abs}_{\text{sample}}$ = Absorbance of the turbidity,

Abs_{blk} = Absorbance of blank solution.

3.2 Sediment texture

3.2.1 Sampling

The samples were collected from the three transects (a, b and c) of intertidal area. Surficial sediments were collected under low tidal conditions to determine Sediment Texture and Organic carbon (C_{org}). Sediments taken to laboratory were dried at 60°C in an oven (more than 12 h) and later analysed for organic content and particle size.

3.2.2 Analysis

a) Sediment Texture

Sediment texture was studied by the method of Buchana and Kain (1984). Isolation of the fine fraction by sieving ($<20 \mu\text{m}$, $<63 \mu\text{m}$) was undertaken to reduce the differences in sediment granulometric compositions. The grading of particles as sand, silt and clay was observed by sieve and pipette analysis.

Around 25 g of exactly weighed air dried sediment was transferred to a one litre beaker with 100-150 ml of 6% hydrogen peroxide and kept overnight which effectively removes the organic matter. The sediment was filtered through a filter paper (Whatman No. 50) in a Buchner funnel under

gentle suction with distilled water to remove any electrolytes. Then the sediment was stirred with 400-500 ml of distilled water and soaked overnight. Next day the sediment was again stirred for 10-5 minutes and sieved through 63 μm sieve in a flat bottom basin/trey, the washings should not exceed the volume of one litre. The sieve with its contents was transferred to a drying oven at 100 $^{\circ}\text{C}$ i.e. the sand fraction. The remaining fine fraction (silt-clay) collected in the basin/trey was transferred into a one litre cylinder and volume was made up to one litre with distilled water. The cylinder was shaken well and placed in a thermostatic water bath with the temperature maintained at 20 $^{\circ}\text{C}$. 20 ml of the sample was pipetted out from a depth of 20 cm in a pre-weighed petridish which was then oven dried at 100 $^{\circ}\text{C}$ [representing (silt+clay) fraction of the sample]. The second pipette sample was withdrawn at exactly 7 minutes and 44 seconds which was also oven dried at 100 $^{\circ}\text{C}$ [representing (fine silt+clay) fraction], while the third pipette sample was withdrawn at 2 h and 3 minutes representing the clay fraction of the sample. The calculations were made accordingly to find out the respective % of the individual fraction of the sediment sample (Ackermann *et al.*, 1983; Klamer *et al.*, 1990).

b) Organic carbon (C_{org})

The percentage of C_{org} in the dry sediment was determined by oxidising organic matter in the sample by chromic acid and estimating the excess chromic acid by titrating against ferrous ammonium sulphate with ferroin as an indicator. The precision of the method is better than 1% (Walkley and Black, 1934).

3.3 Phytoplankton

3.3.1 Sampling

Water samples for determination of phytoplankton were collected during August 2000 to September 2001 at both flood and ebb tides from Versova and Gorai.

The samples for phytoplankton pigments were collected in 500 ml polyethylene bottles and preserved immediately in ice-box till further processing. Samples for phytoplankton population were collected in 500 ml polyethylene bottles and preserved with Lugol's solution. Lugol's solution was prepared by dissolving 100 g potassium iodide, 50 g iodine and 100 ml glacial acetic acid in 1 litre distilled water respectively.

3.3.2 Analysis

a) Phytoplankton pigment:

The seawater sample collected in 500 ml was filtered through the 0.45 μm Millipore membrane filter paper and the pigment retained on the filter paper were extracted in 90% acetone for determination of chlorophyll *a* and phaeophytin. To restrict the formation of phaeophytin, few drops of 1% MgCO_3 (1 gm in 100 ml) was added while filtering the sample. Sample was kept overnight in the dark at 4 °C. The sample was centrifuged at 5000 rpm for 15 min and absorbance was measured on Shimadzu UV-160 spectrophotometer, at 750, 665 nm wavelengths, before acidification. The extract was then acidified with two drops of 1N HCl and absorbance was again measured at 750 and 665 nm, after acidification. Instrument was calibrated using 90% acetone as reference blank. The chlorophyll *a* and phaeophytin were calculated according to Strickland and Parsons (1972) and APHA (1998).

$$\text{Chlorophyll } a \text{ (mg/m}^3\text{)} = \frac{26.7 (665b - 665a) \times v}{V \times l}$$

and

$$\text{Phaeophytin (mg/m}^3\text{)} = \frac{26.7 [1.7 \times (665a - 665b)] \times v}{V \times l}$$

Where,

V = Volume of sample (ml),

v = Volume of acetone used (ml),

665a = absorbance after acidification,

665b = absorbance before acidification.

b) Phytoplankton cell count

Phytoplankton samples were decanted and measured volume (100 ml) was taken for analysis. Identification and enumeration of phytoplankton cell were undertaken with a compound microscope (magnification up to 400 times, Litz make and Motic make) using Sedgwick Rafter counting chamber. Counting of phytoplankton were carried out in 1 ml of subsample (100 ml) using the above counting slide. The counting of cells were repeated to confirm the results.

Population of phytoplankton was calculated for 1 litre and values were expressed as number / litre cell counts.

c) Identification of Phytoplankton

Phytoplankton species were identified by following books and manuals (Lebour, 1930, Subrahmanyam, 1946, Hendey, 1964, Tomas *et al.*, 1997).

3.4 Microphytobenthos

3.4.1 Sampling

The samples of microphytobenthos were collected from three transects (a, b and c) of intertidal area, during both high water level (HWL) and low water level (LWL). Sediment core was taken for microphytobenthic analysis. Triplicate samples with the help of a manual Plexiglas corer (3 mm thick, total sediment volume 1 cm³; 12 cm length) were taken from each transect. Two cores were used to extract pigments and one core was used to identify the microphytobenthic species. Cores were sectioned at every 1 cm to determine vertical distribution of microphytobenthic pigments and population.

3.4.2 Analysis

i) Microphytobenthic pigment:

The determination of microphytobenthic pigments were carried out using sediment core cut into equal pieces of 1 cm and collected in weighing glass bottles. Estimation of chlorophyll *a* and phaeophytin were undertaken by following the method of Lorenzen (1967); Colijn *et al.*, 1981.

Microphytobenthic chlorophyll *a* was determined spectrophotometrically correcting for phaeopigments (Lorenzen, 1967). The pigments of each 1 cm slice of sediment were expressed in mg / m², according to the following equation:

$$\text{Chlorophyll } a \text{ (mg/m}^2\text{)} = \frac{A \times K \times (E - E_a) \times v \times 10}{O \times l}$$

Ox l

And

$$\text{Phaeophytin (mg/m}^2\text{)} = \frac{A \times K \times (R \times E_a - E) \times v \times 10}{O \times l}$$

Ox l

Where,

A, R and K are constants as defined by Lorenzen,

V is the volume of acetone (ml),

E is the extinction at 665 nm / 750 nm, before acidification,

E_a is the extinction at 665nm, after acidification,

O is sample surface (cm²),

And

l is the optical path length.

To avoid the error due to patchy distribution of microphytobenthos random three cores were taken at each HWL and LWL.

ii) Microphytobenthic population:

For estimation of microphytobenthic population, the sectioned sediment slices preserved in lugol's solution were mixed in a variable

volume of filtered seawater depending on the content of small particles to make the measured the volume of sample. Subsample of 1 ml of water was placed under a microscope in a sedwick-raffe counting slide. After sedimentation the slide was scanned at 400 X magnification using a compound microscope. The cells in healthy state were counted corresponding to the counting slides. The scanned area of slide and the volume of water added were taken into account to calculate cell abundance. Cell abundance of each 1 cm slice of sediment was expressed in No. / cm³.

iii) Species Identification of Microphytobenthos:

The species of microphytobenthos were identified using the standard keys (Lebour, 1930, Subrahmanyam, 1946, Hendey, 1964, Tomas, 1997, Raymount, 1980).

4 Study location

The 1893, Salsette, Trombay and Dharavi were merged with Bombay Island to form Greater Bombay which was named as Mumbai. Mumbai consists of two distinct regions: Mumbai City district and Mumbai Suburban district, which form two separate revenue districts of Maharashtra. The city district region is also commonly referred to as the Island City or South Mumbai. The total area of Mumbai is 603.4 km² (233 sq miles). Of this, the island city spans 67.79 km² (26 sq miles), while the suburban district spans 370 km² (143 sq miles), together accounting for 437.71 km² (169 sq miles) under the administration of Brihanmumbai Municipal Corporation (BMC). The remaining area belongs to Defence, Mumbai Port Trust, Atomic Energy Commission and Borivali National Park, which are out of the jurisdiction of the BMC. The total population of metropolitan area is approximately 21 million.

Mumbai has a tropical climate, specifically a tropical wet and dry climate, with seven months of dryness and peak of rains in July. The cooler season from December to February is followed by the summer season from March to June. The period from June to about the end of September constitutes the south-west monsoon season, and October and November form the post-monsoon season.

Mumbai has numerous creeks. The Vasai Creek to the north and Thane Creek to the east separates Salsette Island from the mainland. Within the city the Versova (Malad) Creek and the Gorai (Manori) Creek inundate the suburban region. The Mahim Creek forms the border between the two districts. On the eastern front, a large creek—the Thane Creek—is present. The study area lies between latitude 19°7'48" to 19°11'55" N and longitude 72°47'13" to 72°50'2" E.

4.1 Versova Creek

The Versova creek (Latitude:19⁰08.8'N; Longitude:72⁰48.2'E) is on west coast of Mumbai which is adjacent to Versova Village, a well known fish landing centre, receives wastewater and sewage from open drains and preliminary treated wastewater from Malad and secondary treated wastewater from Versova treatment facilities. The untreated or partially treated sewage and other anthropogenic pollutants are deteriorating the environmental quality of Versova Creek and adjoining coast (Jiyalal, 1985 and Mukherji 2002), which are concern. Hence Versova was considered as a polluted station for present study. (Figure 3.1-a)

4.2 Gorai Creek

Gorai Creek (Latitude:19⁰14.0'N; Longitude:72⁰49.5'E) is the inland extension of the Manori Creek and is the recipient of the untreated sewage from the settlements around its bank. Gorai creek covers the north-west reach of suburban Mumbai extends beyond Mira Road to the west, after cutting through vast mangrove mudflats and low lying marshy areas. The area was chosen because of the recently published information on the seasonal changes in chlorinity, micronutrients, pH and alkalinity in porewaters from high porosity, carbon rich sediment cores of this creek (Jaiswar, A R and Zingde, 2000) (Figure 3.1-b). Keeping the environmental condition in the view, the Gorai is considered as comparatively less polluted for the present study.

5 Results and Discussion

5.1 Versova

The Versova Creek sustaining dense mangrove stands on its both banks is a shallow salt marsh along the tidal creek of Mumbai with a depth of about 1 to 1.5 m and has a width ranging from 30 to 40 m. The major vegetation of the swamp includes mangrove species viz., *Avicennia marina* and *Avicennia alba* with the height ranging between 1.5 - 5.0 meter. During flood tide flow, the sea water inundates the creek and during extensive high tides, even the swamp vegetation is submerged. Dwivedi and Padmakumar (1980) reported that Mumbai mangrove habitat is disappearing due to human interference. Versova Creek is subjected to various threats of anthropogenic pollution as a result of which significant depletion of dissolved oxygen, marked enhancement of nutrients and excessive growth of phytoplankton prevails in the region (Desai, *et al.*, 1984, Jiyalal, 1985).

The present study includes a continuous monitoring for fourteen months (August 2000 – September 2001) on water quality, sediment quality, phytoplankton and microphytobenthos. The water quality was evaluated based on the samples collected during flood from the overlying water on the same intertidal area where microphytobenthos was sampled. The characteristic of overlying water during different seasons are discussed below:

5.1.1 Physicochemical parameter

Substantial change in water quality of coastal areas may affect the aquatic life, which may become vulnerable to these changes. The results of water quality are illustrated in Figures 5.1.1 to 5.1.2 and Table 5.1.1.

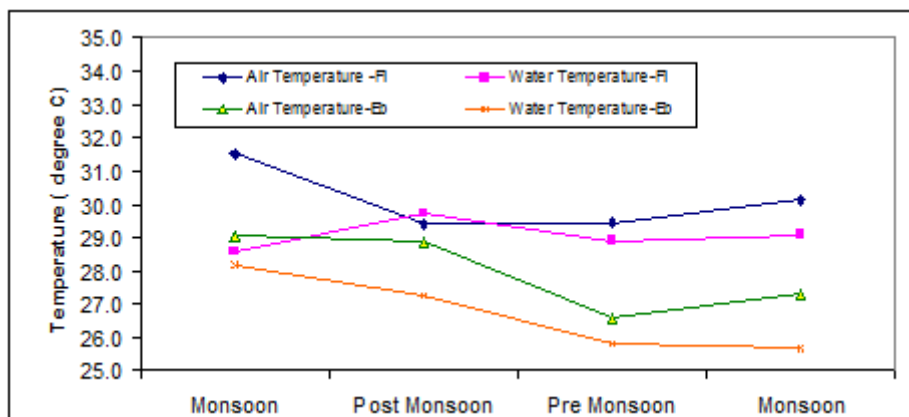
a. Temperature

Temperature is an important parameter that can influence the water chemistry. Rates of chemical reactions generally increase with increasing temperature. Temperature is a regulator of the solubility of gases and minerals. The solubility of important gases, such as oxygen and carbon dioxide increases as temperature decreases. For example, warm water contains less dissolved oxygen (DO) than cold water. Inversely the solubility of most minerals increases with increasing temperature.

Water temperature generally varies in relation to air temperature and plays a major role in regulating biochemical reactions, dissolution of DO and microbial activities. Hence, any change in water temperature may influence the ecological conditions.

The variation of water temperature was observed in accordance with air temperature. The seasonal impact on water temperature was evident (Figures 5.1.1 to 5.1.2. and Table 5.1.1).

The highest water temperature (30.6° C) was recorded during September whereas lowest (22.8° C) was during January (Table 5.1.1). The impact of tide on water temperature was also discernible by recording highest temperature during flood and lowest during ebb which could be associated with influx of domestic waste water from upper region of the creek. The overall average of water temperature during different seasons at Versova is described in the Figure shown below:

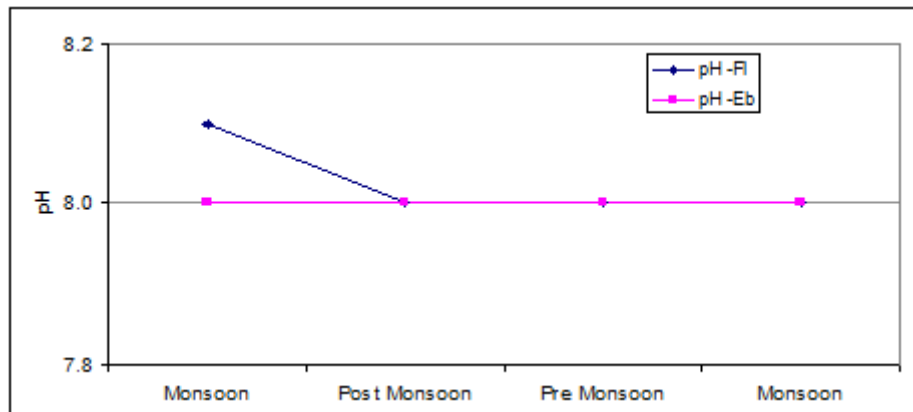


As evident in the above Figure, the water during first series of observation of monsoon was warmer than that of other season. The lowest temperature was also recorded during monsoon of last phase of study which may be due to natural variation. The overall scenario of temperature was in the agreement of other neighboring areas.

b. pH

The principal systems that regulate pH in seawater are the carbonate system consisting of CO_2 , H_2CO_3 , HCO_3^- and CO_3^{2-} , salt content and alkalinity due to borates. Because of buffering capacity of seawater, generally seawater pH has variability limited to 8.0 to 8.3. In shallow, biologically active tropical waters, large diurnal pH changes from 7.3 to 9.5 may, however, occur naturally because of photosynthesis. In the nearshore and estuarine system influx of freshwater, particularly during monsoon, largely affects the buffering effect and pH generally remains below 8.0. The pH affects the degree of dissociation of weak acids and bases enhancing toxicity of some contaminants such as HCN, H_2S etc. Shift in equilibrium of ionic species such as NH_4^+ to NH_3 can enhance its toxicity at higher pH. Though pH range of 5 to 9 is not directly harmful to the aquatic life, such changes can make many common pollutants more toxic. For instance pH range of 5 to 6 may become lethal when CO_2 is liberated from bicarbonates in water.

The present study revealed narrow range of variation (av 8.0 ± 0.1) in pH (Figures 5.1.1- 5.1.2) and indicated the characteristics similar to that of nearshore coastal area. The tidal impact on pH was not very clear since the water of Versova Creek could be oscillating in a short distance and coming back to the shore during next tide. The slight variation of pH did not indicate any seasonal impact on it. The overall average values of pH for the different seasons are presented below:



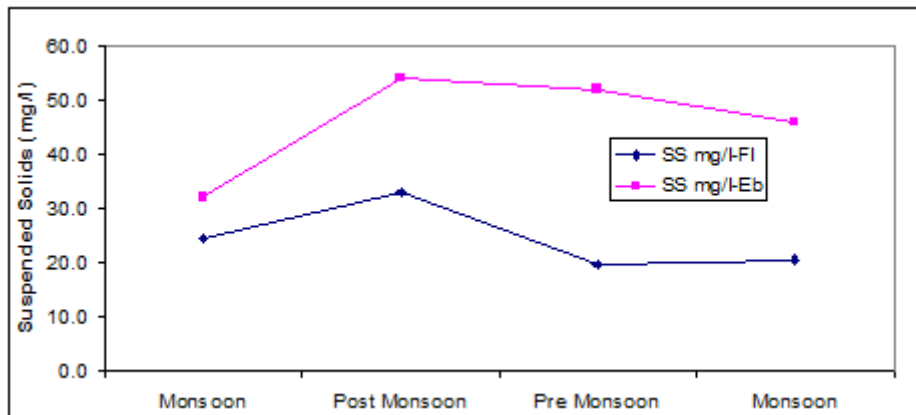
The homogenous distribution of pH during present study did not show any clear tidal impact. However, the concentration of pH was indicative of the characters of water similar to coastal water.

c. Suspended Solids (SS)

The SS can include a wide variety of material, such as silt decaying plant and animal matter, industrial wastes, sewage, and inorganic particles. The inorganic portion is usually considerably higher than the organic in estuaries. Both contribute to turbidity, or cloudiness of the water. High concentration of SS can cause many problems for aquatic life such as decreasing light penetration and hampering photosynthesis. High SS can also cause an increase in surface water temperature, since the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further (warmer waters can hold less DO), and can harm aquatic life in many other ways. Organic content in SS increases oxygen

demand in the water column and its settlement on the bed can make the sediment anoxic. Suspended solids in water are due to dispersion of fine grained sediment of the bed and mudflats by tidal currents.

The results of SS as evident in Figures 5.1.1 to 5.1.2 showed wide variation (av 35.1 ± 17.6 mg/l) during the period of study which could be due to high tidal currents churning out the bed sediments. The average values of SS for the different seasons are presented below:



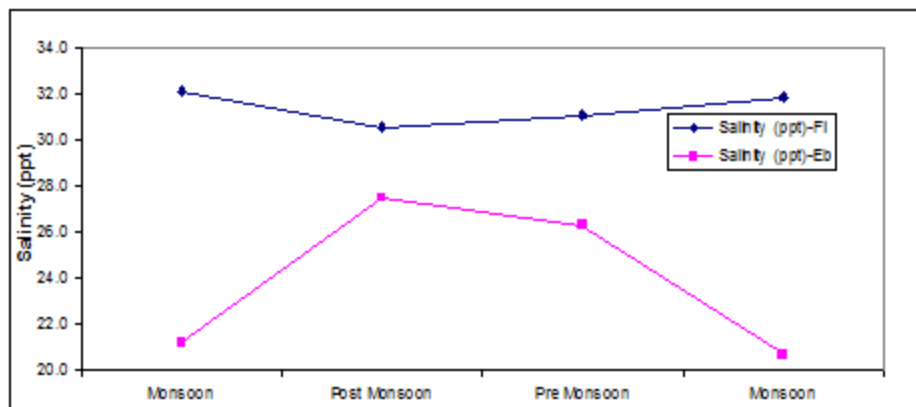
As evident in above Figure, the lower concentration of SS was observed during pre monsoon period than that of post monsoon. The period of monsoon could not enhance the SS and the values were slightly lower than that of other seasons which could be attributed to fresh water influx into the creek.

d. Salinity

Salinity is an indicator of freshwater intrusion in nearshore coastal waters as well as excursion of salinity in inland water bodies such as estuaries, creeks and bays. Normally seawater salinity is 35.5 ppt which may vary depending on competition between evaporation, precipitation and freshwater influx. Salinity is an ecological factor of considerable importance, influencing the types of organisms that live in a water body. Biota is generally acclimatized to a certain range of salinity where they thrive.

Sudden changes in salinity may cause high mortality of biota including fish due to salinity shock.

The lower salinity recorded during ebb in the comparison of flood period as evident in Figures 5.1.1-5.1.2, could be associated with discharge of domestic waste water in the creek. The effect of monsoon on salinity was significant in the creek with always declined level. The overall scenario of salinity is presented in the following Figure:



The above Figure clearly indicates that Versova Creek is under the influence of domestic waste water discharges resulting decrease in the concentration of salinity even during premonsoon period. A clear salinity gradient with markedly lower values during ebb influenced by domestic waste water discharges is discernible in the above Figure.

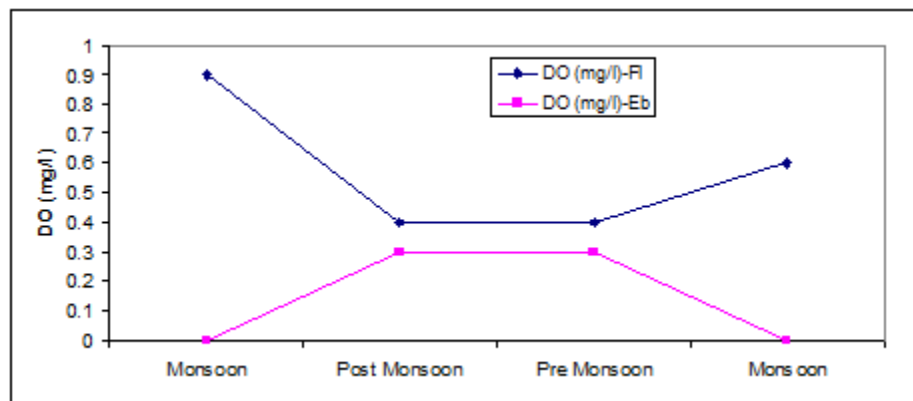
e. Dissolved Oxygen (DO)

The health of aquatic life is closely linked with the level of DO in water thereby making it the most critical parameter while assessing the water quality. Much of the dissolved oxygen in water comes from the atmosphere. After dissolving at the surface, oxygen is distributed by current and turbulence. Algae and rooted aquatic plants also deliver oxygen to water through photosynthesis. The main factor contributing to changes in dissolved oxygen levels is the build-up of organic wastes. Decay of organic wastes consumes oxygen and is often accelerated in summer, when

aquatic animals require more oxygen to support higher metabolisms. Depletions in dissolved oxygen can cause major shifts in the kinds of aquatic organisms found in water bodies. Consumption of DO during heterotrophic oxidation of oxidizable organic matter and respiration by aquatic flora and fauna gives high concentration of BOD. In natural waters rate of consumption of DO is less than the rate of replenishment resulting in its adequate level in water which is often more than the saturation value.

It has been reported that if DO falls below 3 mg/l concentration, the rich and diversified aquatic life may not be maintained. It is now well established that level of DO falling below 2 mg/l for prolonged periods may develop stress condition for aquatic life. There are information's that the DO depleting to the level < 1 mg/l causes fish kill. DO content reveals the stress on the environment due to decomposable organic matter.

The results of DO are depicted in Figures 5.1.1-5.1.2 which suggest a significant decline in the level, may be due to anthropogenic discharges in the creek. The overall status of DO in the creek is evident in the following Figure:



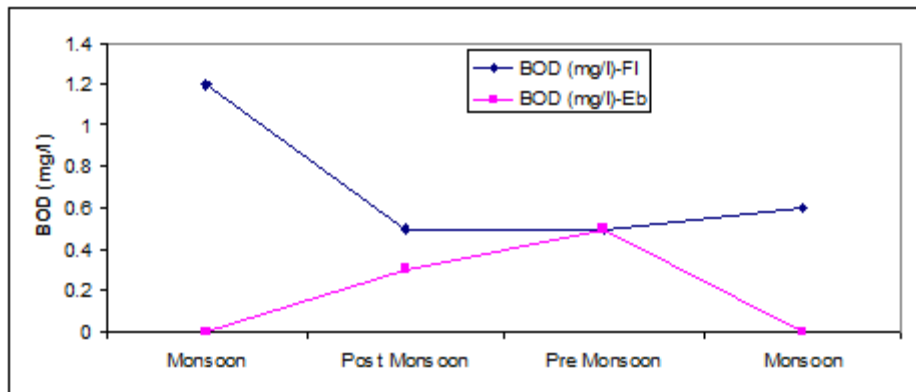
Often lack of oxygen (0 mg/l) in Versova Creek clearly suggested the influence of anthropogenic pollutants in the region. The improvement in the concentration of DO during flood (av 0.4 ± 0.2 mg/l) was still significantly lower than the level (3.0 mg/l) required for the marine organisms which

suggested the scenario of anthropogenic pressure on marine ecology of Versova Creek.

The sewage polluted (Versova creek) revealed very low levels of DO (<0.2 mg/l), high value of phosphate (39.7 µg/l) and nitrate (37.1 µg/l) which was similar to that of Nair *et. al.* (1991), Gupta *et. al.* (2009) who stated Versova as a comparatively highly polluted locations around Mumbai. Vijay, *et. al.* (2010), claims that Mumbai receives wastewater and sewage through open drains including partially treated sewage from Malad and Versova treatment plants. Gajbhiye, *et. al.* (1991) and Gajbhiye and Abidi, (1993) also recorded the depleted DO levels around zero at Versova Creek.

f. Biochemical Oxygen Demand (BOD)

High concentration of BOD indicates an input of organic load in water body which could be related to release of sewage. When the DO is nil the level of BOD would be very high. Since, the analysis of BOD was undertaken without unseeded method the values obtained here do not give correct picture. The organic load due to urban activity in Versova area could result very high BOD. However, the values of BOD during present study can give an idea of stress condition during different seasons which are furnished below:



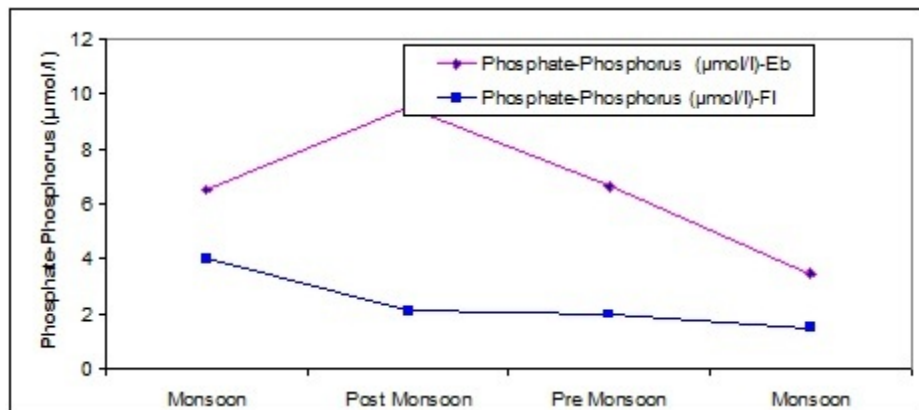
The BOD level was slightly higher during premonsoon than that of monsoon and postmonsoon and indicated the influence of organic load in

the creek. A marked decline in BOD during monsoon seasons clearly suggested the dilution of organic load due to heavy pouring in the region.

g. Reactive Phosphate-Phosphorus ($\text{PO}_4^{3-}\text{-P}$)

Phosphate ($\text{PO}_4^{3-}\text{-P}$) is one of the major nutrients required for plant nutrition and essential for aquatic life. Source of phosphate in coastal marine environment can be domestic sewage, detergents, wastewaters from agro based, fertilizer, agricultural runoff and organic detritus such as leaves, cattle waste etc. Phosphorous compound though present in low concentration in sea water play a major role in primary productivity.

The concentration of $\text{PO}_4^{3-}\text{-P}$ (av $4.5 \pm 4.3 \mu\text{ mol / l}$) was significantly high suggesting the input through release of domestic waste water. The overall scenario of $\text{PO}_4^{3-}\text{-P}$ is shown in the following Figure:

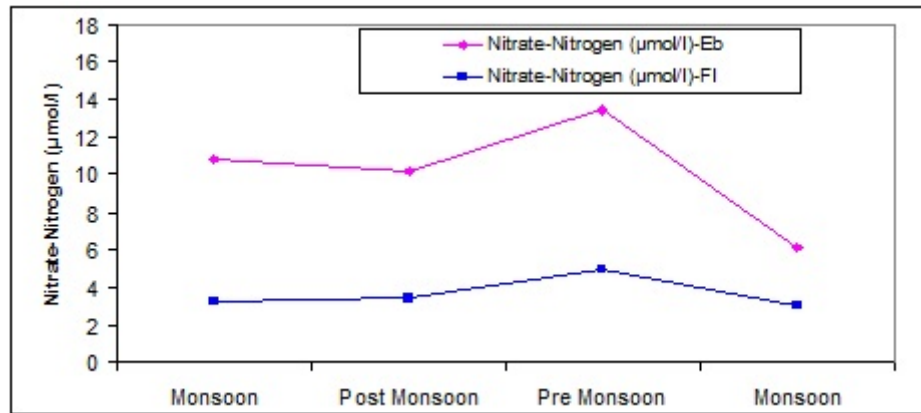


A gradual increase in the level of $\text{PO}_4^{3-}\text{-P}$ from monsoon to post monsoon attaining as high as $14.2 \mu\text{ mol / l}$ could suggest an enrichment in the creek due to anthropogenic releases. The ebb periods always sustained higher concentrations of phosphates than that at flood which clearly indicated the influence of waste water release in the creek. Thus the overall structure of phosphate in Versova Creek indicated a built up in nutrient facilitating the growth of marine algae.

h. Nitrate-Nitrogen ($\text{NO}_3^- \text{N}$)

Nitrogen compound is mainly present as nitrate and ammonia. Their high concentrations in water can lead to an excessive growth of undesirable and sometime toxin producing algae which can induce fish mortality and eutrophication in extreme cases.

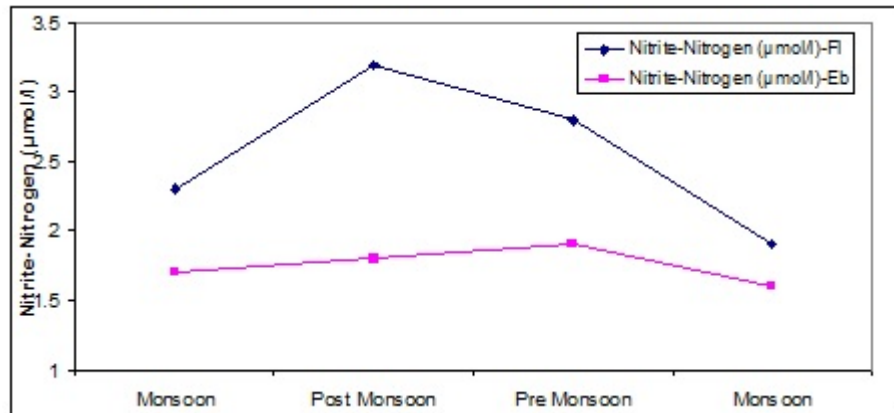
The results of nitrate-nitrogen are illustrated in Figures 5.1.1-5.1.2 which indicates an enhancement of nutrients in the creek. The highest concentration of nitrate recorded during premonsoon in the comparison of other season clearly indicated an input through anthropogenic sources. The overall status of nitrate nitrogen is shown as below:



The concentration of nitrate was always seen higher during ebb than that of flood which again confirmed a definite trend of variation influenced by anthropogenic releases.

i. Nitrite-Nitrogen ($\text{NO}_2^- \text{N}$)

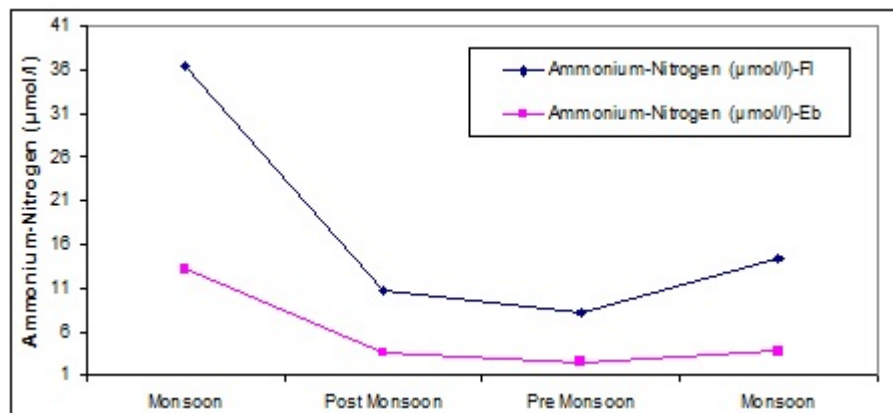
The values of nitrite was also enhanced in the creek. The overall average values of nitrite are depicted in the Figure shown below:



The concentration of nitrite is similar to nitrate and revealed a similar trend of variation with higher value during ebb than that of flood. The overall level was enhanced and suggested the impact of anthropogenic releases in Versova creek.

j. Ammonium-Nitrogen ($\text{NH}_4^+ \text{N}$)

The Figure shown below clearly indicates a seasonal variability in the concentration of ammonia with highest level during monsoon. This could be associated with land drainage in the region. However, the high organic load associated with land drainage during monsoon gets oxidized which results an increase in ammonia similar to the case of present study in Versova Creek.



Therefore, the concentration of ammonia following the similar trend of nitrate and nitrite showed higher level during ebb period than that of flood

when oxygen was very low. Thus the creek water during ebb was dominated by anthropogenic releases as a consequence of which the nutrients in terms of nitrite and ammonia were always in an enhanced level.

Thus the results of present study conclude that the anthropogenic releases have deteriorated the ecology resulting, an excess level of nutrients in Versova Creek.

5.1.2 Sediment texture

a. Texture and Total organic carbon.

The sources of C_{org} in coastal marine sediment are the decaying organic matter produced within the system and that settles on the sediment after death of organisms as well as detritus and organic matter from the terrestrial sources through point and non point sources. Benthic productivity is in part depends on the organic matter in the sediment but their high concentration in sediment can create reducing condition thereby adversely affecting benthic organism.

The variable distribution of C_{org} is attributed to an array of hydrographic and sedimentary parameters such as upwelling and primary productivity, texture of sediments, rate of sedimentation, bottom currents, benthic population in bottom sediments, DO in bottom waters terrigenous supply of organic matter and shelf and slope morphology. Among these parameters DO in bottom water plays a significant role. The principal reason for high (>4%) to very high (>8%) concentration of C_{org} in the slope region of the Indian West Coast is the impingement of the low DO zone ($DO \leq 0.05$ ml/l) on the floor of the slope (Paropkari; 1991, 1992) Phytoplankton convert inorganic carbon dissolved in seawater as CO_2 to C_{org} through the complex process of photosynthesis in the photic zone. The C_{org} thus produced is passed through the food web and ultimately a significant percentage of the C_{org} is discarded in the remains of organism

and sinks to the seafloor. The C_{org} is consumed by organism living in the mud with any left over C_{org} becoming buried in the sediments.

The sediment during present study was sandy with low silt concentration. The C_{org} was higher in Post and pre monsoon period (Table 5.1.2). The overall average of $686.9 \% \pm 70.5 \% C_{org}$ was indicative of high variability. C_{org} recorded during the period of study suggested an enhanced level in the creek. The texture of the sediment is shown in the Table below:

Season	C_{org} (%)	Sand (%)	Silt-clay (%)	Silt (%)	Clay (%)
	Min-Max (av)	Min-Max (av)	Min-Max (av)	Min-Max (av)	Min-Max (av)
Period 2000-2001					
Monsoon	661.1- 712.8 (686.9)	80.0-85.5 (82.8)	14.5-20.0 (17.3)	8.3-12.6 (10.5)	6.2-7.4 (6.8)
Post Monsoon	709.2-744.8 (728.4)	77.0-78.5 (77.9)	21.5-23.0 (22.1)	15.0-20.5 (16.9)	1.6-6.8 (5.2)
Pre Monsoon	665.9-739.7 (712.1)	76.2-77.6 (76.7)	22.4-23.8 (23.3)	16.8-21.4 (18.1)	1.9-6.9 (5.2)

It is evident from the above Table that the sediment was dominated by sand in all the seasons. However, the higher composition of sand in the sediment during monsoon than that of other seasons could be due to strong water currents of monsoon washing out the clay part.

5.1.3 Phytoplankton

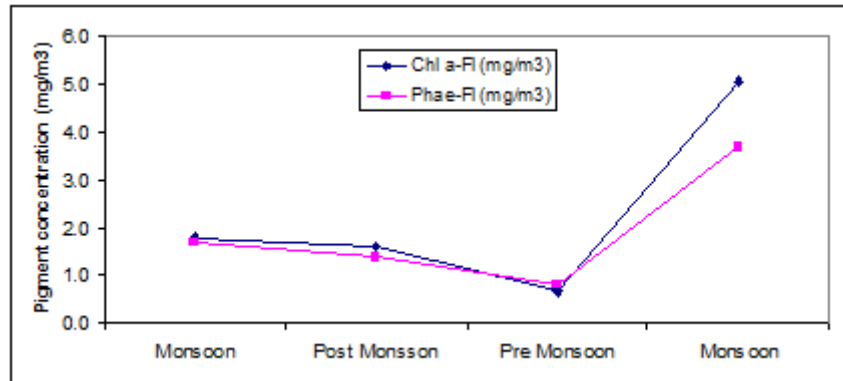
In marine environment, organism experience natural stress which varies in magnitude and frequency depends on changes in the physicochemical characteristics of the water mass. Though the organisms have evolved to withstand the natural changes within the certain limits, they may not be well adapted to artificial stress and this may even affect their capacity to adapt to natural variation. Hence, to understand the ecological condition of Versova Creek and link that with primary level of food web it was necessary to assess the status of primary producers in the region. Thus status of primary producers is evaluated in terms of the studies on phytoplankton including both biomass and population which are discussed below:

i. Phytoplankton Pigments

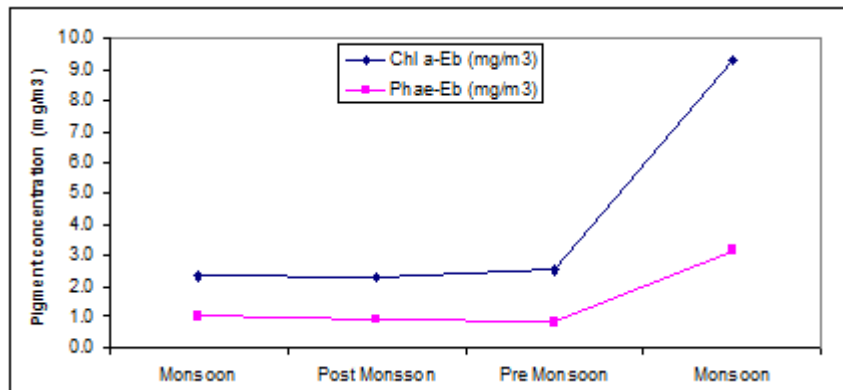
Phytoplankton being the basic component of food chain, play a major role in the assessment of marine ecology. Phytoplankters are primary producers and are known as a very good indicator of pollution. There are large number of species of phytoplankton which vary widely in space and time. Among phytoplankton pigments, chlorophyll *a* is the most active one and takes major part in the photosynthesis process. The ratios of Chlorophyll *a* / phaeophytin help to understand the condition of phytoplankton cells in an ecosystem (Jiyalal, 1985). The concentration of phytopigments can give a reliable estimation of primary production potential of an aquatic body. Also chlorophyll *a* in combination with phaeophytin is a good index to evaluate the health of the ecosystem (Jiyalal, 1985).

A continuous study for 14 months (August 2000- September 2001) was conducted on concentration of chlorophyll *a* and phaeophytin. The results (Table 5.1.3) clearly indicated a marked increase in the level of chlorophyll *a* during ebb in the comparison of flood period which could be attributed with the anthropogenic nutrients prevailing comparatively more

during ebb. However, the poor ratios of Chlorophyll *a* / phaeophytin particularly during ebb period as compared with flood clearly indicated the influence of anthropogenic pollutants in the creek. The overall variation of pigments observed during present study (Flood) is discussed in the following Figure:

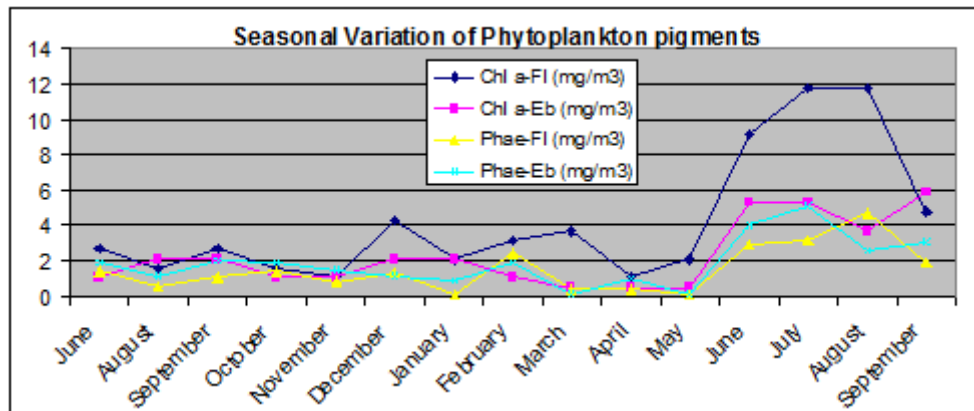


The decreased level of pigment during flood as compared with ebb is discernible in the above Figure. Seasonal variability in phytoplankton standing crop is not very clear during flood period. Ratios of Chlorophyll *a* / phaeophytin are seen to be almost similar in all the seasons except the occasional decrease during premonsoon.



The above Figure indicates a detectable variation in the concentration of Chlorophyll *a* (av $4.2 \pm 3.6 \text{ mg/m}^3$) and suggested an enhanced phytoplankton biomass indicating an excess growth of phytoplankton stimulated by high concentration of nutrients during ebb tide. The average

Chlorophyll a value of 2.3 mg/m³ during first monsoon was seen to be significantly increased to 11.3 mg/m³ during second phase of monsoon of study indicating the high natural variability in Versova Creek. The anthropogenic pollutants may be playing a major role in such variation of pigments. The ratios of chlorophyll a/ phaeophytin decreased significantly low during pre and postmonsoon which are evident in the Figure shown above.

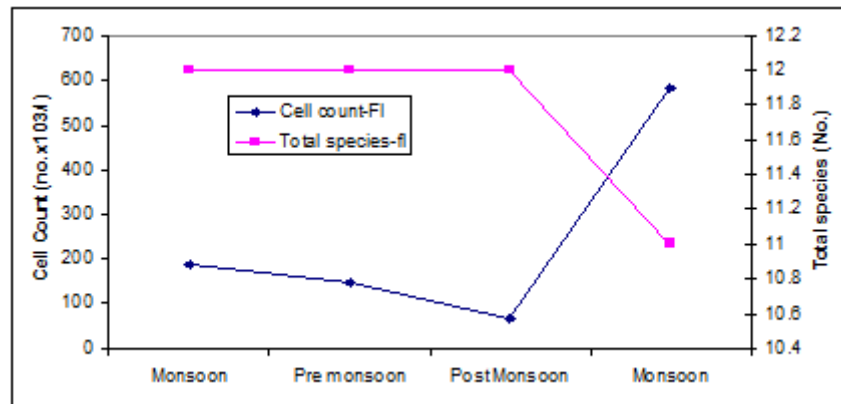


Seasonal variation of phytoplankton pigments is shown in the above Figure which clearly indicates a significant variation with high concentration during June-August of second phase of study. Significance level of $p < 0.05$ was recorded between chlorophyll a and Nitrate – Nitrogen.

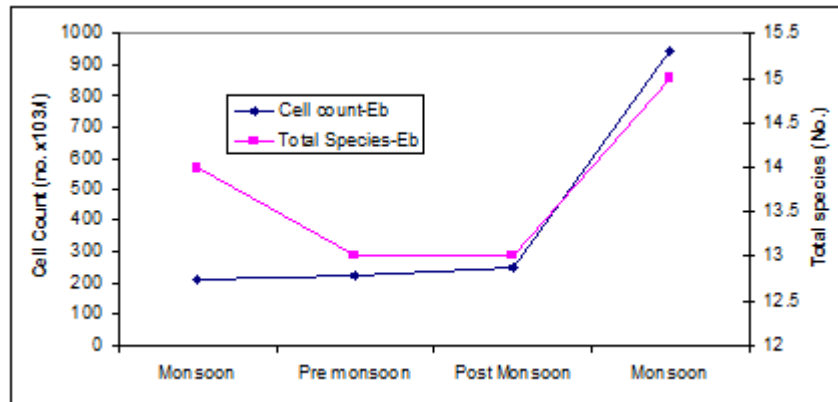
ii. Phytoplankton Cell count

Pollution influences phytoplankton in many ways including direct and indirect impact on its population, biomass, community structure and growth. The polluted water may retard phytoplankton growth or result an enhancement in population and reduce species diversity. Thus, the qualitative and quantitative study on phytoplankton of the marine ecology becomes imperative. Marine coastal environment of Mumbai with pockets of severely polluted regions offers an opportunity to study the role of phytoplankters and assess the degree of pollution on marine ecology. Hence, the present investigation was undertaken in all seasons to evaluate

the impact of prevailing organic pollution on the primary producers in Versova Creek. The results presented in Tables 5.1.4 and 5.1.5 give an idea of an anthropogenic pollution resulting, an alteration in natural structure of phytoplankton of Versova Creek. The present investigation was carried out in all the seasons in order to study phytoplankton populations in terms of cell counts, total species and results of which are presented in the following Figure:



An increase in phytoplankton population during ebb as compared with flood is discernible from the results (Tables 5.1.4, Plate 1 to Plate 3) which is similar to that of pigments and clearly indicates that the water during low tide with higher concentration of nutrients due to anthropogenic releases, results a significant increase in phytoplankton growth. However, a marked decrease in species diversity particularly during ebb in the comparison of flood suggested the impact of pollution on phytoplankton structure. Neritic species brought from offshore during flood could be the reason for an enhancement in species diversity during this period. Seasonal variability in phytoplankton standing crop is also clear with lower population during pre and post monsoon than that of monsoon periods.



The above Figure indicates a high seasonal variability in phytoplankton stock during ebb tide. The overall scenario of phytoplankton revealed a marked enhancement in population and total species in Versova Creek which may be attributed with high concentration of nutrients available in the creek system during ebb periods.

iii. Phytoplankton Species

Phytoplankton species recorded during present study were belonging to mainly classes such as Bacillariophyceae; Dinoflagellates and Cyanophyceae. A total 55 species were recorded in Versova Creek during the whole period of study. The details of classification for these phytoplankton species are presented in Table 5.1.6.

Foregoing account of results indicated that *Navicula membranacea* was predominant followed by *Nitischia closterium* in Versova Creek during ebb period which was associated with markedly decreased DO (0 mg/l) and high concentration of nutrients. The *Oscillatoria formosa* also existing in high number particularly during ebb period associated with very low salinity, nil DO and significantly high concentration of nutrients clearly indicated the hardy nature of this algae. The presence of *Stauronies membranacea* and *Thalassiosira subtilis* and sometimes *T. gravida* though in low numbers in Versova Creek gave an idea of adaptation of these algae and preferring the creek environment dominated by organic pollution.

5.1.4 Microphytobenthos

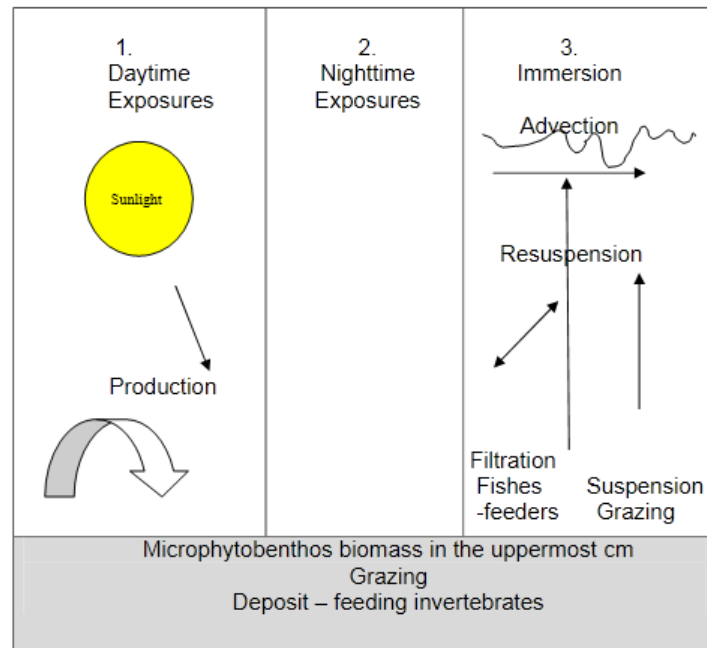
Intertidal, clayey, sandy or silty sediment deposits support abundant population of phototrophic microorganism. The importance of these assemblage is widespread, acting as primary producers (Pinckey & Zingmark, 1991), to be food resource for benthic infauna (Sullivan & Moncrieff, 1990) and influencing the stability of the sediment bed (Paterson & Daborn, 1991; Underwood & Paterson, 1993). Populations may form recognizable biogenic structures on non-cohesive intertidal sediments which are termed microbial mats (Krumbein, 1977). Equally obvious but more transient, accumulations of cells also occur at the surface of muddy cohesive sediments. These 'biofilms' often appear daily in response to the inherent rhythmic migration of the dominant epipelagic diatoms under the influence of light and tidal cycles (Happey-Wood & Jones, 1988; Paterson, 1989).

Extracellular polymeric substances form an important part of the microbial matrix and may have several functions that enhance the survival and competitive success of microbial cells under natural conditions (Decho, 1990). Extracellular polymeric substances have been implicated in diatom and cyanobacterial motility (Fogg *et al.*, 1973; Edgar & Pickett-Heaps, 1983) adhesion to sediment grains (Daniel *et al.*, 1987), protection from desiccation and in the collation of xenobiotic compounds. The extracellular polymeric substance from microphytobenthos has the potential to influence the rheology which enhances the stability of sediments (de Boer, 1981; Grant & Gust, 1987; Paterson, 1989; Dade *et al.*, 1990).

Microphytobenthos can be the principal oxygen producer in coastal environments (Varela & Penas, 1985 ; Plante-Cuny & Bodoy, 1987 ; Charpy Roubaud, 1988) controlling the oxygen balance at the water – sediment interface (Hawkins & Lewis , 1982; Davis & McIntyre , 1983; Johnstone *et al.*, 1990; Rizzo *et al.*, 1992) . As a producer of new organic matter that can enter the benthic and pelagic trophic web,

microphytobenthos is a key component in the carbon cycle in littoral environments.

According to Blanchard *et al.*, 2001, the schematic representation of the processes and the environmental conditions affecting microphytobenthos biomass in the uppermost layer of intertidal mudflat is shown in the following Figure:



The schematic representation suggest that the microphytobenthos in the intertidal area of Versova and Gorai will meet a certain dynamics which is explained as follows:

1. during daytime exposures, primary production can occur and induces a biomass increase (grazing rates are low compared to production rates);
2. during night exposures, there is no production and biomass decrease due to grazing by deposit feeders;
3. during the period of flushing, tides- and wind- induced currents erode or deposit the biomass in addition to grazing by deposit- feeders and fishes.

Thus microphytobenthos play a vital role in primary production intermingling with benthos and pelagic food chain and it constitutes the primary food for a wide variety of meiofaunal organisms (Admiraal, 1984). Highest production of benthic microalgae generally occurs between March and June along with high phaeopigments due to intense grazing activity of benthic inhabitants (Cariou-Le Gall and Blanchard, 1995). Their distribution and abundance are controlled by many factors such as salinity, temperature, organic load, grazing pressure and sediment texture (Colijn and Dijkema, 1981; Amspoker and McIntyre, 1986).

Point source of nutrient may result in increased benthic algal productivity with little increase in benthic algal biomass because of rapid transfer of organic matter to grazers. The types of top-down forces that mask benthic algal responses have been well documented in several aquatic ecosystems (Peterson *et al.*, 1985; Colletti *et al.*, 1987, Marks and Lowe, 1989). The detailed seasonal and spatial study on microphytobenthos would be useful in the assessment of benthic renewable resources of Versova.

i) Microphytobenthic pigments

The results of microphytobenthic pigments in terms of chlorophyll *a* and phaeophytin studied at different depth of sediments are discussed as follows:

The microphytobenthic pigment indicates highest values at superficial sediment layer as compared with deeper layers. The vertical distribution of pigments revealed a clear trend of variation with significantly enhanced values of microphytobenthic chlorophyll *a* (av 180.6 ± 155.4 mg/m²) in 1cm layer of sediments during HWL and (av 613.2 ± 278.1 mg/m²) during LWL at Versova Creek. Similar observation on microphytobenthos at 1cm layer of sediment with the chlorophyll *a* ranging between 11.2 and 278.8 mg/m² was also recorded in Northern Adriatic sea by Totti, 2003. Underwood,

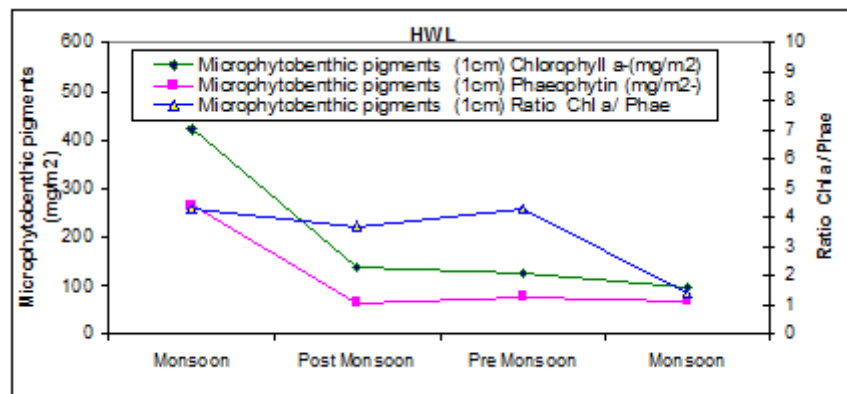
2010, has reported a very high variation (1–560 mg m²) of microphytobenthic Chlorophyll *a* in Severn estuary at superficial layer of sediment.

The microphytobenthic pigment in terms of Chlorophyll *a* was seen in gradually decreasing trend with deeper layer of sediments (Table 5.1.7 to 5.1.13). The similar observations were also reported by Blanchard and Cariou-Le Gall, (1994). Photophysiological characteristics of microphytobenthos following the ecological constrains imposed on the intertidal mudflats were explained by Blanchard and Cariou-Le Gall, (1994), Rasmussen *et al.*, (1983), Blanchard and Montanga, (1992). The phaeophytin also revealed the similar trend like chlorophyll *a* implying the higher values at superficial layer and gradual decrease with the increasing depth of sediment. The higher ratios (> 1.0) of chlorophyll *a*/ phaeophytin at superficial layer of sediment could be attributed with the sufficient irradiance (Jiyalal *et al.*, 2011) available there.

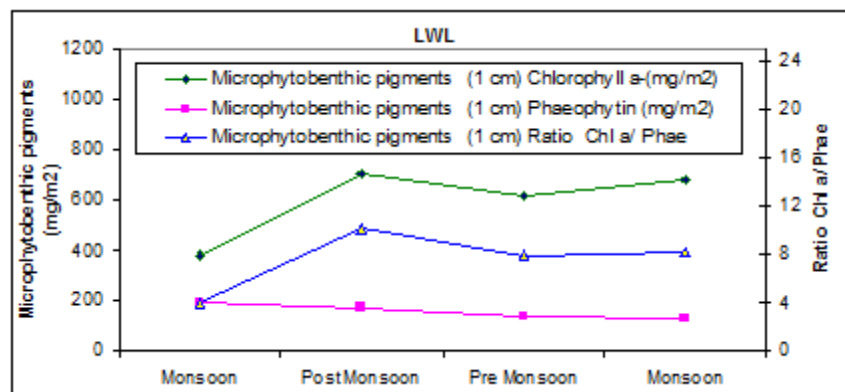
However, the ratios of chlorophyll *a*/ phaeophytin were recorded in gradually decreasing (< 1.0) trend corresponding to the depth which could be due to degradation of chlorophyll *a* into phaeophytin as a consequence of cell diagenesis by microbial activity or grazing similar to the observation by Bianchi and Findlay (1991), Barlow *et al.*, (1993). The lower concentration of chlorophyll *a* than that of phaeophytin gives a general indication of physiological or grazing state of microphytobenthic community (Barranguet 1997 and Cartaxana *et al.*, 2003). The photosynthetic irradiance parameters affected by environmental factors such as light, temperature, salinity and pH were also explained by Colijn & Van Buurt (1975) Rasmussen *et al.*, (1983), Blanchard and Montanga (1992). A consistent difference between a photosynthetic response of microphytobenthic cells from photic zone and an underlying aphotic layer of the sediment was clear with the significant poor ratios of chlorophyll *a* /

phaeophytin in the deeper layer of sediment as compared to superficial layer during present study.

The concentration of phaeophytin was recorded av 118.7 ± 132.6 mg/m^2 during HWL whereas at LWL the values varied with av 221.2 ± 133.2 mg/m^2 at 1cm sediment layer. In the present study the values of phaeophytin were lower than chlorophyll *a* in 1cm sediment depth at HWL during all the seasons suggesting a healthy condition of microphytobenthic cells, which is evident in the following Figure:

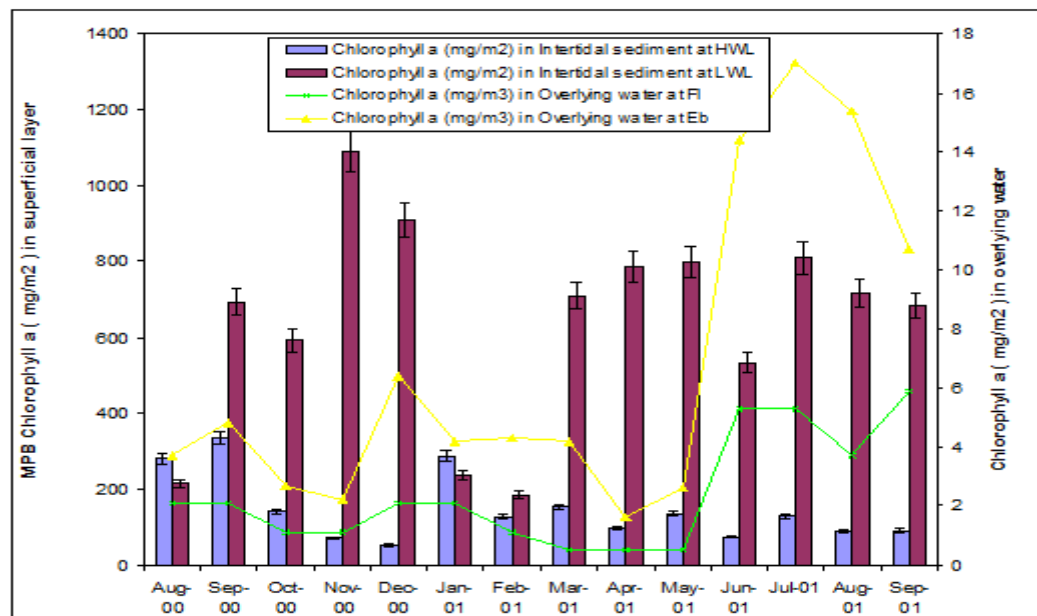


The same pattern of variation of pigments indicating lower concentration of phaeophytin than chlorophyll *a* with the ratios always higher than 1 suggesting a healthy condition of microphytobenthic cells at LWL also were similar to the results of Riaux-Gobin and Bourgoin, 2002; The ratios of chlorophyll *a*/ phaeophytin are higher than 1 which is evident in the following Figure:



The above Figure clearly indicates that the concentrations of phaeophytin are always lower than chlorophyll *a* at superficial layer of sediment. This structure of pigments always results the ratios of chlorophyll *a* / phaeophytin to be higher than 1, suggesting a healthy condition of microphytobenthic cells at superficial layer.

The comparison of results between microphytobenthic pigments at superficial layer and phytoplanktonic pigments in overlying water at Versova have been worked out and depicted in the following Figure:



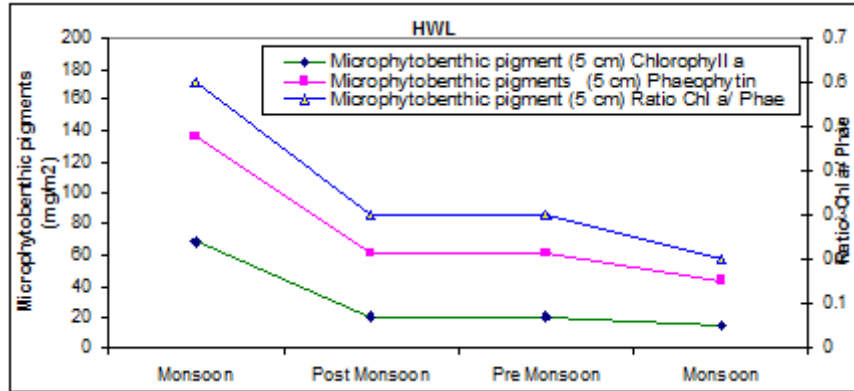
A distinct variation in microphytobenthic chlorophyll *a* between LWL and HWL is evident in above Figure. The values of chlorophyll *a* were significantly higher in the layer of 1 cm sediment at LWL than that of HWL which was similar to the observation of Chevalier *et al.*, (2010). In general, distribution pattern of phytoplankton pigments in overlying water follow a similar trend of variation of microphytobenthos in the layer of 1 cm sediment, over the period of 14 months. Higher values of chlorophyll *a* recorded during ebb than that of flood in overlying water could be attributed with an enrichment due to anthropogenic releases in the creek. Thus the higher concentration of nutrients during ebb supported phytoplankton

growth as a result of which pigments levels during ebb were significantly higher than flood similar to the observation of Jiyalal, (1985). Seasonal variation in the concentration of microphytobenthic chlorophyll *a* is not very clear except a peak value during postmonsoon (November) during LWL whereas the peak in pigment for HWL is seen during premonsoon (June).

The comparison of microphytobenthic biomass with phytoplankton biomass existing in overlying water showed consistently 10 - 50 orders of magnitude higher microphytobenthic chlorophyll *a* than chlorophyll *a* of phytoplankton. Same has been observed by Nozais *et al.*, 2001; Perissinotto *et al.*, 2002). The concentration of microphytobenthic biomass in the Mpenjati and the Mdloti estuary were reported to be 500 to 600 mg/m² by Nozais *et al.*, (2001) and Perissinotto *et al.*, (2002) which showed the similar trend of variation as in present study.

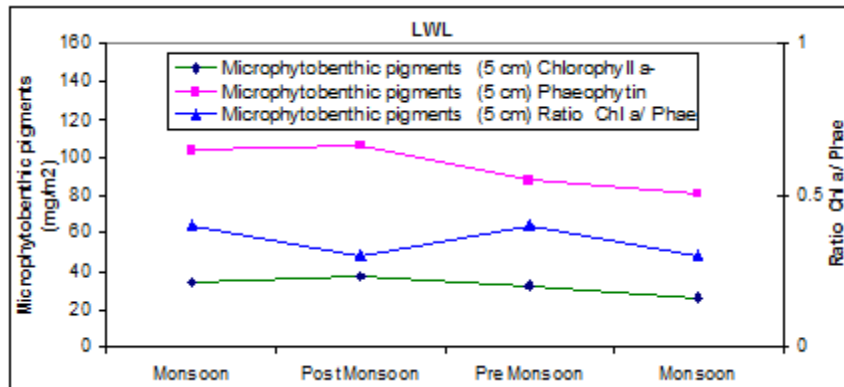
The scenario of microphytobenthic pigments at 5 cm depth of sediment was seen to be completely changed in the comparison of superficial layer. The values of microphytobenthic chlorophyll *a* and phaeophytin were always seen decreasing with increasing depths of sediments. Thus the average concentration of microphytobenthic chlorophyll *a* (av 31.05 ± 24.2 mg/m²) was 2.4 times lower than the values of phaeophytin (av 75.3 ± 47.5 mg/m²) which resulted the poor ratio (0.41) at 5 cm layer of sediment at HWL.

The pigment structure in different seasons remains same showing markedly higher phaeophytin than chlorophyll *a* at 5 cm depth of intertidal sediment during HWL. This has resulted significantly poor ratios of chlorophyll *a*/ phaeophytin as evident in following Figure:



The poor ratios of chlorophyll *a*/ phaeophytin in deeper layers of sediment could be the result of poor irradiance available in aphotic zone. Chevalier *et al.*, (2010) and Totti, (2003) also reported the similar trend.

The results recorded during LWL indicated still lower values (av 32.3 ± 17.5 mg/m²) of Chlorophyll *a* than the values of microphytobenthic phaeophytin (av 94.4 ± 37.1 mg/m²) at 5 cm depth of sediment. This trend of pigments variation in sediment at the depth of 5 cm, resulted significantly poor ratios (0.34) of chlorophyll *a*/ phaeophytin and suggested an unhealthy condition of cells. The overall structure of microphytobenthic pigments are shown in following figure:



Such a depletion in chlorophyll *a* and enhancement in phaeophytin at deeper layer of sediment could be due to degradation of pigments by grazing effect on microphytobenthic cells which is similar to the results

reported by Chong and Sasekumar,(1981); Leh and Sasekumsar,(1984); Sasekumar, and Chong (1987).

Thus the present study concludes that the superficial layer of sediment exhibits high ratio (av 5.5) of microphytobenthic chlorophyll *a* / phaeophytin. The ratios of microphytobenthic chlorophyll *a* / phaeophytin decreases with increasing depth of sediment with miserably low values (av. 0.4) at deeper layer (5 cm) and still lower values (av. 0.09) at deepest (10 cm) sediment studied at Versova.

Markedly decreasing ratios of chlorophyll *a* / phaeophytin with the deeper layer in the comparison of superficial layer of sediment, suggesting an unhealthy condition of microphytobenthic cells during present study was similar to the findings explained by Blanchard and Cariou-Le Gall, (1994). Similar results were also obtained in the aphotic zone, at Marennes – Oleron bay, by Cariou Le Gall and Blanchard, (1995), who described an impact of bioturbation and physical mixing (resuspension / redeposition) of the upper sediment layer . The present study clearly revealed a decrease of the pigment content in the deeper sediment layers. Significantly decrease in microphytobenthic chlorophyll *a* (0.7 mg/m^2) and marked increase in phaeophytin (8.0 mg/m^2) resulting a noticeable poor ratio of these pigments in deeper layer of sediment was similar to the finding of Chevalier, *et al.*, (2010). In Nakdong estuary, Du G Ying, (2010) has also reported markedly high concentration of microphytobenthic phaeophytin (9.86 mg/ cm^3) in the depth of 0 –1 cm sediments whereas the 9 –10 cm layer of sediment sustained significantly low value (0.19 mg / cm^3). Subtidal microphytobenthos density in the Northern Adriatic Sea was also reported to be decreased at 6 cm depth of sediment (Totti, 2003).

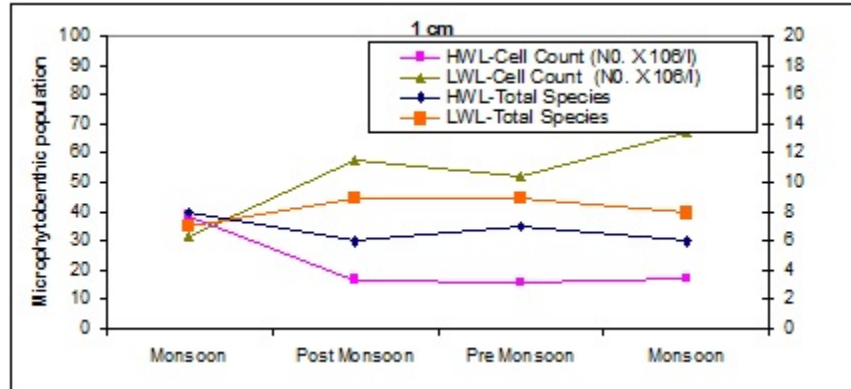
ii) Microphytobenthic Cell count

The phytoplankton in overlying water and the microphytobenthos in and in sediments were belonging to almost same algal classes. The

distinction between benthic and pelagic life styles can be fluid especially in shallow water systems since; the exchange of organisms between the sediment and the water column is common. The microphytobenthos can be resuspended by water currents and wave action and thus they then dwell in the water column and contribute to the planktonic community (Drebes, 1974; de Jonge & van Beusekom, 1995; de Jonge & de Jonge, 1995). On the other hand, phytoplanktonic organisms can sink to the bottom under calm conditions and settle on the sediment in considerable amounts where they live and photosynthesise and become incorporated into the microphytobenthos (Potter *et al.*, 1975; Gaetje, 1992; Blomqvist, 1996).

Taking these benthic-pelagic forms into consideration a long term regular study on microphytobenthos in the intertidal area of Versova was studied over the period of 14 months. The results of microphytobenthic population in terms of cell count and species are discussed as follows:

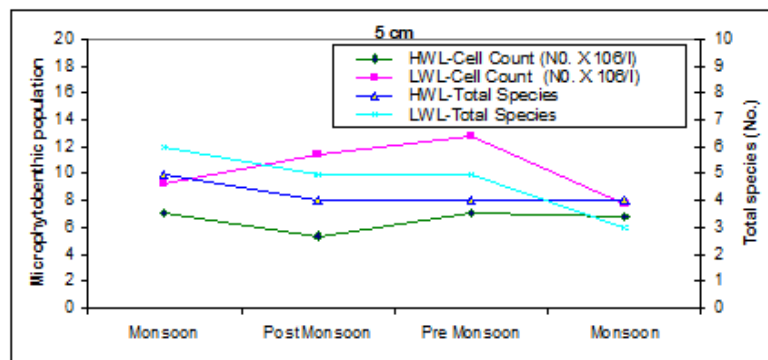
Foregoing account of the results revealed that the population of microphytobenthos were seen higher at LWL (av $54.9 \times 10^6 \pm 26.0 \times 10^6$ cells/ cm^3) than that of HWL (av $21.1 \times 10^6 \pm 12.5 \times 10^6$ cells / cm^3) in the intertidal area of Versova (Table 5.1.14 to Table 5.1.20). During the period of study a total of 33 species of diatoms dominated by *Navicula membranacea*, *Nitzschia pungens* and *Osillatoria formosa*, were seen at HWL whereas *Navicula membranacea*, *Osillatoria formosa*, *Spirulina aeruginosa* were recorded at LWL in 1st cm layer of sediment (Plate 4, 5 and 6). Totti, (2003) also reported the dominance of diatom with the cell count ranging from 728 to 9278 cells / cm^3 at 1 cm layer of sediment in Northern Adriatic sea. The species recorded in 1 cm layer of the sediment were almost similar to the species observed in overlying water (Table 5.1.21) which indicates a clear trend of transfer of species from water to sediment. The overall scenario of microphytobenthic population is depicted in the following Figure:



The seasonal variation was not very clear as evident in above Figure. The distribution of microphytobenthic population was almost homologous except a slight increase during monsoon (June 2001) particularly at LWL.

The results observed at 5 cm depth of sediment clearly showed a conspicuous decrease at 5 cm layer of the sediment. Thus cell count recorded at 1 cm was seen to be gradually decreasing with deeper layer (Table 5.1.14 to 5.1.20). Tidal impact on the distribution of microphytobenthic population with higher values (10.4×10^6 cells / cm^3) at LWL than that of HWL (6.5×10^6 cells / cm^3) in 5 cm layer was evident from the results. The variation in population due to changing environmental condition related to high tide and low tide and light irradiance is also described by Chevalier *et al.*, (2010) and Totti, (2003).

Overall structure of microphytobenthic population at 5 cm layer of the sediment is shown in the following Figure:



There was no definite trend of seasonal variation in microphytobenthos population at LWL at 5 cm depth of sediment. However, tidal impact was significant with higher population at LWL than that of HWL except one occasion of premonsoon. The numbers of total species, observed at LWL were also higher than HWL.

iii) Microphytobenthos community structure

The microphytobenthos includes representatives of several algal classes (Baccilariophyceae, Chlorophyceae, Cyanobacteria, and Dinophyceae). On sandy and muddy substrate, edaphic microalgae living on a variety of benthic surfaces are often dominated by diatoms (Colijn & de Jonge, 1984; Admiraal, 1984; de Jonge & Colijn, 1994; Agatz *et al.*, 1999) whereas coccal and filamentous green algae and Cyanobacteria are usually known to occur at some seasonal stages (Yallop *et al.*, 1994; Taylor & Paterson, 1998; Hillebrand & Kahlert, 2001; Nozaki *et al.*, 2003). Microphytobenthic diatoms are usually composed of pennate, prostrate forms, which are either epipsammic or epipellic (Daehnick *et al.*, 1992; Moncreiff *et al.*, 1992; Gaetje, 1992; Agatz *et al.*, 1999; Mitbavkar & Anil, 2002). Epipsammic diatoms are monoraphidean, araphidean, biraphidean and centric species of small size that grow attached to sediment particles to which they are glued by mucilaginous pads or stalks. The epipellic forms are biraphidean species which actively move through the sediment by means of the mucilaginous secretion of their raphes (Round, 1971). This was conspicuous in the present study since an existence of microphytobenthos was seen at as deep as 10 cm depth of sediment in the sandy and clayey shore of Versova during July. However, the difference between the two categories is not absolute as there are epipsammic diatoms that are moving, though generally much slower than epipellic species (Harper, 1969; Wolff, 1979) and furthermore, many diatom genera have representatives in these groups (e.g. *Nitzschia spp.*, *Navicula spp.*, *Amphora spp.*). The microphytobenthos is characterized as a distinctly flat, two-dimensional

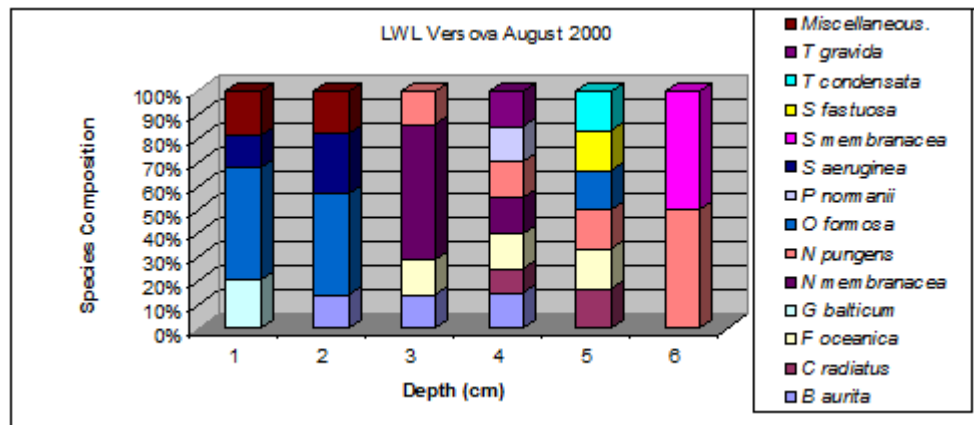
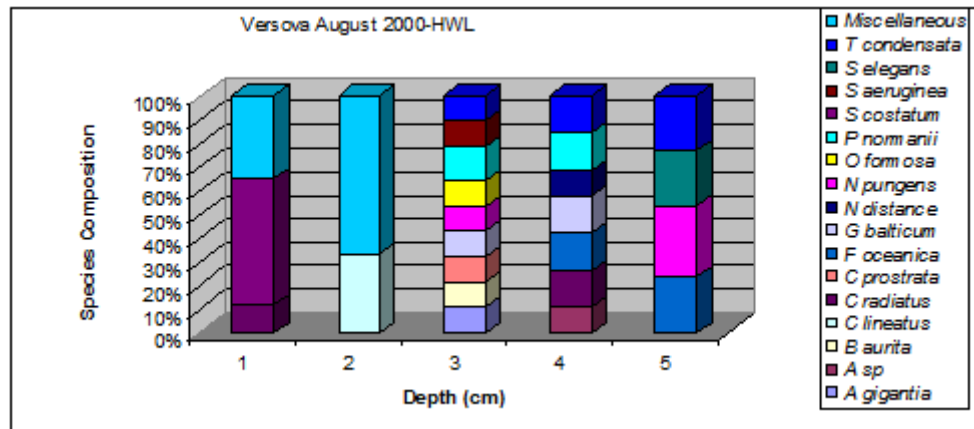
community (Miller *et al.*, 1996). Despite the typical characteristics of a microphytobenthic community, it has increasingly been seen that benthic algae may not be strictly edaphic and that planktonic forms can temporarily dwell on sediments (Drebes, 1974, Gaetje, 1992; de Jong & de Jonge, 1995).

The studies by Thong *et al.*, (1993); Cariou and Blanchard (1995), indicated that the microphytobenthic community was dominated by diatoms throughout the sampling year. Similar results have been recorded at Versova Creek during present study.

A gradual decline in microphytobenthic population from superficial layer to deeper sediment could be due to absence of irradiance and oxygen. Thus, a significantly reduced cellcount (1.4×10^6 cell / cm^3) of microphytobenthos at 9 cm depth in the comparison of superficial layer was associated with very poor chlorophyll *a* and markedly high phaeophytin (Table 5.1.20). *Biddulphia aurita* was the only species recorded at 9 cm depth which suggested its survival capability in an anoxic condition and absence of irradiance.

The sediment at 8 cm depth revealed higher population than that of 9 cm. The cell count at LWL was seen to be higher (2.8×10^6 - 2.8×10^6 cell / cm^3) higher than that of HWL (1.4×10^6 - 1.4×10^6 cell / cm^3). The community structure recorded at LWL showed *Nitzschia pungens*, *Amphiprora gigantia*, *Gyrosigma balticum* as predominant species at different period whereas a slight change in community structure at HWL with presence of only *Biddulphia aurita* was seen at deeper layers of sediment (9 cm) from the results (Table 5.1.20). Following the similar trends as superficial layer, the cell count of microphytobenthic algae at deeper layer of sediment also was almost in the agreement of pigments.

Depthwise variation of microphytobenthos species are shown in Figures below:



Similarly the results of percentage composition of every month are shown in Figure 5.1.3 to Figure 5.1.6 which indicates the species number decreases with increasing depth of sediment. These are only few hardy species which survive at the deeper layer of sediment. However, positive correlation was observed between microphytobenthic chlorophyll a in sediment and nitrate–nitrogen in overlying water and is represented in Table 5.1.22.

5.2 Gorai

Gorai is a village in the North-western part of Mumbai. Gorai is accessed more usually by a ferry crossing the Manori Creek which separates Gorai from the island of Salsette or otherwise by the overland route through Bhayander.

Gorai lies on a peninsula protruding off the north-west of the Salsette island and connects Malad Creek & Manori Creek. Gorai Creek is also connected with Vasai Creek through the Ghodbunder Creek. However, with the building of the railways over the Ghodbunder Creek, and with successive urbanization and reclamation, the Ghodbunder Creek is largely gone, and the Dharavi Island is now reduced to a peninsula of the Salsette Island.

Gorai is bordered by the villages of Manori and Uttan. Gorai is known for its beaches and East Indian population, though in recent times the beaches have become polluted. Till the 1980s Gorai was known for its clean beaches and palm trees. However with the increasing pollution around Mumbai, the Arabian Sea is unfit for swimming although it is less polluted at Gorai than at Versova.

Gorai has a large and controversial garbage dumping ground. The Essel World amusement park has been set up in part of Gorai. Gorai is also the site for an 'Special Economic Zone' proposed by Esselworld.

At Gorai in Thane district, 1.25 lakh people belonging to the Koli fishing community, saltpan workers and farmers are slated for eviction. The proposed Special Entertainment Zone (SEZ), spread over 14183 acres, is to expand Pan India Paryatan Ltd's Essel World. Fishermen believe that the extension of the entertainment zone, two kilometers into the sea would affect fish resources and deny them access to fishing grounds. Keeping above view into consideration and considering Gorai as a less polluted zone than Versova, the present study is aimed to evaluate the status of

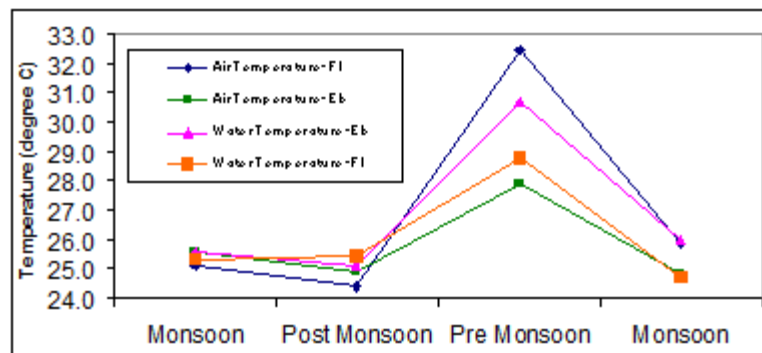
microphytobenthos which are the basic food for pelagic organisms. The results are discussed as follows:

5.2.1 Physicochemical properties

The results of water quality of overlying water are presented in Table 5.2.1. Variability in water quality is illustrated in Figures 5.2.1 to 5.2.2.

a. Temperature

It is evident from the Table 5.2.1 that the water temperature at Gorai varies between 21.5° C and 32.3° C which is in the agreement of air temperature variability. Average water temperature during different season is illustrated in Figure shown below:

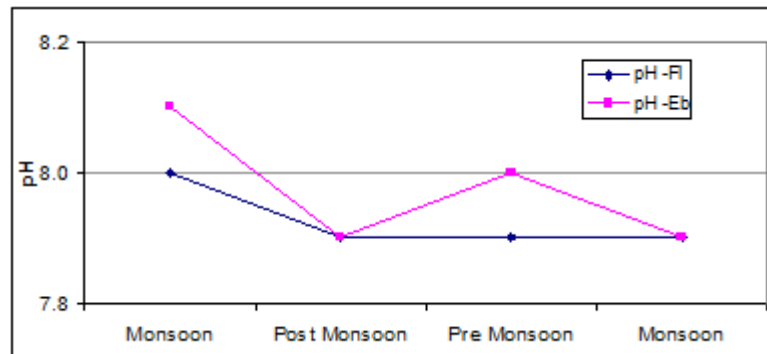


The present study revealed that the water during premonsoon was warmer than that of the other season. The lowest temperature recorded during post monsoon could be associated with the air temperature of winter season which was similar to that of Versova. The monsoon seasons also exhibited lower temperature agreeing with natural variation. The overall scenario of temperature was in the agreement of the other neighboring areas (Narveker and Zingde, 1992).

b. pH

The pH showed narrow range of variation (av. 7.9 ± 0.1) as evident from the results. The tidal impact on pH with slightly higher values during ebb than flood was evident from the results.

The overall average values of pH for the different seasons are presented in the Figure below:

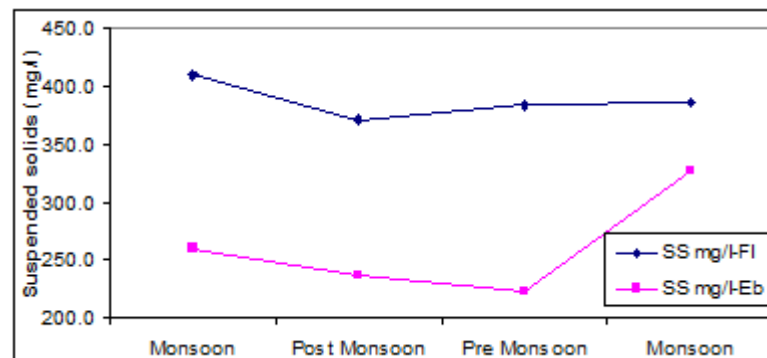


The variation in pH with respect to seasons was not very clear and indicated a typical characteristic of nearshore water of the region.

c. SS

A wide range of variation (av 324.7 ± 90.1 mg/l) in SS is evident in Table 5.2.1.

The SS recorded during present study are presented as follows:

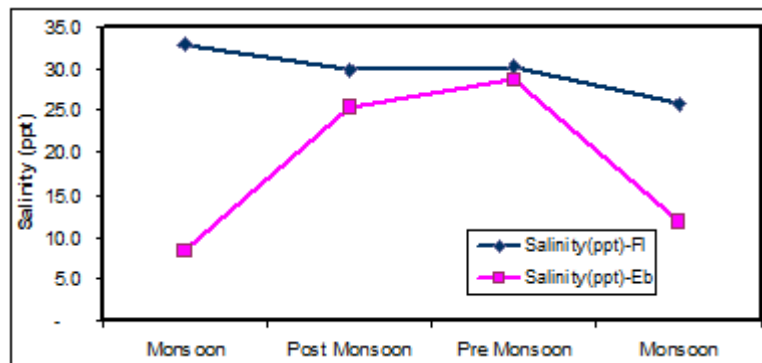


Tidal impact on the SS concentration showed a clear trend with significantly higher values during flood than ebb which could be due to high turbulence of water associated with accelerated waves by strong winds. Slightly high values during monsoon period may be associated with land drainage.

d. Salinity

Significantly wide variation in the concentration of salinity (7.7 - 33.3 ppt) could be attributed with fresh water influx during monsoon period.

The overall scenario of distribution pattern of salinity is shown in the following Figure:

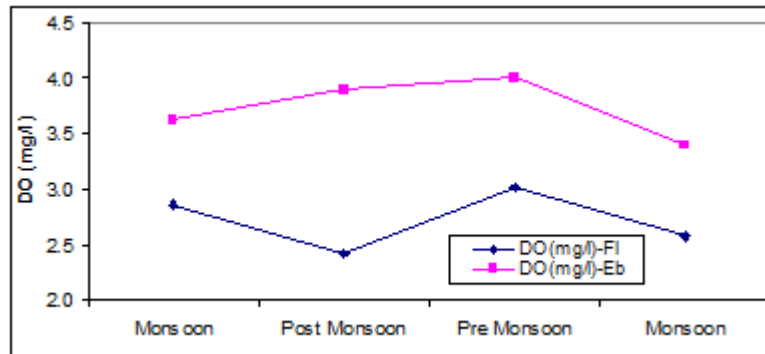


A clear pattern of distribution with high values during flood than ebb may be due to fresh water influx resulted by rain water during monsoon and also domestic waste water discharges in Gorai Creek. The result of salinity was conspicuously an indicative of a typical estuarine zone.

e. Dissolved Oxygen (DO)

A wide variation in the concentration of DO (av 2.3 ± 0.7 mg/l) could be due to high pressure of anthropogenic pollutants resulted by domestic waste water discharges in Gorai Creek. The impact of pollution

on DO level was still clear with lower values recorded during ebb than that of flood as evident in the following Figure:

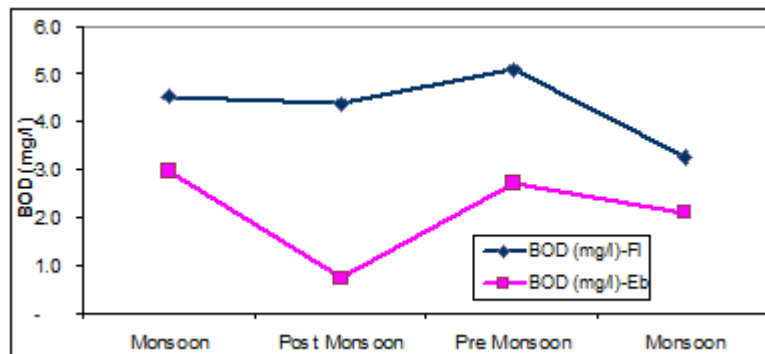


Seasonal variation on the concentration of DO was not discernible in above Figure which could be due to pollutants dominating the other factors responsible for it.

f. Biochemical Oxygen Demand (BOD)

The concentration of BOD was recorded to an av 3.2 ± 1.5 mg/l. High concentration of BOD (6.0 mg/l) indicated an input of organic load in water body which could be related to release of domestic sewage.

BOD levels during at different seasons are presented in the Figure below:

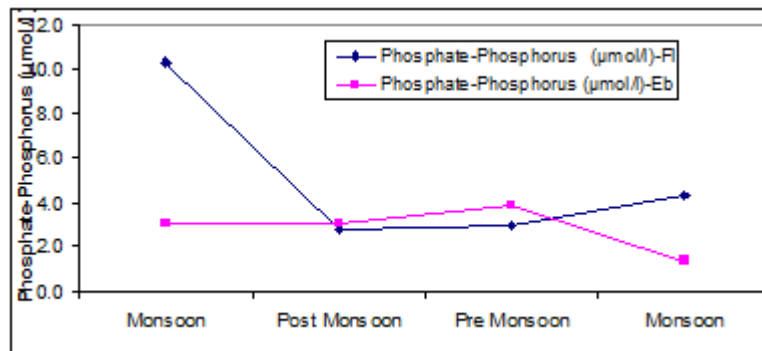


The above Figure clearly indicates the pollutants influencing the concentration of BOD with higher values during ebb than that of flood.

The higher values during ebb could be due to enhanced organic load prevailing during this period.

g. Phosphate-Phosphorus ($\text{PO}_4^{3-}\text{-P}$)

The concentration of reactive phosphate phosphorus ($\text{PO}_4^{3-}\text{-P}$) showed a wide range of variation (av $4.0 \pm 2.4 \mu\text{mol/l}$) suggesting the input through release of domestic waste water. The overall scenario of $\text{PO}_4^{3-}\text{-P}$ is depicted in the following Figure :

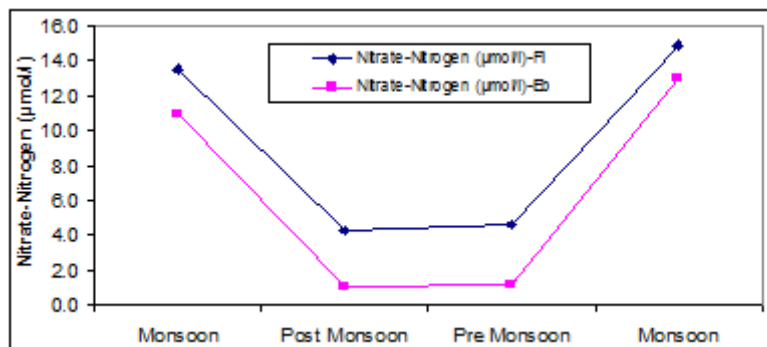


The highest concentration of $\text{PO}_4^{3-}\text{-P}$ was noticed during ebb which could be related to input through domestic waste water releases in the creek. Seasonal variation was not clear and there was no definite trend. However the highest concentration recorded during monsoon could be attributed with the land drainage in the region.

h. Nitrate-Nitrogen ($\text{NO}_3^- \text{-N}$)

The results of nitrate-nitrogen are presented in Table 5.2.1 and Figure 5.2.1 - 5.2.2. A markedly high variation in the concentration of nitrate (av $8.0 \pm 5.6 \mu\text{mol/l}$) suggested that the anthropogenic releases in the creek was major source of nitrate nitrogen in the region. The high concentration of nitrate also suggested that the dense mangrove vegetation contributed high nutrient level in the region.

The overall values of nitrate are illustrated in following Figure:

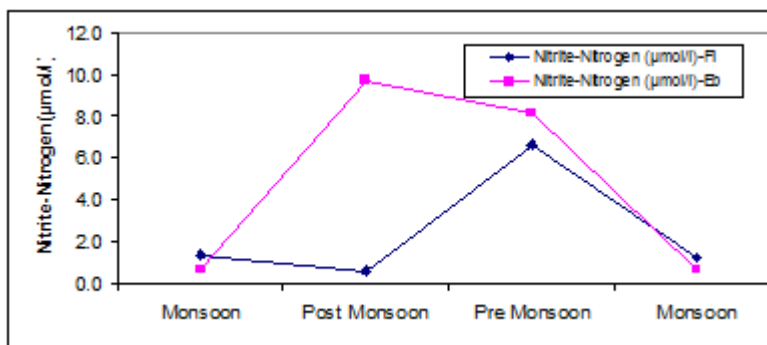


A definite trend of seasonal variation on the distribution pattern of nitrate showed significantly high values during monsoon which could be associated with land drainage in the area. Always higher concentration of nitrate resulted due to domestic waste water discharges during ebb in the creek gets diluted during the period of flood. As a consequence of this process the values of nitrate during flood were always lower than the one recorded during ebb suggesting an influence of pollutants in the creek.

i. Nitrite-Nitrogen NO_2^- -N ($\mu\text{mol/l}$)

As evident in Table 5.2.1, the variation of NO_2^- -N was recorded with av $3.6 \pm 3.9 \mu\text{mol/l}$ similar to NO_3^- -N, was significant revealing the influence of anthropogenic pollution in the creek.

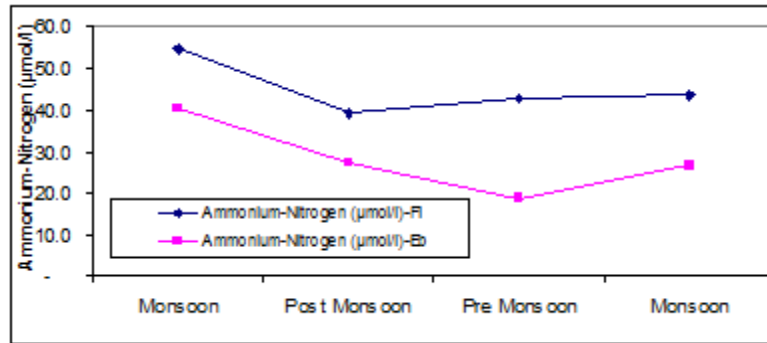
The overall nitrite-nitrogen concentration during the study period can be seen in the following Figure:



The distribution pattern of nitrite follows the similar trend as nitrate with the higher concentration during ebb than that of flood. The variation with respect to seasons revealed higher values during post and pre monsoon in the comparison of monsoon periods.

j. Ammonium-Nitrogen $\text{NH}_4^+ - \text{N}$ ($\mu\text{mol/l}$)

The ammonium-nitrogen (av $36.6 \pm 14.1 \mu\text{mol/l}$) suggested significantly high level in the study area (Table 5.2.1). The overall scenario of ammonium-nitrogen is shown in the following Figure:



The concentration of ammonia was always higher during ebb than flood which suggested that the anthropogenic releases in this region could be the source.

5.2.2 Sediment texture

a. Texture and Total organic carbon.

The sediment quality was studied during 2000-2001 and again the study was repeated during 2003. Results of sediment texture showed that the sediment was silty- clay with low sand percentage. The C_{org} varied from 1.8 to 4.9 %; av 3.4 ± 1.1 % in the sediment (Table 5.2.2). The overall range and average of C_{org} and sediment texture are discussed in the following Table:

Parameter	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Pre Monsoon 2003
	2000-2001				
C _{org} (%)	3.4-3.9	1.8-4.4	4.2-4.7	2.1-4.5	4.5-4.9
	(3.6)	(2.6)	(4.4)	(3.4)	(4.7)
Sand (%)	16.0-17.4	12.3-15.9	13.4-16.7	12.8-15.4	12.4-12.8
	(16.7)	(13.8)	(15.3)	(13.9)	(12.6)
Silt-clay (%)	82.6-84.0	84.1-87.7	83.3-86.6	84.6-87.2	87.2-87.6
	(83.3)	(86.2)	(84.7)	(86.1)	(87.4)

The sediment being silt-clayey (82.6- 87.7) could hold the organic carbon from 1.8 to 4.9 % in the intertidal area. However, the characteristics of sediment recorded during 2000-01 were more or less similar to that of 2003.

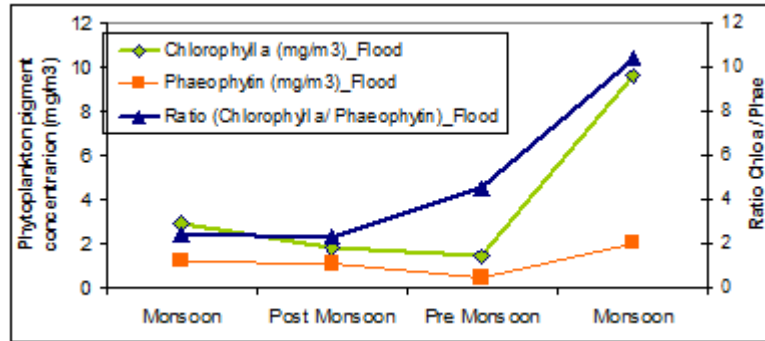
5.2.3 Phytoplankton

A study on phytoplankton standing crop in terms of biomass and population including community structure, in overlying water was conducted for 14 months (August 2000- September 2011) at Gorai. The results of these studies are described as follows:

i) Phytoplankton Pigments

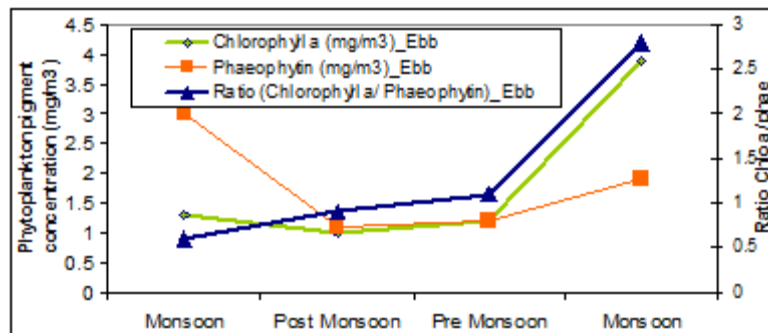
The results of phytoplankton pigments in terms of Chlorophyll *a* and phaeophytin are presented in the Table 5.2.3. The results revealed a wide variation in Chlorophyll *a* (av 4.1 ± 4.3 mg/m³) suggesting an enhanced phytoplankton biomass which could be due to an excess growth of phytoplankton in Gorai Creek (Table 5.2.3). The concentration of phaeophytin (av 1.2 ± 1.1 mg/m³) was also seen to be enhanced in

this water. Ratios of chlorophyll *a* / phaeophytin was always higher than 1 (av 5.3 ± 5.9), indicating a healthy condition of phytoplankton cells in the region. Overall structure of seasonal variation of phytoplankton pigments are shown in the following Figure:

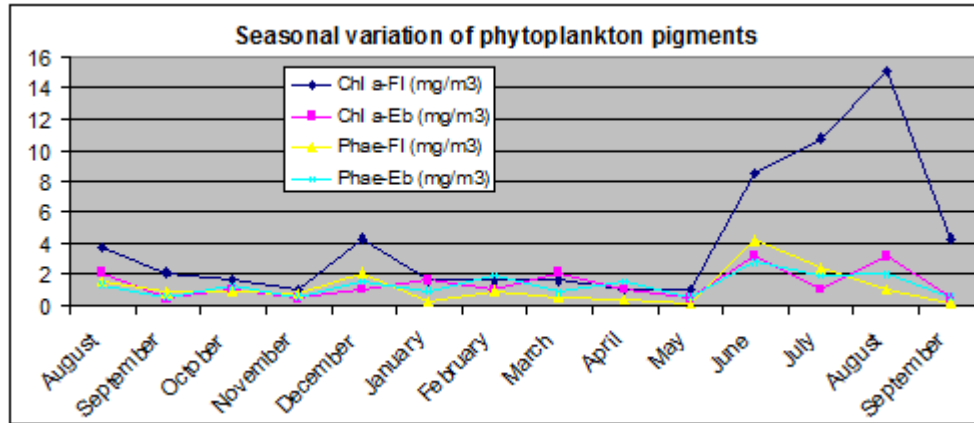


The concentration of pigments during flood period did not show any definite trend of seasonal variation excepting a marked increase in the next monsoon.

During ebb period the concentration of chlorophyll *a* varied with av 1.9 ± 1.5 mg/m³; whereas phaeophytin was recorded with av 1.6 ± 1.3 mg/m³. Pigments exhibited the ratios of chlorophyll *a* / phaeophytin often higher than 1 (av 1.0 ± 0.5). During the period of ebb pigments distribution shows lower concentration than that of flood periods which, clearly indicated an impact of anthropogenic pressure on ecology. The overall concentration is shown in the following Figure:



Although the concentration of phytoplankton pigments were decreased during ebb as compared to flood, the pattern of distribution remained same with an enhanced values in the second monsoon.

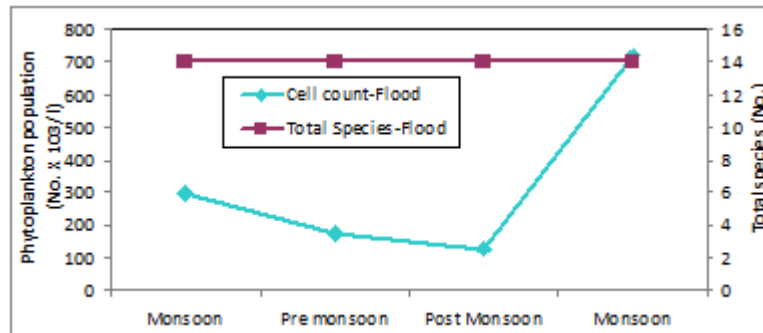


Seasonal variation of phytoplankton pigments is shown in the above Figure which indicates significant variation with high concentration during June- August of second phase of monsoon which was similar to the distribution trend recorded at Versova.

ii) Phytoplankton Cell count

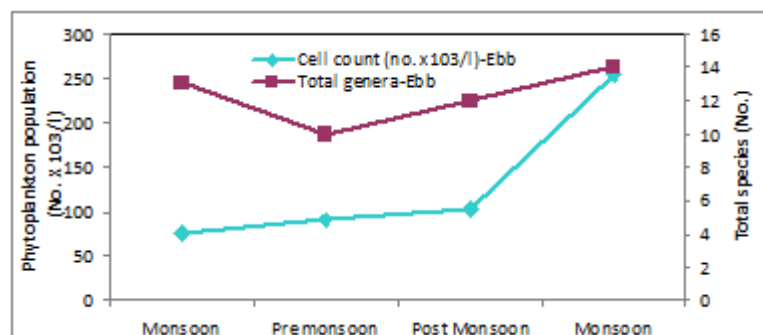
Phytoplankton population was studied in terms of cell count and total species. The results are presented in Table 5.2.4 The marked enhancement in phytoplankton population (av $335.2.1 \pm 391.0 \times 10^3/l$) at Gorai Creek could be attributed with high concentration of nutrients prevailing in the region. The species diversity of phytoplankton in terms number (12-15, av 14) was also stimulated by nutrients showing a good growth of phytoplankton in Gorai Creek. The prevailing species as evident in Table 5.2.5 revealing that the community structure was dominated by *Navicula membranacea* 23.8%, *Chaetoceros decipiens* 20.3% and *Oscillatoria formosa* 16.6%. The overall scenario of phytoplankton population was in the agreement of pigments.

The distributions of phytoplankton population during different seasons are shown in the following Figure:



Phytoplankton population similar to that of chlorophyll *a* indicated again a significant increase during next monsoon. Species diversity revealed a homogenous distribution in all the seasons irrespective to cell counts during flood period.

During the period of ebb the structure of phytoplankton population was different as compared to flood showing significantly decreased cell count (av $110.1 \pm 139.2 \times 10^3/l$) as evident in Table 5.2.4. This indicated that the ebb water dominated by pollutants hampered phytoplankton growth. The average values of phytoplankton population during ebb of different seasons are depicted in following Figure:



Seasonal distribution pattern during the period was almost similar to that of flood suggesting a significant increase in the cell count during next monsoon. Marked decrease in species diversity (7-14; av 12) particularly during ebb in the comparison of flood clearly suggested the

impact of pollution on phytoplankton structure at Gorai. Contribution of offshore water bringing more species during flood could be the reason for an enhancement in species diversity than that of ebb period.

5.2.4 Microphytobenthos

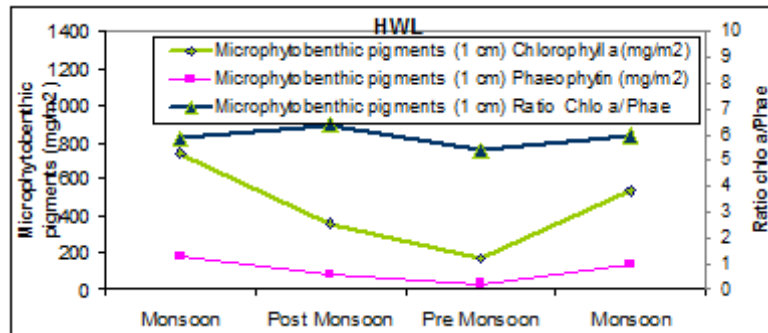
Microphytobenthos studied in terms of pigments and populations at different depths of sediment at Gorai are discussed as follows:

a) Microphytobenthic pigment

The microphytobenthic chlorophyll *a* was seen in gradually decreasing trend with deeper layer of sediments (Table 5.2.7 to Table 5.2.13). Thus vertical distribution of microphytobenthic pigments revealed a clear trend of variation with significantly augmented level of chlorophyll *a* (av 411.3 ± 336.0 mg/m²) in 1cm layer of sediment at HWL. Nozais *et al.*, (2001); and Perissinotto *et al.*, (2002) have also reported microphytobenthic chlorophyll *a*, as high as 500 to 600 mg/m² in the superficial layer of sediment. Similarly the LWL also exhibited significantly high values of chlorophyll *a* (av 501.1 ± 371.1 mg/m²) at superficial layer of sediment and gradual decrease in chlorophyll *a* with the deeper layer. An enhanced level of microphytobenthic chlorophyll *a* (1.4 - 480 mg/m²) at superficial layer of sediment and gradual decrease at deeper layer was also recorded by Nozais *et al.*, (2005).

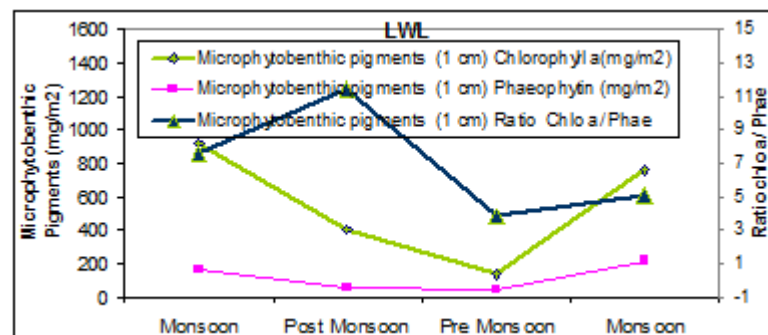
The distribution pattern of phaeophytin was also seen with decreasing trend corresponding to depth of sediment. However, the ratios of chlorophyll *a*, phaeophytin was higher at superficial layer but showed lower values in the comparison of at deeper layer of sediments. This trend was confirmed with the results of superficial layer of sediment showing lower phaeophytin (av 106.0 ± 81.6 mg/m²) than Chlorophyll *a* (av 411.3 ± 336.0 mg/m²). The values of microphytobenthic chlorophyll

a and phaeophytin recorded at Gorai are illustrated in the following Figure:



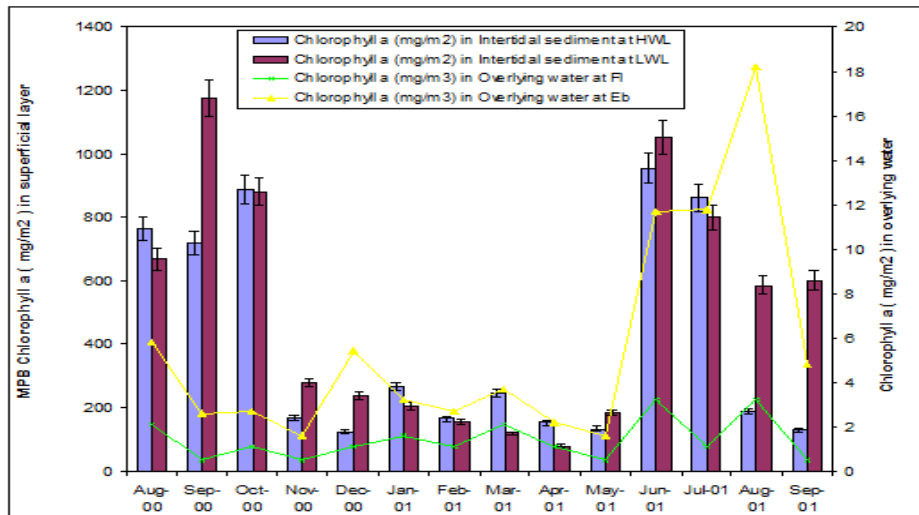
The above Figure clearly indicates that ratios of chlorophyll *a* / phaeophytin at 1 cm of sediment are higher than 1 during all the seasons, suggesting a healthy condition of microphytobenthic cells at HWL. The similar observations were also reported by Riaux-Gobin, (2002). Thus the overall results of microphytobenthic pigments revealed that the average ratio of chlorophyll *a* / phaeophytin was as high as 7.2 at superficial layer of sediment whereas same ratio decreased as low as 1 at deeper layer of sediment. This significant decrease in the ratio of chlorophyll *a* / phaeophytin at deeper layers of sediment clearly indicated that unhealthy cells were unable to synthesise the pigments due to lack of light energy and oxygen.

The distribution pattern of microphytobenthic pigments are also studied at LWL and the results are depicted in the following figure:



The ratios of chlorophyll *a* / phaeophytin at LWL were similar to that of HWL showing the values of chlorophyll *a* always higher than phaeophytin at superficial layer of sediment.

The comparison of results between microphytobenthic pigment recorded at superficial layer of sediments and phytoplanktonic pigments in overlying water at Gorai have been worked out and depicted in the following Figure:



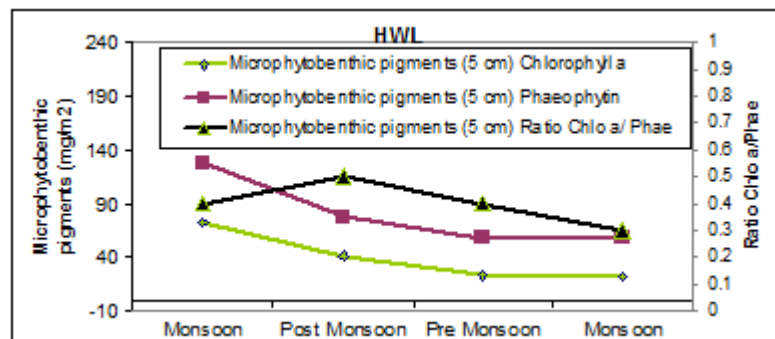
The variation in microphytobenthic chlorophyll *a* between LWL and HWL is not in definite trend as evident in above Figure: The values of chlorophyll *a* were some time higher in the layer of 1 cm sediment at LWL than that of HWL which was similar to the observation of Chevalier *et al.*, (2010). In general, the phytoplankton pigments in overlying water follow a similar trend of variation as microphytobenthic pigments in the layer of 1 cm sediment, over the period of 14 months. Higher values of chlorophyll *a* recorded during ebb than that of flood in overlying water could be attributed with the influence of anthropogenic nutrients during this period. Thus the higher concentration of nutrients due to anthropogenic releases during ebb support phytoplankton growth as a result of which pigment level during ebb was higher than flood similar to the observation of Jiyalal, (1985). The influence of anthropogenic

nutrients, resulting significantly higher concentration of pigments, in both water and sediment, during premonsoon and postmonsoon than that of monsoon is conspicuous in the above Figure.

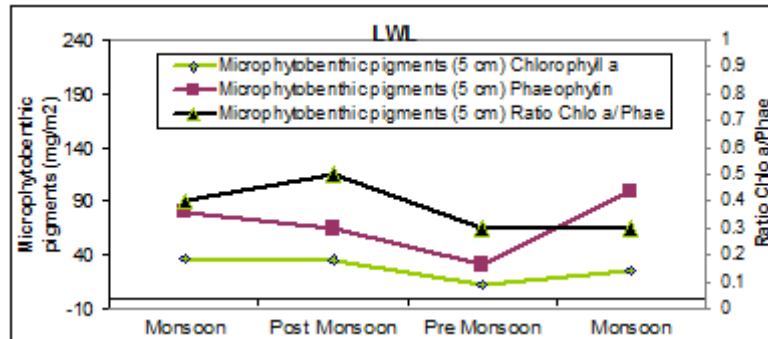
The microphytobenthic biomass in sediments was consistently multiple orders of magnitude higher than chlorophyll *a* in overlying water. The similar trends were also observed by Nozais *et al.*, (2001); Perissinotto *et al.*,(2002).

The scenario of microphytobenthic pigments at 5 cm depth of sediment was seen to be completely changed in the comparison of superficial layer. The values of microphytobenthic chlorophyll *a* were seen in descending order whereas microphytobenthic phaeophytin revealed the reverse trend with ascending order corresponding to the depth of sediment. Thus the present study showed that the level of microphytobenthic chlorophyll *a* varied with av 39.3 ± 34.0 mg/m² whereas the values of phaeophytin with av 80.9 ± 41.4 mg/m² at 5 cm layer of sediment at HWL resulting the ratios lower than 1. The average values of microphytobenthic chlorophyll *a* and phaeophytin, revealed the ratio as low as 0.49 suggesting a markedly unhealthy condition of microphytobenthos at 5 cm depth of sediment.

The pigment structure in 5 cm depth of intertidal sediment at HWL indicating the noticeably high values of phaeophytin and resulting significantly poor ratios is depicted in following Figure:



The results at LWL indicates still lower values (av 27.9 ± 14.8 mg/m^2) of Chlorophyll *a* and higher values of microphytobenthic phaeophytin (av 69.0 ± 39.0 mg/m^2) at 5cm depth of sediment. The structure of microphytobenthic pigments are illustrated in the Figure shown below:



The grazing effect on phytoplankton cells resulting higher concentration of phaeophytin than chlorophyll *a* in the intertidal mud flats at LWL similar to the results of HWL is discernible in above Figure. The similar results have also been reported by Chong and Sasekumar,(1981); Leh and Sasekumsar,(1984); Sasekumar, and Chong, (1987).

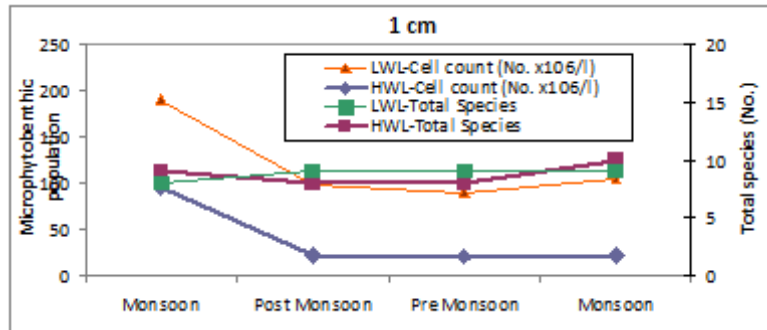
The pigment structure in 10 cm depth of intertidal sediment showed a significantly decrease in microphytobenthic chlorophyll *a* (0.6 mg/m^2) and markedly increase in phaeophytin (8.2 mg/m^2) resulting a expressively poor ratio (0.01) of these pigments at deeper layer of sediment. The finding of Chevalier, *et al.*, (2010) was in accordance with results of present study. Thus vertical variation of microphytobenthic pigments resulting miserably low values (av. 0.01) of chlorophyll *a*/ phaeophytin ratio at deeper layer (10 cm) of sediment distinctly indicated an unhealthy condition of microphytobenthic cells. Markedly decreasing ratios of chlorophyll *a* / phaeophytin with the deeper layer in the comparison of superficial layer of sediment in present study was similar to the findings explained by Blanchard, and Cariou-Le Gall,

(1994). Similar results were also obtained in the aphotic zone, at Marennes –Oleron bay, by Cariou Le Gall and Blanchard, (1995).

The overall results recorded at Versova and Gorai both clearly indicated that the microphytobenthos thriving at superficial layer of sediment obtain sufficient sunlight and function well with the photosynthetic activities, as a result of which the cells maintain a healthy balance of chlorophyll *a* / phaeophytin ratio (> 1). As the cells of microphytobenthos are driven at the deeper layer of sediment through the process of bioturbation or biogenic sorting by the pelagic organisms, they are unable to photosynthesize resulting in significantly decreased level of synthesis of pigments. Due to lack of photosynthesis concentration of chlorophyll *a* converts into phaeophytin in the cell resulting in the poor ratios of chlorophyll *a* / phaeophytin at deeper layer of sediment. This process results the degradation of chlorophyll *a* and causes a marked decrease in ratios of chlorophyll *a* / phaeophytin with increasing depth of sediment. As a consequence of this the microphytobenthic cells develop an unhealthy condition corresponding to deeper layer of sediment. Thus the ratio of the Chlorophyll *a* / phaeophytin can refer as best indicator of cell condition of microphytobenthos or phytoplankton population.

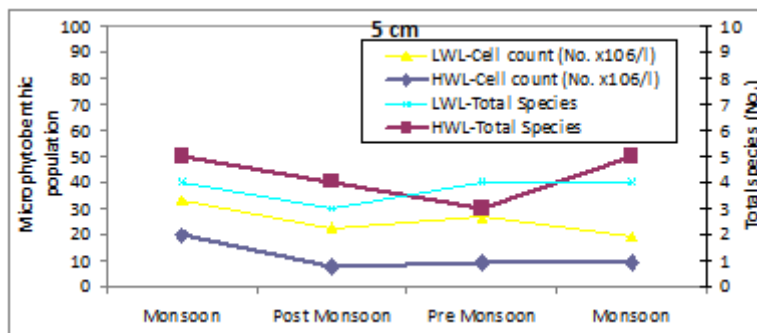
b) Microphytobenthic Population

The results of microphytobenthic cell count revealed, that the population recorded at superficial layer of sediment were in decreased significantly at deeper layer of sediment. This trend of variation of microphytobenthic population was in the agreement of pigments distribution. The species recorded in 1 cm layer of the sediment were similar to the species observed in overlying water (Table 5.2.6, Table 5.2.21 and Plate 1 to 6) which indicates a clear trend of transfer of species from water to sediment. The overall scenario of microphytobenthic population is depicted in the following figure:



The microphytobenthic population exhibited a wide range of variation (av: $32.7 \pm 28.0 \times 10^6$ cells /cm³) at HWL (Table 5.2.14 to Table 5.2.20). The sediment at LWL sustained higher population (av: $78.7 \pm 25.0 \times 10^6$) than the values recorded at HWL which followed the similar trend at distribution as pigments. Totti, (2003) also reported the dominance of diatom with the cell count ranging from 728 to 9278 cells / cm³ at 1 cm layer of sediment in Northern Adriatic sea. During the period of study a total of 57 species of microphytobenthos with the pre-dominance of *Navicula distans* (22.9%), *Fragilaria oceanica* (12.8%), *Navicula membranacea* (12.5%) and *Nitzschia seriata* (12.3%) at different occasions was seen at HWL whereas *Oscillatoria formosa* (19.5%), *Nitzschia pungens* (17.6%), *Navicula membranacea* (17.2%), *Spirulina aeruginea* (12.7%) and *Gyrosigma balticum* (11.1%) was noticed at LWL in 1st cm layer of sediment (Figure 5.2.3 to Figure 5.2.6).

The population of microphytobenthos at 5 cm depth is illustrated in the Figure below:



Overall values of cell count at HWL at 5 cm depth of sediment varied with av: 10.1×10^6 cells /cm³ (Table 5.2.18 and Figure 5.2.4 to 5.2.6) whereas population at LWL was seen to be increased with the average of 13.9×10^6 cells/ cm³ . The microphytobenthic population was dominated by *Navicula membranacea* (20.6 %), *Nitzschia pungens* (16.3 %), *Coscinodiscus radiatus* (14.4 %) was seen at HWL whereas *Nitzschia pungens* (27.3 %), *Navicula membranacea* (19.6%) and *Gyrosigma balticum* (12.0 %) were at LWL in 5th cm layer of sediment (Table 5.2.18 and Figure 5.2.3 to 5.2.6) .

c) Community structure

Similarly the results of percentage composition of every month are shown in Figure 5.2.3 to Figure 5.2.6 which again indicates that the species decreases with increasing depth of sediment. There are only few hardy species which survive at the deeper layer of sediment. During first monsoon, of the study period the community was dominated by *Navicula distans* (31.6%), *Fragilaria oceanica* (29.05 %) and *Nitzschia seriata* (16.4 %) at HWL whereas the sediment of LWL was dominated by *Gyrosigma balticum* (35.9 %) *Oscillatoria formosa* (18.8 %), *Coscinodiscus radiatus* (16.1 %), *Nitzschia pungens* (12.2%), *Spirulina aeruginea* (10.7%). (Figure 5.2.3 to 5.2.6)

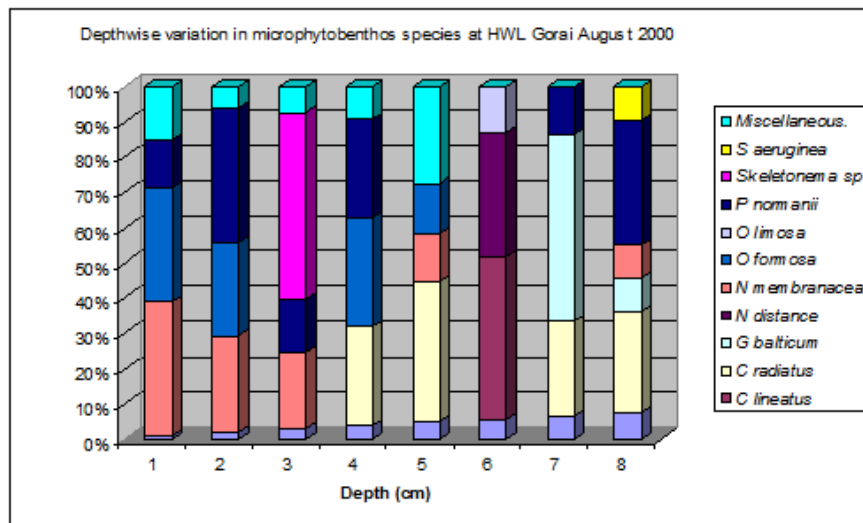
During next monsoon the community was dominated by *Navicula membranacea* (22.8 %), *Navicula distans* (19.5 %), *Achnanthes* (11.7%) and *Nitzschia seriata* (11.1 %) at HWL whereas at LWL

Spirulina areuginea (19.5 %), *Nitzschia pungens* (18.9%) were recorded. (Figure 5.2.3 to 5.2.6)

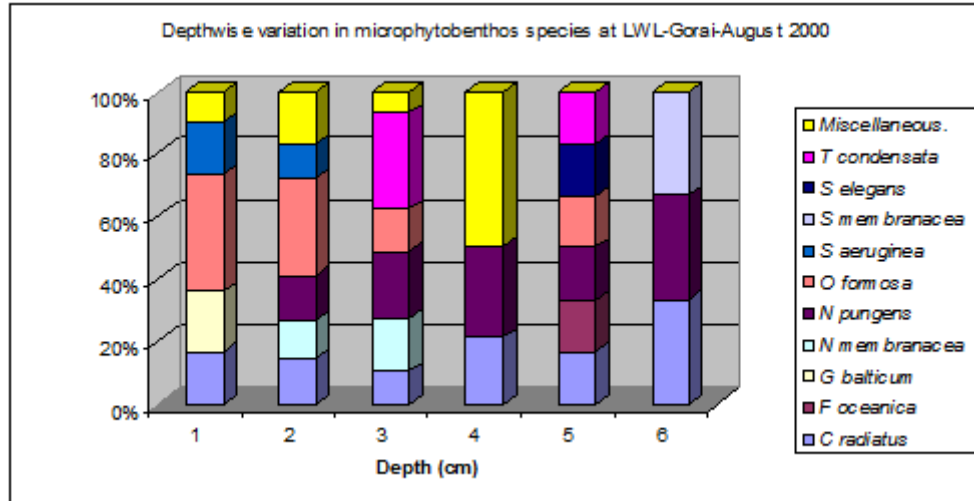
During post monsoon the community structure of microphytobenthos was dominated by *Navicula distans* (24.3%), *Fragilaria oceanica* (14.2 %), *Peridinum ovata* (12.2 %) and *Gyrosigma balticum* (10.6 %) at HWL whereas LWL was dominated by *Gyrosigma balticum* (22.6 %), *Navicula membranacea* (19.7 %), *Nitzschia pungens* (13.5%) . (Figure 5.2.3 to 5.2.6)

The pre monsoon period sustained *Navicula distans* (31.6%), *Fragilaria oceanica* (29.05 %) and *Nitzschia seriata* (16.4 %) as dominated species at HWL whereas LWL was dominated by *Gyrosigma balticum* (35.9 %) *Oscillatoria formosa* (18.8 %), *Coscinodiscus radiatus* (16.1 %), *Nitzschia pungens* (12.2%) and *Spirulina aeruginea* (10.7%). (Figure 5.2.3 to 5.2.6)

The community structure recorded at HWL as depicted in the Figure shown below:



The species recorded after 5 cm depth of sediment are seen in below Figure, which suggests their hardy nature



The microphytobenthic community structure at different depth of sediment recorded at LWL again showed that there were only a few species viz., which thrived at deeper layer below 5 cm of sediment. This could give a clear idea of their hardy nature due to survival in an anoxic condition and absence of irradiance.

The results of chlorophyll a and physicochemical parameters in overlying water suggested no significant correlation (Table 5.2.22)

Table 5.1.1: Physicochemical characteristics at Versova during August 2000- September 2001.

Period	Tide	AT*	WT	pH	SS	Sal	DO	BOD	PO ₄ ³⁻ - P	NO ₃ ⁻ -N	NO ₂ ⁻ -N	NH ₄ ⁺ - N
					(mg/l)	(ppt)	(mg/l)	(mg/l)	(μmol/l)	(μmol/l)	(μmol/l)	(μmol/l)
Aug-2000	Fl	32.5	28.9	7.9	19.5	31.1	0.9	1.2	5.6	3.3	2	10.7
	Eb	31.5	30.0	7.8	22.0	20.5	0.0	0.0	7.4	11.2	2.6	33.4
Sept-2000	Fl	30.5	28.3	8.2	28.9	33.1	0.9	1.2	2.3	3.4	1.4	15.6
	Eb	26.6	26.4	8.2	42.0	21.9	0.0	0.0	5.5	10.4	2	39.3
Oct-2000	Fl	28.2	29.8	7.9	27.1	30.4	0.0	0.0	2.2	3.2	1.3	5.8
	Eb	32.1	29.8	7.9	27.6	27.2	0.0	0.0	14.2	8.5	2.4	10.6
Nov-2000	Fl	32.2	29.8	8.2	35.2	31.8	0.3	0.6	3.2	2.8	1.6	2.6
	Eb	27.6	26.8	8.1	77.8	29.0	0.0	0.0	10.1	9.5	3.6	9.4
Dec-2000	Fl	27.9	29.8	7.8	31.5	28.6	0.6	0.6	1.5	5.5	1.8	1.2
	Eb	31.5	29.6	7.9	44.1	25.4	0.6	0.6	7.5	14	2.8	5.8
Jan-2001	Fl	29.2	29.5	8.2	37.9	31.7	0.6	0.6	1.5	1.8	2.5	4.8
	Eb	24.2	22.8	8.1	67.5	28.3	0.6	0.6	6.3	8.7	3.8	16.8
Feb-2001	Fl	29.6	29.2	7.9	23.4	29.5	0.3	0.6	2.1	3.6	2.5	3.2
	Eb	24.5	23.8	7.9	71.9	23.7	0.0	0.0	10	6.3	3.2	6
Mar-2001	Fl	28.7	27.8	8.1	18.9	31.1	0.6	0.6	3.5	5.7	1.8	1.8
	Eb	22.5	23.8	8.0	64.7	25.4	0.6	0.6	8.6	8.2	2.5	7.1
Apr-2001	Fl	30.0	29.8	7.9	13.4	31.5	0.0	0.0	1	6.2	1.4	3
	Eb	32.0	29.8	8.2	38.7	27.6	0.0	0.0	4.2	18.7	2.5	10.4
May-2001	Fl	29.5	28.8	7.9	23.1	32.4	0.6	0.6	1.2	4.1	1.9	2.2
	Eb	27.3	25.8	8.0	32.3	28.6	0.6	1.3	3.4	20.9	2.8	9.6
Jun-2001	Fl	29.7	28.9	7.9	20.8	34.3	0.6	0.6	1	4.8	1.7	5.6
	Eb	25.5	23.2	8.1	54.3	19.9	0.0	0.0	2	7.6	2.5	29.9
Jul- 2001	Fl	28.7	28.1	8.0	24.6	29.4	0.6	0.6	1.3	2.6	2.1	4.6
	Eb	30.0	29.4	8.0	45.7	19.4	0.0	0.0	3.6	6.5	3.3	23.8
Aug-2001	Fl	30.2	28.7	8.1	19.2	29.4	0.6	0.6	1.1	3.1	1.9	3.5
	Eb	26.5	23.1	8.1	45.1	19.9	0.0	0.0	4	7.1	0.8	1.5
Sept-2001	Fl	31.8	30.6	7.9	17	34.3	0.6	0.6	2.6	1.6	0.6	0.9
	Eb	27.2	27	7.9	38	23.5	0.0	0.0	4.3	3.3	0.8	2.1

Table 5.1.2: Sediment characteristics at Versova during August 2000- September 01.

Period	Sediment Texture				
	Sand (%)	Silt-clay (%)	Silt (%)	Clay (%)*	Corg(%)
August,00	80.0	20.0	12.6	7.4	712.8
September,00	85.5	14.5	8.3	6.2	661.1
October,00	78.5	21.5	15.8	5.7	744.8
November,00	78.2	21.8	15.0	6.8	744.7
December,00	77.0	23.0	16.3	6.7	709.2
January,01	77.9	22.1	20.5	1.6	714.8
February,01	76.7	23.3	21.4	1.9	723.3
March,01	76.2	23.8	16.9	6.9	665.9
April,01	76.2	23.8	17.4	6.4	739.7
May,01	77.6	22.4	16.8	5.6	719.5
June,01	75.6	24.4	17.6	6.8	702.3
July,01	75.0	25.0	13.5	11.5	486.0
August,01	73.2	26.8	20.3	6.5	592.1
September,01	76.9	23.1	16.8	6.3	691.3

Table 5.1.3: Phytoplankton pigments at Versova during August 00-September 01.

Period	Chlorophyll a (mg/m ³)		Phaeophytin (mg/m ³)		Ratio Chl a / Phae	
	Fl	Eb	Fl	Eb	Fl	Eb
Aug-2000	2.1	1.6	1.2	0.6	1.8	2.7
Sept-2000	2.1	2.7	2	1.1	1.1	2.5
Oct-2000	1.1	1.6	1.9	1.4	0.6	1.1
Nov-2000	1.1	1.1	1.5	0.8	0.7	1.4
Dec-2000	2.1	4.3	1.2	1.3	1.8	3.3
Jan-2001	2.1	2.1	0.9	0.1	2.3	21
Feb-2001	1.1	3.2	1.9	2.4	0.6	1.3
Mar-2001	0.5	3.7	0.2	0.4	2.5	9.3
Apr-2001	0.5	1.1	1	0.4	0.5	2.8
May-2001	0.5	2.1	0.2	0.1	2.5	21
Jun-2001	5.3	9.1	4	2.9	1.3	3.1
Jul-2001	5.3	11.7	5.1	3.2	1	3.7
Aug-2001	3.7	11.7	2.6	4.7	1.4	2.5
Sept-2001	5.9	4.8	3.1	1.9	1.9	2.5

Table 5.1.4: Phytoplankton cell count, total species and major species recorded at Versova during August 2000- September 2001.

Period	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
Aug, 00	Flood	112.0	14	<i>Nitzschia seriata</i> (25.7) <i>Pleurosigma elongatum</i> (18.2) <i>Coscinodiscus marginatus</i> (15.7)
	Ebb	203.0	11	<i>Surirella fastuosa</i> (19.3) <i>Gyrosigma balticum</i> (16.0) <i>Rhizosolenia styliformis</i> (16.2)
Sep, 00	Flood	194.0	12	<i>Navicula membranacea</i> (16.2) <i>Pleurosigma elongate</i> (16.1) <i>Thalassiosira subtilis</i> (14.9)
	Ebb	262.8	14	<i>Navicula membranacea</i> (20.1) <i>Thalassiosira subtilis</i> (18.7) <i>Pleurosigma elongatum</i> (10.8) <i>Stauroneis membranesis</i> (10.2)
Oct, 00	Flood	111.3	9	<i>Navicula membranacea</i> (34.7) <i>Coscinodiscus radiatus</i> (30.9) <i>Gyrosigma balticum</i> (20.4)
	Ebb	160.0	13	<i>Gyrosigma balticum</i> (25.0) <i>Oscillattoria limosa</i> (22.5) <i>Oscillattoria lauterbomii</i> (20.0)
Nov, 00	Flood	89.0	10	<i>Nitzschia seriata</i> (39.6) <i>Navicula membranacea</i> (30.2)
	Ebb	112.8	11	<i>Navicula membranacea</i> (46.8) <i>Oscillattoria limosa</i> (25.5)
Dec, 00	Flood	200.7	15	<i>Navicula distance</i> (18.2) <i>Navicula membranacea</i> (16.9) <i>Ditylum sol</i> (15.7) <i>Nitzschia closterium</i> (14.0)
	Ebb	401.2	15	<i>Navicula membranacea</i> (27.7) <i>Nitzschia closterium</i> (21.1) <i>Gyrosigma balticum</i> (14.8)

Table 5.1.4 (Continued...)

Period	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
Jan, 01	Flood	188.0	15	<i>Navicula distance</i> (23.0) <i>Nitzschia closterium</i> (19.1) <i>Coscinodiscus sublineatus</i> (14.5) <i>Pleurosigma angulatum</i> (14.5)
	Ebb	232.0	13	<i>Navicula distance</i> (31.0) <i>Pleurosigma elongatum</i> (25.9) <i>Stauroneis membranesis</i> (20.7)
Feb, 01	Flood	98.0	16	<i>Thalassiosira condensata</i> (49.0) <i>Oscillatoria limosa</i> (14.3)
	Ebb	312.2	11	<i>Navicula membranacea</i> (22.0) <i>Nitzschia seriata</i> (33.8) <i>Biddulphia mobiliensis</i> (19.5)
Mar, 01	Flood	58.0	7	<i>Pleurosigma elongatum</i> (34.5) <i>Stauroneis membranacea</i> (24.1) <i>Navicula membranacea</i> (24.1)
	Ebb	360.0	14	<i>Coscinodiscus marginatus</i> (13.3) <i>Rhizosolenia styliformis</i> (17.8) <i>Oscillatoria formosa</i> (15.0) <i>Navicula membranaceae</i> (12.2)
Apr, 01	Flood	49.2	13	<i>Navicula membranacea</i> (22.0) <i>Pleurosigma elongatum</i> (16.3)
	Ebb	120.0	11	<i>Navicula membranacea</i> (28.3) <i>Stauroneis membranacea</i> (28.3) <i>Pleurosigma elongatum</i> (16.7)

Table 5.1.4 (Continued...)

Parameter	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
May, 01	Flood	58.4	12	<i>Navicula membranacea</i> (37.0) <i>Pleurosigma elongatum</i> (27.4) <i>Skeletonema costatum</i> (13.7)
	Ebb	204.5	14	<i>Nitzschia seriata</i> (19.7) <i>Rhizosolenia styliformis</i> (15.0) <i>Oscillattoria formosa</i> (12.7) <i>Navicula membranaceae</i> (10.3)
Jun, 01	Flood	520.0	13	<i>Navicula membranaceae</i> (41.5) <i>Nitzschia closterium</i> (15.6)
	Ebb	912.0	14	<i>Oscillattoria formosa</i> (35.3) <i>Navicula membranaceae</i> (27.4) <i>Stauroneis membranesis</i> (14.2)
Jul, 01	Flood	680.0	17	<i>Nitzschia closterium</i> (25.3) <i>Chaetoceros pendulus</i> (16.5) <i>Navicula distance</i> (14.1)
	Ebb	1232.0	17	<i>Nitzschia closterium</i> (26.9) <i>Navicula distance</i> (14.3) <i>Chaetoceros pendulus</i> (12.3) <i>Rhizosolenia habetata</i> (10.4)
Aug, 01	Flood	345.0	14	<i>Rhizosolenia styliformis</i> (17.4) <i>Stauroneis membranacea</i> (24.6) <i>Skeletonema costatum</i> (11.6) <i>Nitzschia seriata</i> (10.1)
	Ebb	1125.0	14	<i>Navicula membranaceae</i> (20.4) <i>Nitzschia seriata</i> (16.4) <i>Oscillattoria formosa</i> (10.2)

Table 5.1.4 (Continued...)

Parameter	Tide	Cell count (no. x103/l)	Total Species (No.)	Major species (%)
Sept, 01	Flood	504.0	14	<i>Oscillatoria formosa</i> (21.4) <i>Stauroneis membranacea</i> (13.5) <i>Skeletonema costatum</i> (14.3) <i>Navicula membranaceae</i> (17.5)
	Ebb	792.0	14	<i>Navicula membranacea</i> (26.3) <i>Nitzschia seriata</i> (32.8) <i>Oscillatoria formosa</i> (11.1)

Table 5.1.5: Percentage composition of Phytoplankton recorded at Versova during August 2000 - September 2001.

Genera- Species	Monsoon	Post Monsoon	Pre Monsoon	Monsoon
	(%)	(%)	(%)	(%)
<i>Anacystis nidulans</i>	0.2	-	-	-
<i>Amphiprora gigantean</i>	-	0.6	-	0.2
<i>Amphora decusatta</i>	-	0.2	-	-
<i>Bacteriastrum delicatulum</i>	-	0.1	0.3	1.4
<i>Biddulphia rhombus</i>	-	0.2	-	0.1
<i>Biddulphia mobilensis</i>	-	-	2.8	0.4
<i>Biddulphia alternas</i>	-	0.8	-	-
<i>Chaetoceros affinis</i>	-	0.6	-	-
<i>Chaetoceros pendulus</i>	-	-	-	3.6
<i>Coscinodiscus radiatus</i>	4.2	5	3.7	0.7
<i>Coscinodiscus concinnus</i>	-	1.2	-	-
<i>Coscinodiscus lineatus</i>	-	0.2	-	-
<i>Coscinodiscus sublineatus</i>	-	1.8	-	-
<i>Coscinodiscus eccentricus</i>	-	-	0.3	-
<i>Coscinodiscus marginatus</i>	4.6	-	2.5	1.1
<i>Cyclotella menenghiniana</i>	-	0.3	0.3	-
<i>Cymbella prostrate</i>	-	0.9	-	0.1
<i>Diatoma aurita</i>	-	-	0.1	-
<i>Diploneis weissflogii</i>	-	-	0.3	0.1
<i>Ditylum brightwellii</i>	-	2	-	-
<i>Eucampia zodiacus</i>	-	0.1	-	-
<i>Fragillaria oceanic</i>	5.5	-	1.6	1.5
<i>Gymnodinium estuariale</i>	-	-	-	0.7
<i>Gyrosigma balticum</i>	4.9	8.1	2.8	0.7
<i>Licmophora abbreviate</i>	-	0.1	-	-
<i>Leptocylindrus danicus</i>	-	0.1	-	-
<i>Melosira borrei</i>	-	-	-	0.1
<i>Navicula membranaceae</i>	14.9	19.9	19.7	17.7
<i>Navicula distans</i>	-	9.3	-	3.6
<i>Nitzschia seriata</i>	9	6.5	10.2	9.8
<i>Nitzschia closterium</i>	-	7.1	-	8.5
<i>Nitzschia longissima</i>	-	0.3	-	1.2
<i>Nitzschia sigmoids</i>	-	0.4	-	0.9
<i>Oscillattoria limosa</i>	2.6	8.3	3.7	1.9
<i>Oscillattoria formosa</i>	5.5	2.8	3.5	10.7
<i>Oscillattoria lauterbomii</i>	-	2.5	-	0.7
<i>Pleurosigma elongatum</i>	15.7	7	13.4	4
<i>Pleurosigma angulatum</i>	-	1.1	0.2	1
<i>Pleurosigma directum</i>	-	-	-	0.7
<i>Predinium ovatum</i>	-	0.3	-	0.5
<i>Prorocentrum oblongatum</i>	-	0.1	-	-
<i>Rhizosolenia styliformis</i>	7.1	0	5.5	3.9
<i>Rhizosolenia setigera</i>	-	0.2	-	-

Table 5.1.5 (Continued...)

<i>Genera Species</i>	Monsoon	Post	Pre	Monsoon
	(%)	Monsoon	Monsoon	(%)
<i>Rhizosolenia robusta</i>	-	-	1.5	-
<i>Rhizosolenia habeta</i>	-	-	-	2.1
<i>Skeletonema costatum</i>	4.3	-	4	6.7
<i>Spirulina aeruginea</i>	0.7	0.5	2.3	0.1
<i>Stauroneis membranensis</i>	7.4	4.1	10.9	10.6
<i>Surirella fastuosa</i>	3.3	0.1	0.8	0.3
<i>Synedra ulna</i>	0.9	0.3	1.7	0.5
<i>Thalassiosira subtilis</i>	9.2	3.6	1.5	4
<i>Thalassiosira gravida</i>	-	2.9	0.3	-
<i>Thalassiosira condensata</i>	-	-	6.1	-
<i>Thalassionema nitzschoides</i>	-	0.1	-	-
<i>Thalassiothrix fraunfeldii</i>	-	0.3	-	-

Table 5.1.6: Classification of phytoplankton species recorded in the neashore waters of Versova.

ORDER Centrales

FAMILY Coscinodisceae

SUB FAMILY Melosiraceae

Melosira borrei

SUB FAMILY Skeletonemineae

Skeletonema costatum

Thalassiosira subtilis

Thalassiosira gravida

Thalassiosira condensate

SUB FAMILY Coscinodiscineae

Cyclotella meneghiniana

Coscinodiscus marginatus

Coscinodiscus lineatus

Coscinodiscus radiatus

Coscinodiscus concinnus

Coscinodiscus sublineatus

Coscinodiscus eccentricus

SUB ORDER Solenolodeae

FAMILY Soleniceae

SUB FAMILY Lauderineae

Leptocylindrus danicus

FAMILY Eupodisceae

SUB FAMILY Rhizosoleniinae

Rhizosolenia styliformis

Rhizosolenia Setigera

Rhizosolenia robusta

Rhizosolenia habetata

SUB ORDER Biddulphioideae

FAMILY Chaetocereae

Bacteriastrum delicatulum

Chaetoceros affinis

Chaetoceros pendulus

FAMILY Biddulphieae

SUB FAMILY Eucampineae

Eucampia zoodiacus

Table 5.1.6 (Continued...)

SUB FAMILY Triceratineae

Ditylum brightwelli

SUB FAMILY Biddulphineae

Biddulphia rhombus

Biddulphia mobilensis

Biddulphia alternans

ORDER Pennales

FAMILY Fragilarioideae

SUB FAMILY Tabellarieae

Licmophora abbreviate

SUB FAMILY Fragilarieae

Fragilaria oceanica

Synedra ulna

Thalassionema nitzschioides

Thalassiothrix frauenfeldii

Diatoma aurita

FAMILY Naviculoides

SUB FAMILY Naviculeae

Gyrosigma balticum

Pleurosigma elongatum

Pleurosigma directum

Pleurosigma angulatum

Diploneis Weissflogii

Navicula distans

Navicula membranaceae

Stauroneis membranacea

SUB FAMILY Amphiprotoideae

Amphiprora gigantean

Amphiprora hyperborean

SUB FAMILY Gomphocymbelloideae

Amphora decussate

Cymbella prostrate

Table 5.1.6 (Continued...)

FAMILY Nitzschiaceae

SUB FAMILY Nitzschioideae

27. *Nitzschia seriata*

Nitzschia closterium

Nitzschia longissima

Nitzschia sigma

FAMILY Surirellaceae

28. *Surirella fastuosa*

ORDER Prorocentrales

FAMILY Prorocentraceae

29. *Prorocentrum oblongatum*

CLASS Cyanophyceae

ORDER Chamasiphonales

FAMILY Oscillatoriales

30. *Oscillattoria limosa*

Oscillattoria formosa

Oscillattoria lauterbonii

31. *Spirulina aeruginea*

ORDER Gymnodiniales

FAMILY Gymnodiniaceae

32. *Gymnodinium estuariale*

ORDER Nostocales

FAMILY Nostocaceae

33. *Anacystis nidulans*

Table 5.1.7: Microphytobenthic pigment occurrence in sediment at 1 cm depth at Versova during August 2000 - September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
Aug-2000	648.4	237.5	552.1	87.5	1.1	3.5
Sept-2000	281.7	214.8	39.6	53.1	7.2	6.3
Oct-2000	335.2	693.9	199.2	420.9	4.6	2.0
Nov-2000	140.5	592.2	105.4	433.1	1.3	1.3
Dec-2000	70.2	1091.4	58.5	109.1	1.1	13.9
Jan-2001	52.8	910.0	69.3	135.9	0.7	8.0
Feb-2001	286.4	236.2	27.9	14.8	11.6	17.1
Mar-2001	125.0	185.3	16.3	30.5	8.0	9.6
Apr-2001	152.5	709.9	166.8	77.9	0.9	11.3
May-2001	97.0	786.3	99.1	309.3	1.0	3.3
Jun-2001	135.8	797.6	25.8	131.6	7.1	7.4
Jul-2001	74.2	531.9	72.3	171.7	1.0	2.8
Aug-2001	129.8	809.0	87.0	214.9	1.7	4.2
Sept-2001	87.6	718.0	59.4	85.3	1.6	8.6
Aug-2000	89.6	683.8	56.2	61.3	1.3	16.7

Table 5.1.8: Microphytobenthic pigment occurrence in sediment at 2 cm depth at Versova during August 2000 - September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
Aug-2000	207.4	145.6	64.2	62.9	3.3	2.5
Sept-2000	180.0	403.5	106.6	506.6	3.3	0.7
Oct-2000	104.4	186.7	126.1	164.6	0.8	1.1
Nov-2000	40.2	588.8	61.0	140.9	0.6	4.7
Dec-2000	28.8	609.6	52.3	172.6	0.5	3.6
Jan-2001	218.8	174.6	46.7	19.7	5.9	8.8
Feb-2001	74.2	95.0	34.4	47.3	2.8	3.4
Mar-2001	104.4	451.0	138.2	157.9	0.7	2.9
Apr-2001	60.9	448.3	81.0	387.8	0.7	1.4
May-2001	98.3	541.3	55.7	242.7	2.6	2.5
Jun-2001	62.8	329.2	68.7	164.1	0.9	2.4
Jul-2001	74.2	487.1	94.3	253.8	1.0	1.9
Aug-2001	74.1	442.3	64.5	330.1	0.6	1.3
Sept-2001	65.5	374.7	63.7	179.4	1.0	3.1

Table 5.1.9: Microphytobenthic pigment occurrence in sediment at 3 cm depth at Versova during August 2000 - September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
Aug-2000	154.6	119.1	96.5	69.6	1.7	1.8
Sept-2000	105.7	196.1	100.8	481.3	1.8	0.5
Oct-2000	70.4	158.6	104.0	194.1	0.7	0.8
Nov-2000	26.1	297.1	72.8	167.6	0.4	1.9
Dec-2000	20.1	265.0	46.9	252.1	0.4	1.0
Jan-2001	145.2	116.4	50.6	36.3	3.3	3.6
Feb-2001	57.5	74.3	37.5	54.1	1.9	2.0
Mar-2001	90.3	159.3	126.5	168.6	0.7	1.1
Apr-2001	45.5	355.3	66.4	376.8	0.7	1.1
May-2001	57.6	242.9	75.5	254.1	0.8	0.8
Jun-2001	40.2	176.1	76.5	226.4	0.5	0.6
Jul-2001	46.2	208.1	80.3	335.7	0.6	0.6
Aug-2001	31.4	278.4	48.6	362.4	0.7	0.8
Sept-2001	56.2	153.3	57.6	145.1	1.2	1.2

Table 5.1.10: Microphytobenthic pigment occurrence in sediment at 4 cm depth at Versova during August 2000 - September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
Aug-2000	107.1	78.9	89.7	91.6	1.2	0.8
Sept-2000	69.6	112.4	98.6	215.6	0.8	0.3
Oct-2000	66.9	68.3	98.0	132.7	0.7	0.6
Nov-2000	12.1	123.8	60.1	148.3	0.2	0.8
Dec-2000	10.0	107.7	37.3	162.5	0.3	0.6
Jan-2001	66.3	52.9	49.9	45.0	1.3	1.2
Feb-2001	28.1	58.9	45.4	47.4	0.6	1.5
Mar-2001	51.5	65.6	98.8	97.4	0.5	0.7
Apr-2001	21.4	189.4	65.7	240.1	0.3	0.7
May-2001	40.2	66.9	79.8	199.1	0.5	0.4
Jun-2001	36.8	48.4	71.4	81.3	0.5	0.4
Jul-2001	28.1	97.0	73.1	250.6	0.4	0.4
Aug-2001	14.7	91.7	49.4	144.4	0.3	0.6
Sept-2001	20.8	85.7	71.1	97.5	0.4	0.8

Table 5.1.11: Microphytobenthic pigment occurrence in sediment at 5 cm depth at Versova during August 2000 - September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
Aug-2000	72.9	52.9	101.3	94.7	0.7	0.7
Sept-2000	46.2	26.1	87.3	138.3	0.6	0.2
Oct-2000	37.5	12.1	92.8	104.6	0.4	0.1
Nov-2000	6.7	81.6	61.7	144.1	0.1	0.5
Dec-2000	6.7	31.5	36.9	122.7	0.2	0.3
Jan-2001	30.1	24.8	52.8	52.5	0.5	0.5
Feb-2001	13.4	35.5	31.1	46.5	0.3	0.6
Mar-2001	32.1	24.8	78.9	51.6	0.3	0.5
Apr-2001	13.4	45.5	55.0	145.6	0.3	0.3
May-2001	22.7	23.4	78.0	106.8	0.4	0.2
Jun-2001	24.1	10.1	66.3	52.1	0.4	0.1
Jul-2001	11.4	30.1	30.3	135.7	0.1	0.2
Aug-2001	6.0	35.5	24.4	72.7	0.1	0.5
Sept-2001	18.1	28.1	51.0	60.9	0.2	0.3

Table 5.1.12: Microphytobenthic pigment occurrence in sediment at 6 cm depth at Versova during August 2000 - September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
Aug-2000	10.0	13.4	110.8	117.3	0.1	0.1
Sept-2000	24.8	4.0	60.0	44.3	0.4	0.1
Oct-2000	20.7	1.3	77.6	34.2	0.3	<0.1
Nov-2000	3.3	56.2	14.5	110.1	0.2	0.4
Dec-2000	4.0	11.4	22.2	70.6	0.1	0.2
Jan-2001	6.0	9.4	53.9	53.9	0.2	0.2
Feb-2001	6.7	7.4	31.7	34.8	0.1	0.1
Mar-2001	21.4	11.4	66.6	45.8	0.2	0.3
Apr-2001	7.4	8.0	39.5	66.5	0.1	0.1
May-2001	12.7	7.4	34.6	84.9	0.3	0.1
Jun-2001	5.3	0.7	48.5	15.7	0.1	0.0
Jul-2001	8.7	5.3	24.1	72.4	0.1	0.1
Aug-2001	2.7	15.4	9.5	37.5	0.1	0.3
Sept-2001	6.7	8.7	40.0	36.7	0.2	0.1

Table 5.1.13: Microphytobenthic pigment occurrence in sediment from 7 cm to 10 cm depth at Versova during August 2000 - September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
7 cm						
Aug-2000	4.0	1.3	55.0	97.1	0.1	<0.1
Sept-2000	16.1	0.0	46.2	0.0	0.3	0.0
Oct-2000	6.7	0.0	43.6	0.0	0.1	0.0
Nov-2000	0.7	41.5	4.0	70.5	0.1	0.6
Dec-2000	0.0	1.3	0.0	26.3	0.0	0.1
Jan-2001	0.7	1.3	9.6	18.3	0.0	0.1
Feb-2001	1.3	1.3	29.6	14.6	<0.1	0.1
Mar-2001	14.1	7.4	32.3	21.2	0.1	0.2
Apr-2001	0.7	0.7	8.7	8.7	0.0	0.0
May-2001	7.4	0.7	27.8	19.9	0.2	<0.1
Jun-2001	2.0	0.0	15.8	0.0	0.0	0.0
Jul-2001	6.7	0.7	25.6	12.4	0.1	0.0
Aug-2001	1.3	0.7	11.3	8.2	0.0	0.0
Sept-2001	0.7	0.7	12.0	10.1	0.0	0.0
8 cm						
Aug-2000	0.7	0.0	21.8	0.0	<0.1	0.0
Sept-2000	6.7	0.0	13.0	0.0	0.2	0.0
Oct-2000	3.3	0.0	18.7	0.0	0.1	0.0
Nov-2000	0.0	14.1	0.0	30.4	0.0	0.2
Mar-2001	0.7	2.7	8.7	9.0	0.0	0.1
May-2001	4.0	0.0	14.3	0.0	0.1	0.0
Jul-2001	0.7	0.0	10.1	0.0	0.0	0.0
Aug-2001	0.7	0.0	10.6	0.0	0.0	0.0
9 cm						
Aug-2000	0.7	0.0	7.8	0.0	<0.1	0.0
Sept-2000	0.7	0.0	12.4	0.0	<0.1	0.0
Oct-2000	2.0	0.0	13.0	0.0	0.1	0.0
Nov-2000	0.0	7.4	0.0	27.8	0.0	0.1
Mar-2001	0.0	0.7	0.0	7.8	0.0	0.0
May-2001	3.3	0.0	13.0	0.0	0.1	0.0
Aug-2001	0.7	0.0	8.2	0.0	<0.1	0.0
10 cm						
Oct-2000	0.7	0.0	9.2	0.0	<0.1	0
Nov-2000	0.0	0.7	0.0	5.9	0	<0.1
May-2001	0.7	0.0	9.2	0.0	<0.1	0
Aug-2001	0.7	0.0	7.7	0.0	<0.1	0

Table 5.1.14: Microphytobenthic cell count and total genera in sediment at 1 cm depth at Versova during August 2000 - September 01.

Period	Total Cell Count (No. X 10 ⁶ /cm ³)		Total Species (No.)	
	HWL	LWL	HWL	LWL
Aug-2000	24.0	52.3	8	6
Sept-2000	35.3	70.7	5	5
Oct-2000	16.5	68.3	8	10
Nov-2000	10.4	68.8	6	9
Dec-2000	12.2	74.0	3	10
Jan-2001	28.3	18.8	7	6
Feb-2001	11.8	17.9	6	7
Mar-2001	25.4	59.8	6	7
Apr-2001	13.7	68.8	4	12
May-2001	12.7	62.2	3	9
Jun-2001	17.0	56.1	5	8
Jul-2001	28.3	94.6	6	8
Aug-2001	12.7	63.1	8	7
Sept-2001	11.3	56.5	4	7

Table 5.1.15: Microphytobenthic cell count and total genera in sediment at 2 cm depth at Versova during August 2000 - September 01.

Period	Total Cell Count (No. X 10 ⁶ /cm ³)		Total Species (No.)	
	HWL	LWL	HWL	LWL
Aug-2000	19.8	13.2	11	6
Sept-2000	29.2	63.6	6	8
Oct-2000	13.2	36.3	9	5
Nov-2000	8.0	49.0	6	8
Dec-2000	6.6	54.6	6	9
Jan-2001	17.0	14.1	7	7
Feb-2001	9.4	9.9	8	6
Mar-2001	17.0	45.7	5	8
Apr-2001	11.8	57.0	5	8
May-2001	11.3	56.1	6	8
Jun-2001	9.0	46.6	3	7
Jul-2001	12.7	46.6	7	7
Aug-2001	8.5	58.4	6	7
Sept-2001	8.5	44.3	3	5

Table 5.1.16: Microphytobenthic cell count and total genera in sediment at 3 cm depth at Versova during August 2000 - September 01.

Period	Total Cell Count (No. X 10 ⁶ /cm ³)		Total Species (No.)	
	HWL	LWL	HWL	LWL
Aug-2000	13.2	9.9	9	4
Sept-2000	17.9	48.5	6	8
Oct-2000	13.2	23.6	8	7
Nov-2000	7.1	31.1	4	3
Dec-2000	4.2	33.9	3	7
Jan-2001	15.5	8.5	5	6
Feb-2001	7.1	9.9	5	6
Mar-2001	9.9	21.7	2	6
Apr-2001	7.1	47.1	5	8
May-2001	8.5	33.9	6	10
Jun-2001	8.5	45.7	2	7
Jul-2001	9.9	41.5	4	6
Aug-2001	5.7	50.9	4	7
Sept-2001	8.5	18.8	5	5

Table 5.1.17: Microphytobenthic cell count and total genera in sediment at 4 cm depth at Versova during August 2000 - September 01.

Period	Total Cell Count (No. X 10 ⁶ /cm ³)		Total Species (No.)	
	HWL	LWL	HWL	LWL
Aug-2000	9.0	9.4	7	7
Sept-2000	11.3	30.6	6	9
Oct-2000	13.2	8.5	9	6
Nov-2000	5.2	19.3	4	7
Dec-2000	4.2	21.7	3	5
Jan-2001	8.5	8.5	6	6
Feb-2001	5.7	7.1	4	4
Mar-2001	15.5	12.7	6	5
Apr-2001	7.1	30.2	5	6
May-2001	8.5	19.8	5	8
Jun-2001	8.0	10.8	3	3
Jul-2001	8.5	25.9	3	5
Aug-2001	5.7	18.4	4	6
Sept-2001	7.1	14.1	5	3

Table 5.1.18: Microphytobenthic cell count and total genera in sediment at 5 cm depth at Versova during August 2000 - September 01.

Period	Total Cell Count (No. X 10 ⁶ /cm ³)		Total Species (No.)	
	HWL	LWL	HWL	LWL
Aug-2000	6.1	8.5	4	6
Sept-2000	9.4	12.2	5	6
Oct-2000	8.5	8.5	6	5
Nov-2000	4.7	18.4	3	5
Dec-2000	2.8	13.2	2	6
Jan-2001	5.7	5.7	4	4
Feb-2001	5.7	7.1	4	5
Mar-2001	9.4	5.7	6	4
Apr-2001	6.1	30.2	3	4
May-2001	7.1	8.5	4	5
Jun-2001	7.1	10.4	3	4
Jul-2001	8.5	11.8	4	4
Aug-2001	5.7	8.5	3	2
Sept-2001	5.7	0.0	4	0

Table 5.1.19: Microphytobenthic cell count and total genera in sediment at 6 cm depth at Versova during August 2000 - September 01.

Period	Total Cell Count (No. X 10 ⁶ /cm ³)		Total Species (No.)	
	HWL	LWL	HWL	LWL
Aug-2000	0.0	2.8	0	2
Sept-2000	7.1	4.2	5	3
Oct-2000	7.1	5.7	5	4
Nov-2000	4.2	9.4	3	4
Dec-2000	2.8	4.2	2	3
Jan-2001	4.2	4.2	3	3
Feb-2001	5.7	1.4	4	1
Mar-2001	8.5	4.2	3	3
Apr-2001	4.2	5.7	3	2
May-2001	4.2	8.5	3	6
Jun-2001	7.1	0.0	3	0
Jul-2001	7.1	7.5	4	3
Aug-2001	4.2	5.7	3	3
Sept-2001	4.2	0.0	3	0

Table 5.1.20: Microphytobenthic cell count and total genera in sediment at 7 cm depth at Versova during August 2000 - September 01.

Period	Total Cell Count (No. X 10 ⁶ /cm ³)		Total Species (No.)	
	HWL	LWL	HWL	LWL
7 cm				
Sept-2000	5.7	0.0	4	0
Oct-2000	0.0	2.8	0	2
Nov-2000	1.4	4.2	1	3
Dec-2000	1.4	0.0	1	0
Mar-2001	8.5	2.8	3	2
May-2001	2.8	4.2	1	1
Jul-2001	7.1	4.2	3	3
Aug-2001	1.4	0.0	1	0
8 cm				
Nov-2000	0.0	2.8	0	2
Mar-2001	0.0	2.8	0	2
Jul-2001	1.4	2.8	1	2
Aug-2001	1.4	0.0	1	0
9 cm				
Jul-2001	1.4	0.0	1	0

Table 5.1.21 Classification of Microphytobenthos species recorded in the intertidal sediment of Versova.
ORDER Centrales

FAMILY Coscinodisceae

SUB FAMILY Skeletonemineae

Skeletonema costatum

Thalassiosira subtilis

Thalassiosira condensata

Thalassiosira gravida

SUB FAMILY Coscinodiscineae

Coscinodiscus lineatus

Coscinodiscus radiatus

Coscinodiscus striata

Planktoniella sol

SUB FAMILY Asterolamprineae

Asteromphalus flabellatus

SUB ORDER Solenolodeae

FAMILY Eupodisceae

SUB FAMILY Rhizosoleniinae

Rhizosolenia setigera

SUB ORDER Biddulphioideae

SUB FAMILY Biddulphineae

Biddulphia aurita

Biddulphia mobilensis

ORDER Pennales

FAMILY Fragilarioideae

SUB FAMILY Tabellarieae

Licmophora abbreviate

SUB FAMILY Fragilarieae

Table 5.1.21 (Continued...)

Fragilaria oceanica

Synedra ulna

Thalassionema nitzschioides

SUB ORDER Monoraphideae

FAMILY Achnantheoideae

SUB FAMILY Achnantheaceae

Achnanthes longipes

FAMILY Naviculoides

SUB FAMILY Naviculeae

Gyrosigma balticum

Pleurosigma normanii

Pleurosigma elongatum

Diploneis weissflogii

Navicula distans

Navicula membranaceae

Stauroneis membranacea

SUB FAMILY Amphiproroideae

Amphiprora gigantean

SUB FAMILY Gomphocymbelloideae

Amphora decussate

Cymbella prostrate

FAMILY Nitzschiaceae

SUB FAMILY Nitzschioideae

Bacillaria paradoxa

Nitzschia pungens

Nitzschia seriata

Table 5.1.21 (Continued...)

FAMILY Surirellaceae

Surirella fastuosa
Surirella elegans

ORDER Peridinales

FAMILY Peridiniaceae

Peridinium oblongatum

CLASS Cyanophyceae

ORDER Chamasiphonales

FAMILY Oscillatoriales

Oscillatoria formosa
Oscillatoria limosa

Spirulina aeruginea

Table 5.1.22: Correlation matrix for selected parameters at Versova.

Variable	Correlations (Correlationmp)									
	SS (mg/l)	Sal (ppt)	DO (mg/l)	BOD (mg/l)	PO ₄ ³⁻ - P (μmol/l)	NO ₃ ⁻ -N (μmol/l)	NO ₂ ⁻ -N (μmol/l)	NH ₄ ⁺ - N (μmol/l)	Chlorophyll a (mg/m3)	Phaeophytin (mg/m3)
SS(mg/l)	1.0000									
	p= ---									
Sal (ppt)	-0.5318	1.0000								
	p=0.004	p= ---								
DO (mg/l)	-0.5843	0.5351	1.0000							
	p=0.001	p=0.003	p= ---							
BOD (mg/l)	-0.5748	0.4419	0.8419	1.0000						
	p=0.001	p=0.019	p=0.000	p= ---						
PO ₄ ³⁻ - P (μmol/l)	.2001	-0.5915	-.3138	-.1873	1.0000					
	p=0.307	p=0.001	p=0.104	p=0.340	p= ---					
NO ₃ ⁻ -N (μmol/l)	0.4170	-0.6392	-0.4036	-.3028	.2681	1.0000				
	p=0.027	p=0.000	p=0.033	p=0.118	p=0.168	p= ---				
NO ₂ ⁻ -N (μmol/l)	.0773	.2649	-.2784	-.3501	.0238	-0.5300	1.0000			
	p=0.896	p=0.173	p=0.151	p=0.088	p=0.904	p=0.004	p= ---			
NH ₄ ⁺ - N (μmol/l)	0.5565	-.3624	-0.5662	-0.3825	0.4767	0.3893	.0505	1.0000		
	p=0.002	p=0.058	p=0.002	p=0.045	p=0.010	p=0.041	p=0.799	p= ---		
Chlorophyll a(mg/m3)	-0.4380	-0.4673	-0.4212	-.3507	.0068	0.7064	-0.3748	.3115	1.0000	
	p=0.020	p=0.012	p=0.026	p=0.087	p=0.973	p=0.000	p=0.049	p=0.107	p= ---	
Phaeophytin (mg/m3)	.0747	-.2099	-.1047	-.0711	-.2419	0.6083	-0.4927	.0419	0.7284	1.0000
	p=0.706	p=0.284	p=0.596	p=0.719	p=0.215	p=0.001	p=0.008	p=0.832	p=0.000	p= ---
MPB chl a	.2956	-.1264	-.0719	-.0192	-.1971	0.4695	-.3040	-.1694	.3738	.2363
	p=0.127	p=0.522	p=0.716	p=0.923	p=0.315	p=0.012	p=0.116	p=0.389	p=0.050	p=0.228

Table 5.2.1: Physicochemical characteristics at Gorai during August 2000- September 2001.

Period	Tide	AT*	WT	pH	SS (mg/l)	Sal (ppt)	DO (mg/l)	BOD (mg/l)	PO ₄ ³⁻ - P (μmol/l)	NO ₃ ⁻ -N (μmol/l)	NO ₂ ⁻ -N (μmol/l)	NH ₄ ⁺ - N (μmol/l)
Aug-2000	Fl	25.7	25.5	7.9	250.6	32.6	2.2	4.4	3.9	11.4	0.7	43.1
	Eb	25.1	26.0	7.8	367.4	7.7	1.8	2.5	11.7	14.7	1.6	57.8
Sept-2000	Fl	25.5	25.0	8.2	269.1	33.3	2.9	4.7	2.2	10.5	0.5	37.6
	Eb	25.0	25.1	8.1	453.1	8.9	2.2	3.4	8.9	12.3	1.2	51.2
Oct-2000	Fl	22.1	22.5	7.9	243.9	30.1	2.3	3.7	3.2	1	0.7	35.4
	Eb	28.7	28.9	7.8	337.9	27.0	1.7	1.2	4.2	3.9	12.4	40.3
Nov-2000	Fl	21.3	21.9	7.9	226.9	30.4	3.2	4.7	3.3	1.3	0.6	23.9
	Eb	26.5	26.1	7.9	298.0	26.5	1.4	0.6	3.9	4.7	10.4	35.2
Dec-2000	Fl	27.3	27.5	7.8	232.6	29.4	2.9	4.7	1.7	1.1	0.4	29.5
	Eb	21.0	21.5	7.8	488.8	23.8	1.7	0.3	2.5	4	7.8	39.4
Jan-2001	Fl	28.9	29.8	7.9	244.3	29.9	2.5	4.4	2	1	0.5	20
	Eb	21.5	23.8	7.9	357.3	24.0	2.0	0.9	2.3	4.4	8.1	42.1
Feb-2001	Fl	29.1	29.8	8.0	186.5	30.6	2.9	5.0	2.7	1	7.4	21.8
	Eb	32.1	32.0	7.9	267.1	29.7	2.2	2.2	3.4	5.2	8.7	43.5
Mar-2001	Fl	27.7	29.1	8.0	165.4	31.1	2.6	4.4	5.2	1.5	6.4	21.4
	Eb	33.1	30.1	8.1	403.9	28.6	2.3	2.8	7.3	5	8.8	46.3
Apr-2001	Fl	29.5	30.5	7.9	202.3	31.5	2.9	6.0	2.8	1.2	7.5	18.6
	Eb	32.0	28.5	7.8	383.8	30.1	1.8	3.1	2.4	4.4	8.1	55.5
May-2001	Fl	25.3	25.6	7.9	333.5	27.9	2.8	5.0	1.9	1.1	5.2	12.9
	Eb	32.7	32.3	7.9	483.2	25.8	2.2	2.8	1.7	3.8	7.1	25.1
Jun-2001	Fl	24.9	24.5	7.9	370.5	28.8	2.5	3.7	1.1	13.8	0.5	32.3
	Eb	25.2	25.7	8.0	449.1	14.9	1.7	2.8	3.1	15.1	1.3	66.9
Jul- 2001	Fl	24.3	24.3	7.9	379.3	22.2	2.3	3.4	1.6	11.8	0.6	36.7
	Eb	26.3	30.0	7.9	420.9	22.0	2.0	2.2	4.7	15.3	1.2	54.5
Aug-2001	Fl	25.5	25.8	7.9	289.9	29.9	2.5	2.5	1.3	12.8	0.7	17.1
	Eb	26.1	26.2	7.9	341.2	13.9	1.5	1.9	4.7	14.4	1.3	31
Sept-2001	Fl	24.6	24.1	7.9	267.4	22.2	2.3	3.4	1.3	13.6	0.8	19.7
	Eb	25.9	25.7	7.9	335.5	8.2	2.0	1.5	4.8	14.9	1	21

Table 5.2.2: Sediment characteristics at Gorai during August 2000- September 01.

Period	Sediment Texture				
	Sand (%)	Silt-clay (%)	Silt (%)	Clay (%)	Corg (%)
August,00	16.0	84.0	84.0	ND	3.4
September,00	17.4	82.6	82.6	ND	3.9
October,00	12.9	87.1	87.1	ND	2.4
November,00	12.3	87.7	87.7	ND	1.8
December,00	14.2	85.8	85.8	ND	1.9
January,01	15.9	84.1	84.1	ND	4.4
February,01	16.7	83.3	83.3	ND	4.2
March,01	16.0	84.0	84.0	ND	4.3
April,01	13.4	86.6	86.6	ND	4.5
May,01	15.1	84.9	84.9	ND	4.7
June,01	14.3	85.7	85.7	ND	3.7
July,01	15.4	84.6	84.6	ND	3.3
August,01	12.8	87.2	87.2	ND	4.5
September,01	13.0	87.0	87.0	ND	2.1

Table 5.2.3: Phytoplankton pigments at Gorai during August 00- September 01.

Period	Chlorophyll a (mg/m ³)		Phaeophytin (mg/m ³)		Ratio of Chl a / Phae	
	Fl	Eb	Fl	Eb	Fl	Eb
Aug-2000	2.1	3.7	5.3	1.5	0.4	2.5
Sept-2000	0.5	2.1	0.6	0.9	0.8	2.3
Oct-2000	1.1	1.1	1.2	1	0.9	1.6
Nov-2000	0.5	1.1	0.6	0.8	0.8	1.4
Dec-2000	1.1	3.2	1.5	2.1	0.7	2
Jan-2001	1.1	1.6	1	0.3	1.6	5.3
Feb-2001	1.1	1.6	1.9	1	0.6	1.6
Mar-2001	2.1	1.6	0.9	0.6	2.3	2.7
Apr-2001	1.1	1.1	1.5	0.4	0.7	2.8
May-2001	0.5	1.1	0.6	0.1	0.8	11
Jun-2001	3.2	8.5	2.8	4.2	1.1	2
Jul- 2001	5.9	10.7	1.9	2.4	0.6	4.5
Aug-2001	3.2	15	2	1.1	1.6	13.6
Sept-2001	3.2	4.3	0.6	0.2	0.8	21.5

Table 5.2.4: Phytoplankton cell count, total species and major species recorded at Gorai during August 2000- September 2001.

Period	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
August 2000	Ebb	107.800	11	<i>Chaetoceros decipiens</i> (26.7) <i>Pleurosigma elongatum</i> (18.6) <i>Thalassiosira subtilis</i> (10.8) <i>Navicula membranacea</i> (10.6) <i>Nitzschia seriata</i> (10.0)
	Flood	388.800	13	<i>Chaetoceros decipiens</i> (54.3) <i>Bacteriastrum delicatulum</i> (19.8)
September 2000	Flood	44.000	14	<i>Oscillattoria formosa</i> (24.5) <i>Navicula membranacea</i> (20.0) <i>Stauroneis membranacea</i> (15.5) <i>Skeletonema costatum</i> (16.4)
	Ebb	208.800	15	<i>Oscillattoria formosa</i> (24.3) <i>Navicula membranacea</i> (23.4) <i>Coscinodiscus lineatus</i> (13.8)
October 2000	Flood	97.020	9	<i>Navicula membranacea</i> (35.6) <i>Pleurosigma elongatum</i> (27.2) <i>Nitzschia seriata</i> (16.1) <i>Oscillattoria limosa</i> (13.8)
	Ebb	104.000	14	<i>Navicula membranacea</i> (23.8) <i>Nitzschia seriata</i> (27.7) <i>Rhizosolenia styliformis</i> (12.3) <i>Stauroneis membranacea</i> (10.4)

Table 5.2.4 (Continued...)

Period	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
November 2000	Flood	52.8	12	<i>Navicula membranacea</i> (20.5) <i>Oscillattoria limosa</i> (30.3) <i>Pleurosigma elongatum</i> (19.7) <i>Stauroneis membranacea</i> (12.9)
	Ebb	104.0	14	<i>Oscillattoria formosa</i> (34.6) <i>Navicula membranacea</i> (18.5) <i>Stauroneis membranacea</i> (13.1) <i>Skeletonema costatum</i> (13.8)
December 2000	Flood	107.2	7	<i>Nitzschia seriata</i> (34.3) <i>Pleurosigma elongatum</i> (29.9) <i>Navicula membranacea</i> (27.6)
	Ebb	330.0	14	<i>Nitzschia seriata</i> (24.8) <i>Coscinodiscus marginatus</i> (19.4) <i>Navicula membranacea</i> (18.8) <i>Fragilaria oceanica</i> (12.7)
January 2001	Flood	106.4	10	<i>Nitzschia seriata</i> (30.8) <i>Rhizosolenia setigera</i> (23.3) <i>Navicula membranacea</i> (20.3) <i>Pleurosigma elongatum</i> (18.8)
	Ebb	160.0	14	<i>Navicula membranacea</i> (26.0) <i>Oscillattoria formosa</i> (38.5)

Table 5.2.4 (Continued...)

Period	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
February 2001	Flood	43.8	10	<i>Navicula membranacea</i> (21.5) <i>Pleurosigma elongatum</i> (18.3) <i>Coscinodiscus radiatus</i> (12.8) <i>Fragillaria oceanica</i> (18.7)
	Ebb	150.0	14	<i>Oscillatoria formosa</i> (18.0) <i>Skeletonema costatum</i> (12.0) <i>Navicula membranacea</i> (14.7) <i>Nitzschia seriata</i> (14.7) <i>Stauroneis membranacea</i> (11.3)
March 2001	Flood	150.0	12	<i>Skeletonema costatum</i> (20.0) <i>Pleurosigma elongatum</i> (33.3) <i>Stauroneis membranacea</i> (11.7) <i>Navicula membranacea</i> (11.7)
	Ebb	220.0	14	<i>Oscillatoria formosa</i> (24.5) <i>Navicula membranacea</i> (20.0) <i>Skeletonema costatum</i> (16.4) <i>Stauroneis membranacea</i> (15.5)
April 2001	Flood	104.0	14	<i>Oscillatoria formosa</i> (20.8) <i>Fragillaria oceanica</i> (16.9) <i>Navicula membranacea</i> (16.9) <i>Skeletonema costatum</i> (13.8) <i>Stauroneis membranacea</i> (13.1)
	Ebb	108.0	12	<i>Navicula membranacea</i> (13.0) <i>Stauroneis membranacea</i> (13.0) <i>Coscinodiscus radiatus</i> (11.1) <i>Coscinodiscus lineatus</i> (11.1) <i>Gyrosigma balticum</i> (11.1)

Table 5.2.4 (Continued...)

Period	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
May 2001	Flood	42.6	12	<i>Oscillatoria limosa</i> (19.2) <i>Skeletonema costatum</i> (19.7) <i>Navicula membranacea</i> (17.4) <i>Fragillaria oceanica</i> (19.7)
	Ebb	115.2	14	<i>Oscillatoria formosa</i> (22.5) <i>Navicula membranacea</i> (18.3) <i>Stauroneis membranacea</i> (14.2) <i>Skeletonema costatum</i> (15.0)
June 2001	Flood	352.0	13	<i>Thalassiosira subtilis</i> (31.8) <i>Nitzschia closterium</i> (23.9) <i>Navicula membranacea</i> (12.5)
	Ebb	850.0	14	<i>Navicula membranacea</i> (30.6) <i>Nitzschia seriata</i> (18.8) <i>Oscillatoria formosa</i> (15.9)
July 2001	Flood	49.6	14	<i>Oscillatoria formosa</i> (27.4) <i>Navicula membranaceae</i> (19.4) <i>Skeletonema costatum</i> (12.9) <i>Stauroneis membranaceae</i> (11.3)
	Ebb	105.6	14	<i>Navicula membranacea</i> (20.0) <i>Oscillatoria formosa</i> (24.5) <i>Stauroneis membranacea</i> (15.5) <i>Skeletonema costatum</i> (16.4)

Table 5.2.4 (Continued...)

Period	Tide	Cell count (no. x10 ³ /l)	Total Species (No.)	Major species (%)
August 2001	Flood	319.2	14	<i>Skeletonema costatum</i> (18.3) <i>Nitzschia seriata</i> (14.3) <i>Navicula membranaceae</i> (11.5) <i>Oscillattoria formosa</i> (13.8) <i>Pleurosigma elongatum</i> (10.5)
	Ebb	1490.0	14	<i>Nitzschia seriata</i> (26.2) <i>Navicula membranacea</i> (17.4) <i>Skeletonema costatum</i> (18.1) <i>Stauroneis membranaceae</i> (15.1)
September 2001	Flood	296.0	14	<i>Navicula membranaceae</i> (21.6) <i>Oscillattoria formosa</i> (18.9) <i>Stauroneis membranacea</i> (16.2)
	Ebb	432.0	14	<i>Navicula membranacea</i> (24.1) <i>Oscillattoria formosa</i> (20.4) <i>Skeletonema costatum</i> (16.7) <i>Stauroneis membranacea</i> (15.7)

Table 5.2.5: Percentage composition of phytoplankton recorded at Gorai during August 2000- September 2001.

Genus- species	Monsoon	Post monsoon	Pre monsoon	Monsoon
<i>Amphiprora gigantea</i>	0	0	0.2	0.4
<i>Anabaena constricta</i>	0.3	0	0	0
<i>Anacystis spp</i>	0	0.1	0	0
<i>Bacteriastrum delicatulum</i>	5.7	0	0	0
<i>Biddulphia mobilensis</i>	0	0	0	0.3
<i>Biddulphia rhombus</i>	0	0.1	0	0
<i>Biddulphia alternas</i>	0	0.1	0	0
<i>Bacillaria paradoxa</i>	0	0.1	0	0
<i>Ceratium furca</i>	0	0.1	0	0
<i>Chaetoceros decipiens</i>	20.3	0	0	0.1
<i>Chaetoceros affinis</i>	0	0.1	0	0
<i>Chaetoceros pendulus</i>	0	0.1	0	0
<i>Coscinodiscus sublineatus</i>	0	0.1	0	0
<i>Coscinodiscus concinnus</i>	0	0.1	0	0
<i>Coscinodiscus marginatus</i>	3.3	3.3	2.4	2.7
<i>Coscinodiscus lineatus</i>	3.7	0.2	1.5	0
<i>Coscinodiscus granii</i>	0	0.1	0	0
<i>Coscinodiscus radiatus</i>	1.1	0.5	3.4	0
<i>Cyclotella menenghiniana</i>	0.1	0	0	0.1
<i>Cymbella prostrata</i>	0	0	0.1	0.1
<i>Fragillaria oceanica</i>	0.6	2.4	8.9	2.3
<i>Diploneis weissiflogii</i>	0	0.1	0	0
<i>Gymnodium spp</i>	0.3	0	0	0.3
<i>Gyrosigma balticum</i>	0.3	0.5	3.5	1.8
<i>Navicula distance</i>	0.3	0	1.8	1.6
<i>Hyalodiscus subtilis</i>	0	0.1	0	0
<i>Navicula membranacea</i>	13.5	21.4	14.9	18.1
<i>Navicula radiosa</i>	0	0.1	0	0
<i>Navicula membranaceae</i>	0	0.1	0	0
<i>Navicula distans</i>	0	0.1	0	0
<i>Nitzschia sigmoids</i>	0	0.1	0	0
<i>Nitzschia pungens</i>	0	0.1	0	0
<i>Nitzschia closterium</i>	0.3	3.5	0	3

Table 5.2.5 (Continued...)

Genus- species	Monsoon	Post monsoon	Pre monsoon	Monsoon
<i>Nitzschia longissima</i>	0.6	0	0	0.1
<i>Nitzschia seriata</i>	5	15	5.5	8.8
<i>Oscillattoria formosa</i>	12	11.5	10.6	16.6
<i>Oscillattoria limosa</i>	0.8	5.8	3.5	1.3
<i>Oscillattoria lauterbomii</i>	0	0	0	1.1
<i>Pleurosigma angulatum</i>	0.3	0	0	0.1
<i>Pleurosigma elongatum</i>	10.1	14.6	12.3	7
<i>Pleurosigma normanii</i>	0	0.1	0	0
<i>Predinium oblongata</i>	0.6	0	0	0
<i>Rhizosolenia setigera</i>	0	0	0	0
<i>Rhizosolenia styliformis</i>	1	5.5	5.8	3.9
<i>Rhizosolenia stolterforthii</i>	0	0.1	0	0
<i>Rhizosolenia robusta</i>	0	0.1	0	0
<i>Rhizosolenia habeta</i>	0	0.1	0	0
<i>Skeletonema costatum</i>	5	4.4	12.1	12.4
<i>Spirulina aeruginea</i>	1.6	0.5	1.1	0
<i>Stauroneis membranacea</i>	7.2	7.5	10.7	10.9
<i>Surirella fastuosa</i>	0.3	0.3	0.9	1.1
<i>Synedra ulna</i>	0.3	0.3	0.4	0.8
<i>Thalassiosira subtilis</i>	5.4	0.7	0.4	5.1
<i>Thalassiosira gravida</i>	0	0.1	0	0
<i>Thalassiosira condensata</i>	0	0.1	0	0
<i>Thalassionema nitzschoides</i>	0	0.1	0	0
<i>Thalassiothrix fraunfeldii</i>	0	0.1	0	0

Table 5.2.6: Classification of phytoplankton species recorded in the nearshore waters of Gorai.

ORDER Centrales

FAMILY Coscinodisceae

SUB FAMILY Skeletonemineae

Skeletonema costatum

Thalassiosira subtilis

SUB FAMILY Coscinodiscineae

Cyclotella radiata

Coscinodiscus marginatus

Coscinodiscus lineatus

Coscinodiscus radiatus

SUB ORDER Solenolodeae

FAMILY Eupodisceae

SUB FAMILY Rhizosoleniinae

Rhizosolenia styliformis

Rhizosolenia Setigera

SUB ORDER Biddulphioideae

FAMILY Chaetocereae

Bacteriastrum delicatulum

Chaetoceros decipiens

FAMILY Biddulphieae

SUB FAMILY Biddulphineae

Biddulphia mobilensis

ORDER Pennales

FAMILY Fragilarioideae

SUB FAMILY Fragilarieae

Fragilaria oceanica

Synedra ulna

FAMILY Naviculoides

SUB FAMILY Naviculeae

Gyrosigma balticum

Table 5.2.6 (Continued...)

	<i>Pleurosigma elongatum</i>
	<i>Pleurosigma directum</i>
	<i>Pleurosigma normanii</i>
	<i>Navicula distans</i>
	<i>Navicula membranaceae</i>
	<i>Stauroneis membranacea</i>
SUB FAMILY	Amphiprotoideae
	<i>Amphiproto gigantean</i>
SUB FAMILY	Gomphocymbelloideae
	<i>Cymbella prostrate</i>
FAMILY	Nitzschiaceae
SUB FAMILY	Nitzschioideae
	<i>Nitzschia seriata</i>
	<i>Nitzschia closterium</i>
	<i>Nitzschia longissima</i>
FAMILY	Surirellaceae
	<i>Surirella fastuosa</i>
ORDER	Peridinales
FAMILY	Peridiniaceae
	<i>Peridinium oblongatum</i>
CLASS	Cyanophyceae
ORDER	Chamasiphonales
FAMILY	Oscillatoriales
	<i>Oscillatoria limosa</i>
	<i>Oscillatoria formosa</i>
	<i>Oscillatoria lauterbonii</i>
	<i>Spirulina aeruginea</i>
ORDER	Gymnodiniales
FAMILY	Gymnodiniaceae
	<i>Gymnodinium estuariale</i>
ORDER	Nostocales

Table 5.2.6 (Continued...)

FAMILY Nostocaceae

Anacystis nidulans
Anabaena constricta

Table 5.2.7: Microphytobenthic pigment occurrence in sediment at 1cm depth at Gorai during August 00- September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
24/08/2000	763.5	667.8	264.2	184.2	3.4	3.7
21/09/2000	719.4	1174.4	88.67	129.67	8.30	11.53
19/10/2000	888.0	880.0	145.3	93.9	7.4	9.5
20/11/2000	167.3	277.7	128.7	80.9	1.3	5.4
27/12/2000	124.4	236.2	22.6	14.8	5.9	17.1
17/01/2001	264.3	205.4	30.8	14.7	10.7	13.7
10/02/2001	165.3	153.9	24.0	48.9	7.2	3.5
17/03/2001	247.6	118.5	40.0	30.1	6.6	4.8
13/04/2001	152.6	78.3	35.3	21.0	4.4	4.5
26/05/2001	133.8	183.4	36.7	81.3	3.7	2.3
16/06/2001	954.9	1053.3	186.2	347.3	5.6	5.4
14/07/2001	860.6	801.0	114.2	246.4	7.6	3.6
24/08/2001	188.0	584.8	220.9	150.6	1.6	4.9
23/09/2001	129.1	600.9	21.2	102.2	9.4	6.5

Table 5.2.8: Microphytobenthic pigment occurrence in sediment at 2cm depth at Gorai during August 00- September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
24/08/2000	438.5	490.5	221.5	311.9	2.8	1.8
21/09/2000	323.2	718.1	206.7	146.7	1.7	4.9
19/10/2000	617.7	354.7	280.8	182.6	2.3	2.5
20/11/2000	113.8	158.4	141.1	51.6	0.7	3.2
27/12/2000	59.5	174.7	35.5	19.8	1.7	8.8
17/01/2001	208.8	162.6	32.4	24.8	6.4	6.6
10/02/2001	103.7	97.0	29.3	49.1	3.5	2.1
17/03/2001	200.1	78.3	73.0	31.8	3.0	2.5
13/04/2001	87.0	51.5	45.6	39.3	2.0	1.5
26/05/2001	77.0	123.8	53.7	95.9	1.4	1.2
16/06/2001	536.7	528.0	266.2	317.5	2.1	1.8
14/07/2001	298.4	367.4	183.7	256.1	2.9	1.9
24/08/2001	72.3	292.4	97.8	146.0	1.7	2.1
23/09/2001	79.0	378.1	24.5	232.7	4.5	1.7

Table 5.2.9: Microphytobenthic pigment occurrence in sediment at 3 cm depth at Gorai during August 00- September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
24/08/2000	311.9	248.2	208.9	298.9	2.0	0.9
21/09/2000	104	478.5	123.2	149.7	1.1	0.9
19/10/2000	432.3	134.5	295.2	159.7	1.5	0.8
20/11/2000	73.6	95.7	119.4	47.6	0.6	2.1
27/12/2000	19.4	113.1	48.0	36.3	0.4	3.6
17/01/2001	116.4	105.7	39.1	38.6	3.0	2.7
10/02/2001	80.3	59.6	32.6	48.6	2.4	1.3
17/03/2001	160.6	58.2	90.0	41.1	1.9	1.5
13/04/2001	50.2	35.5	41.6	48.4	1.4	1.0
26/05/2001	42.8	76.9	71.0	94.4	0.6	0.8
16/06/2001	289.1	307.1	281.9	277.4	1.0	1.1
14/07/2001	220.8	122.5	231.7	179.7	0.9	0.9
24/08/2001	70.3	127.1	104.0	128.1	1.0	1.0
23/09/2001	46.2	234.2	59.2	321.3	0.8	0.7

Table 5.2.10: Microphytobenthic pigment occurrence in sediment at 4cm depth at Gorai during August 00- September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
24/08/2000	213.5	104.4	203.3	158.4	1.5	0.6
21/09/2000	63.6	204.1	140.7	165.9	0.5	1.3
19/10/2000	168.5	58.2	251.1	162.4	0.6	0.4
20/11/2000	54.9	64.2	95.5	70.7	0.5	0.9
27/12/2000	15.4	52.9	28.2	45.0	0.6	1.2
17/01/2001	54.9	72.9	44.9	43.2	1.1	1.8
10/02/2001	32.8	31.5	42.1	41.6	0.8	0.7
17/03/2001	101.0	37.5	96.7	42.2	1.1	1.0
13/04/2001	36.8	15.4	40.5	19.3	0.9	0.5
26/05/2001	21.4	49.5	65.7	91.0	0.4	0.6
16/06/2001	81.0	105.1	141.5	157.7	0.6	0.6
14/07/2001	75.6	83.0	144.1	119.8	0.6	0.7
24/08/2001	38.8	38.8	68.0	81.6	0.7	0.5
23/09/2001	20.8	91.7	58.4	271.3	0.4	0.4

Table 5.2.11 : Microphytobenthic pigment occurrence in sediment at 5 cm depth at Gorai during August 2000 to September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
24/08/2000	124.5	38.8	151.0	76.9	0.6	0.4
21/09/2000	19.4	35.4	103.3	82.6	0.2	0.3
19/10/2000	97.0	28.8	158.3	73.8	0.6	0.3
20/11/2000	35.5	48.9	70.9	79.5	0.5	0.5
27/12/2000	5.3	24.8	31.2	52.5	0.4	0.5
17/01/2001	26.1	42.8	48.4	55.5	0.5	0.7
10/02/2001	16.7	16.7	49.8	37.6	0.4	0.4
17/03/2001	43.5	6.7	104.5	9.2	0.4	0.2
13/04/2001	17.4	0.7	39.2	7.3	0.4	0.0
26/05/2001	13.4	22.8	41.0	71.4	0.3	0.4
16/06/2001	23.4	33.5	46.8	86.5	0.3	0.4
14/07/2001	21.4	14.0	85.8	98.3	0.2	0.2
24/08/2001	26.8	14.1	56.6	49.2	0.4	0.3
23/09/2001	14.1	44.2	44.0	164.3	0.3	0.3

Table 5.2.12 : Microphytobenthic pigment occurrence in sediment at 6 cm depth at Gorai during August 2000 to September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
24/08/2000	58.2	8.7	96.4	36.3	0.5	0.3
21/09/2000	1.3	4.7	44.6	42.6	<0.1	0.1
19/10/2000	45.5	2.0	94.6	21.4	0.4	0.0
20/11/2000	19.4	17.4	40.6	72.1	0.3	0.2
27/12/2000	2.0	6.7	16.3	51.7	0.1	<0.1
17/01/2001	2.7	7.4	42.8	59.2	<0.1	<0.1
10/02/2001	6.0	4.0	54.4	21.8	<0.1	0.1
17/03/2001	6.0	0.7	111.1	7.3	<0.1	0.0
13/04/2001	6.0	0.0	29.6	0.0	0.2	0.0
26/05/2001	12.7	14.7	30.4	49.9	0.3	0.3
16/06/2001	0.0	7.4	0.0	25.4	0.0	0.1
14/07/2001	6.7	2.0	32.2	21.0	0.2	0.1
24/08/2001	14.7	4.7	35.9	19.7	0.3	0.1
23/09/2001	2.0	22.8	43.0	107.0	<0.1	0.2

Table 5.2.13: Microphytobenthic pigment occurrence in sediment at 7 cm depth at Gorai during August 2000 to September 01.

Period	Chlorophyll a (mg/m ²)		Phaeophytin (mg/m ²)		Ratio of Chl a/ Phae	
	HWL	LWL	HWL	LWL	HWL	LWL
7 cm						
24/08/2000	44.8	0.0	76.5	0.0	0.4	0.0
21/09/2000	0.0	0.0	0.0	0.0	0.0	0.0
19/10/2000	15.4	0.7	61.4	8.7	0.2	0.0
20/11/2000	10.1	2.0	34.9	59.4	0.2	0.1
27/12/2000	0.0	2.0	0.0	40.6	0.0	0.1
17/01/2001	0.7	2.0	9.6	55.2	0.0	0.1
10/02/2001	2.0	0.7	54.7	5.4	0.1	0.0
17/03/2001	2.0	0.0	86.1	0.0	0.1	0.0
13/04/2001	1.3	0.0	15.1	0.0	0.1	0.0
26/05/2001	1.3	3.3	8.0	39.3	0.1	0.1
16/06/2001	0	0.7	0	8.7	0	0.03
14/07/2001	0	0	0	0	0	0
24/08/2001	0.7	0.7	4	8.3	0.1	0.03
23/09/2001	6.0	10.1	18.3	64.4	0.1	0.2
8 cm						
24/08/2000	17.4	0	63.6	0	0.1	0
21/09/2000	0	0	0	0	0	0
19/10/2000	7.4	0	39	0	0.1	0
20/11/2000	6	0	27.3	0	0.1	0
27/12/2000	0	0	0	0	0	0
26/05/2001	0	0.7	0	5.4	0	0.03
23/09/2001	0	2.6	0	26.3	0	0.1
9 cm						
24/08/2000	10.0	0	47.1	0	0.1	0
19/10/2000	3.3	0	25.7	0	0.1	0
20/11/2000	3.3	0	20.1	0	0.1	0
23/09/2001	0	0.1	0	8.2	0	0.03
18/04/2003	22.7	3.4	63.5	17.4	0.4	0.2
17/05/2003	21.0	15.6	47.3	17.1	0.4	0.9
10 cm						
24/08/2000	1.3	0	14.6	0	0.1	0
19/10/2000	0.7	0	11.9	0	0.03	0
20/11/2000	0.7	0	8.2	0	0.03	0
18/04/2003	8.8	2.5	86.2	16.6	0.1	0.2
17/05/2003	18.1	1.3	41.4	43.2	0.4	<0.1

Table 5.2.14: Microphytobenthic pigment occurrence in sediment at 1 cm depth at Gorai during August 2000 to September 01.

Period	Total Cell Count (No. X 10 ⁶)		Total Species (No.)	
	HWL	LWL	HWL	LWL
24/08/2000	95.9	78.3	14	10
21/09/2000	95.9	110.9	9	12
19/10/2000	21.9	90.9	10	11
20/11/2000	13.8	91.5	11	10
27/12/2000	16.3	98.4	12	10
17/01/2001	37.6	25.1	8	7
10/02/2001	15.7	23.8	9	8
17/03/2001	33.8	79.6	10	9
13/04/2001	18.2	91.5	12	10
26/05/2001	16.9	82.7	8	10
16/06/2001	22.6	74.6	10	7
14/07/2001	37.6	94.6	10	8
24/08/2001	16.9	84.0	8	9
23/09/2001	15.0	75.2	7	10

Table 5.2.15: Microphytobenthic pigment occurrence in sediment at 2 cm depth at Gorai during August 2000 to September 01.

Period	Total Cell Count (No. X 10 ⁶)		Total Species (No.)	
	HWL	LWL	HWL	LWL
24/08/2000	62.7	70.2	3	5
21/09/2000	43.9	92.7	4	3
19/10/2000	17.5	48.2	5	5
20/11/2000	10.7	65.2	6	4
27/12/2000	8.8	72.7	5	6
17/01/2001	22.6	18.8	7	7
10/02/2001	12.5	13.2	6	6
17/03/2001	22.6	60.8	3	4
13/04/2001	15.7	75.8	5	6
26/05/2001	15.0	74.6	6	5
16/06/2001	11.9	62.0	3	4
14/07/2001	16.9	62.0	6	7
24/08/2001	11.3	77.7	6	6
23/09/2001	11.3	58.9	3	3

Table 5.2.16: Microphytobenthic pigment occurrence in sediment at 3 cm depth at Gorai during August 2000 to September 01.

Period	Total Cell Count (No. X 10 ⁶)		Total Species (No.)	
	HWL	LWL	HWL	LWL
24/08/2000	50.1	55.1	3	5
21/09/2000	23.8	64.5	4	2
19/10/2000	17.5	31.3	8	6
20/11/2000	9.4	41.4	4	3
27/12/2000	5.6	45.1	3	5
17/01/2001	20.7	11.3	5	6
10/02/2001	9.4	13.2	5	6
17/03/2001	13.2	28.8	2	3
13/04/2001	9.4	62.7	5	3
26/05/2001	11.3	45.1	6	3
16/06/2001	11.3	60.8	2	5
14/07/2001	13.2	55.1	4	6
24/08/2001	7.5	67.7	4	4
23/09/2001	11.3	25.1	5	3

Table 5.2.17: Microphytobenthic pigment occurrence in sediment at 4 cm depth at Gorai during August 2000 to September 01.

Period	Total Cell Count (No. X 10 ⁶)		Total Species (No.)	
	HWL	LWL	HWL	LWL
24/08/2000	38.8	26.3	3	2
21/09/2000	21.9	37.0	4	3
19/10/2000	17.5	11.3	8	6
20/11/2000	6.9	25.7	4	4
27/12/2000	5.6	28.8	3	4
17/01/2001	11.3	11.3	6	6
10/02/2001	7.5	9.4	4	4
17/03/2001	20.7	16.9	3	5
13/04/2001	9.4	40.1	5	4
26/05/2001	11.3	26.3	5	4
16/06/2001	10.7	14.4	3	3
14/07/2001	11.3	34.5	3	4
24/08/2001	7.5	24.4	4	3
23/09/2001	9.4	18.8	5	3

Table 5.2.18: Microphytobenthic pigment occurrence in sediment at 5 cm depth at Gorai during August 2000 to September 01.

Period	Total Cell Count (No. X 10 ⁶)		Total Species (No.)	
	HWL	LWL	HWL	LWL
24/08/2000	26.9	11.3	3	6
21/09/2000	12.5	14.4	5	5
19/10/2000	11.3	11.3	6	5
20/11/2000	6.3	24.4	3	5
27/12/2000	3.8	17.5	2	6
17/01/2001	7.5	7.5	4	4
10/02/2001	7.5	9.4	4	5
17/03/2001	12.5	7.5	6	4
13/04/2001	8.1	40.1	3	3
26/05/2001	9.4	11.3	4	5
16/06/2001	9.4	13.8	3	4
14/07/2001	11.3	15.7	4	4
24/08/2001	7.5	11.3	3	2
23/09/2001	7.5	0.0	4	0

Table 5.2.19: Microphytobenthic pigment occurrence in sediment at 6 cm depth at Gorai during August 2000 to September 01.

Period	Total Cell Count (No. X 10 ⁶)		Total Species (No.)	
	HWL	LWL	HWL	LWL
24/08/2000	38.8	5.6	3	3
21/09/2000	5.6	0.0	3	3
19/10/2000	9.4	7.5	5	4
20/11/2000	5.6	12.5	3	4
27/12/2000	3.8	5.6	2	3
17/01/2001	5.6	5.6	3	3
10/02/2001	7.5	1.9	4	1
17/03/2001	11.3	5.6	3	3
13/04/2001	5.6	7.5	3	2
26/05/2001	5.6	11.3	3	6
16/06/2001	9.4	0.0	3	0
14/07/2001	9.4	10.0	4	3
24/08/2001	5.6	7.5	3	3
23/09/2001	5.6	0.0	3	0

Table 5.2.20: Microphytobenthic pigment occurrence in sediment at 7 cm depth at Gorai during August 2000 to September 01.

Period	Total Cell Count (No. X 10 ⁶)		Total Species (No.)	
	HWL	LWL	HWL	LWL
24/08/2000	13.2	0.0	3	0
21/09/2000	1.9	0.0	1	0
19/10/2000	0.0	3.8	0	2
20/11/2000	1.9	5.6	1	3
27/12/2000	1.9	0.0	1	0
17/01/2001	-	-	-	-
10/02/2001	-	-	-	-
17/03/2001	11.3	3.8	3	2
13/04/2001	-	-	-	-
26/05/2001	3.8	5.6	1	1
16/06/2001	-	-	-	-
14/07/2001	9.4	5.6	3	3
24/08/2001	1.9	0.0	1	0
23/09/2001	-	-	-	-
8 cm				
24/08/2000	18.2	0.0	5	0
20/11/2000	0.0	3.8	0	2
17/03/2001	0.0	3.8	0	2
14/07/2001	1.9	3.8	1	2
24/08/2001	1.9	0.0	1	0
9 cm				
14/07/2001	1.9	0.0	1	0
10 cm				
13/04/2001	1.9	3.8	1	2
26/05/2001	1.9	0.0	1	0

Table 5.2.21: Classification of Microphytobenthos species recorded in the intertidal sediment of Gorai.

ORDER Centrales

FAMILY Coscinodisceae

SUB FAMILY Skeletonemineae

Skeletonema costatum

Thalassiosira subtilis

Thalassiosira condensate

Thalassiosira gravida

SUB FAMILY Coscinodiscineae

Cyclotella striata

Coscinodiscus lineatus

Coscinodiscus radiatus

Planktoniella sol

SUB ORDER Solenolodeae

FAMILY Eupodisceae

SUB FAMILY Rhizosoleniinae

Rhizosolenia robusta

SUB ORDER Biddulphioideae

SUB FAMILY Biddulphineae

Biddulphia mobilensis

Biddulphia aurita

ORDER Pennales

FAMILY Fragilarioideae

SUB FAMILY Tabellarieae

Licmophora abbreviate

SUB FAMILY Fragilarieae

Fragilaria oceanica

Synedra ulna

Thalassionema nitzschioides

Thalassiothrix frauenfeldii

Table 5.2.21 (Continued...)

SUB ORDER Monoraphideae

FAMILY Achnanθοideae

SUB FAMILY Achnanthaceae

Achnanthes longipes

FAMILY Naviculoides

SUB FAMILY Naviculeae

Mastogloia minuta

Gyrosigma balticum

Pleurosigma normanii

Pleurosigma directum

Diploneis weissflogii

Navicula distans

Navicula membranaceae

Navicula lyra

Navicula closterium

Navicula lanceolata

Stauroneis membranacea

SUB FAMILY Amphiprotoideae

Amphiproto gigantean

SUB FAMILY Gomphocymbelloideae

Cymbella prostrate

FAMILY Nitzschiaceae

SUB FAMILY Nitzschioidae

Nitzschia closterium

Nitzschia sigma

Nitzschia pungens

Nitzschia seriata

FAMILY Surirellaceae

Surirella fastuosa

Surirella elegans

Table 5.2.21 (Continued...)

ORDER Peridinales

FAMILY Peridiniaceae

Peridinium oblongatum

CLASS Cyanophyceae

ORDER Chamasiphonales

FAMILY Oscillatoriales

Oscillatoria formosa

Oscillatoria limosa

Spirulina aeruginea

Class: Chlorophyceae

Order: Chlorococcales

Family: Hydrodictyaceae

Pediastrum boryanum

Table 5.2.22: Correlation matrix for selected parameters at Gorai.

Variable	Correlations (Corrlationmnggorai)										
	Marked correlations are significant at p < .05000 N=28 (Casewise deletion of missing data)										
	AT*	WT	pH	SS (mg/l)	Sal (ppt)	DO (mg/l)	BOD (mg/l)	PO ₄ ³⁻ - P (µmol/l)	NO ₃ ⁻ -N (µmol/l)	NO ₂ ⁻ -N (µmol/l)	NH ₄ ⁺ - N (µmol/l)
WT	.8660	.0000									
	p=.000	p=---									
pH	-.1149	.2789	.0000								
	p=.581	p=.151	p=---								
SS(mg/l)	-.6801	.7033	.2930	1.0000							
	p=.000	p=.000	p=.130	p=---							
Sal (ppt)	.3841	.4721	.0031	-.4731	1.0000						
	p=.044	p=.011	p=.988	p=.011	p=---						
DO (mg/l)	.1317	.1182	.0228	-.2930	.6207	1.0000					
	p=.504	p=.549	p=.908	p=.130	p=.000	p=---					
BOD (mg/l)	.1639	.0648	.0553	-.3037	.5873	.9270	1.0000				
	p=.405	p=.631	p=.780	p=.116	p=.001	p=.000	p=---				
PO ₄ ³⁻ - P (µmol/l)	-.1349	.2462	.1155	.5297	-.3643	-.3140	-.2993	1.0000			
	p=.494	p=.207	p=.558	p=.004	p=.057	p=.104	p=.122	p=---			
NO ₃ ⁻ -N (µmol/l)	-.0858	.2031	.1006	.2859	-.3610	-.2275	-.0757	.3602	1.0000		
	p=.664	p=.300	p=.610	p=.140	p=.059	p=.244	p=.702	p=.080	p=---		
NO ₂ ⁻ -N (µmol/l)	-.2628	.2842	.1009	.6195	-.2829	-.0840	-.0517	.4742	.4656	1.0000	
	p=.177	p=.143	p=.609	p=.000	p=.145	p=.671	p=.794	p=.011	p=.013	p=---	
NH ₄ ⁺ - N (µmol/l)	-.1146	.2059	.2065	.2266	-.5814	-.3274	-.2769	.2220	.3379	.3741	1.0000
	p=.581	p=.293	p=.292	p=.246	p=.001	p=.089	p=.154	p=.256	p=.079	p=.050	p=---
Chlorophyll a(mg/m3)	-.1624	.3456	.0601	.1291	-.6365	-.3102	-.3431	-.1153	-.0420	-.1346	.1777
	p=.409	p=.072	p=.761	p=.513	p=.000	p=.108	p=.074	p=.559	p=.832	p=.495	p=.366

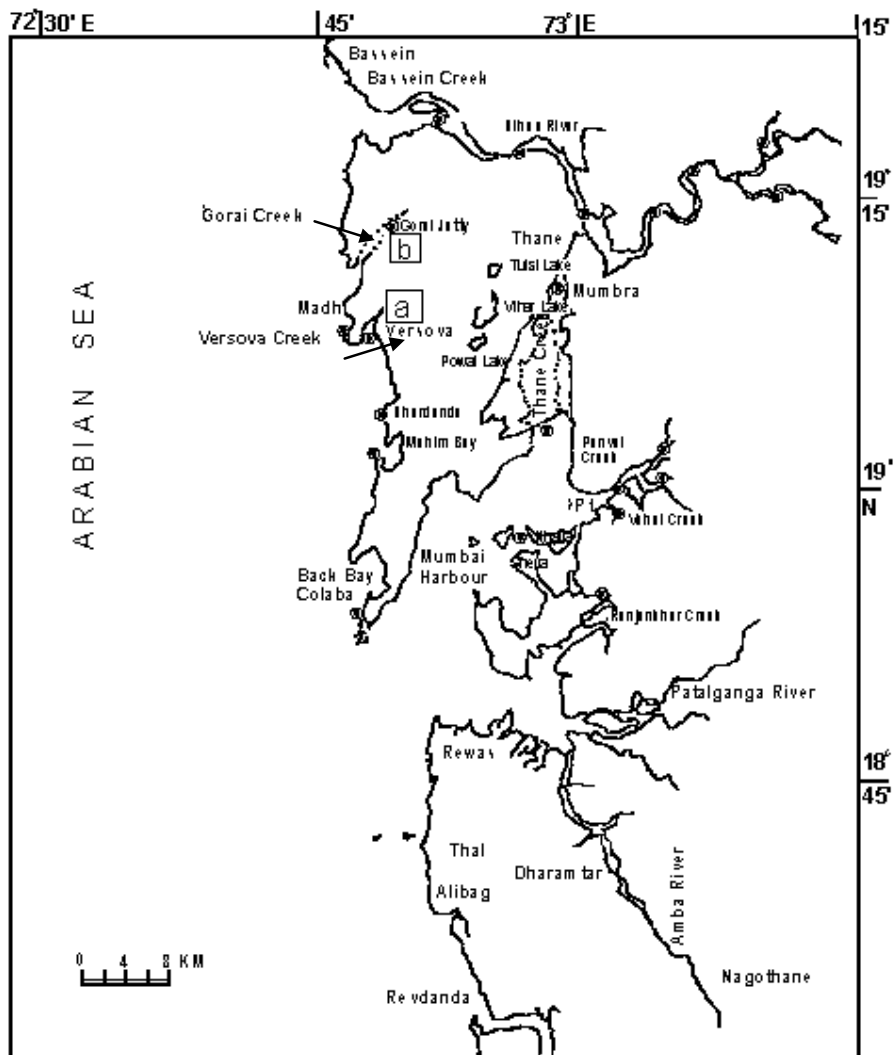


Figure 3.1: Sampling location along Mumbai coast.
a-Versova Creek ; b- Gorai Creek.

Figure 5.1.1: Water quality at Versova during 2000-2001 at Flood.

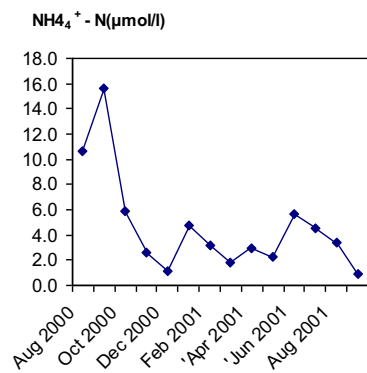
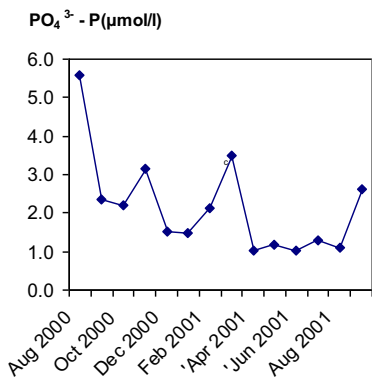
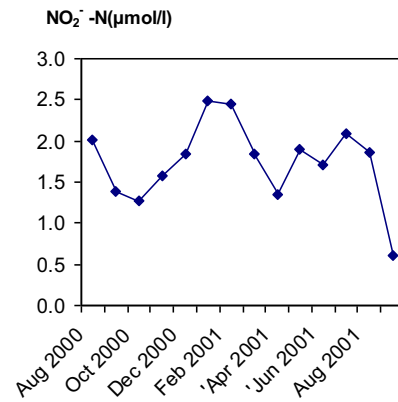
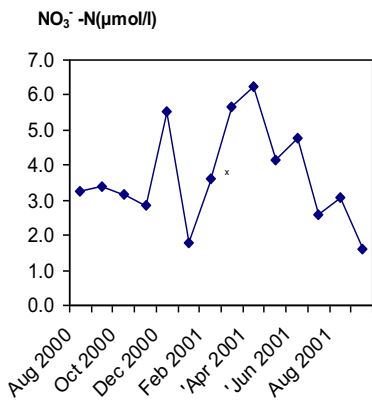
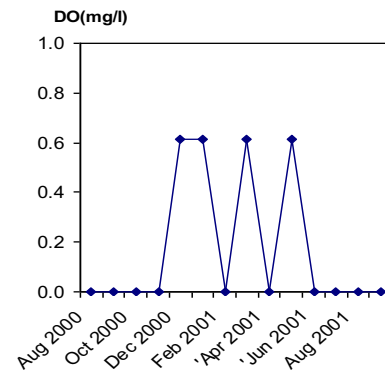
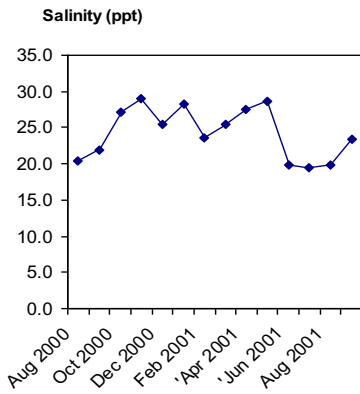
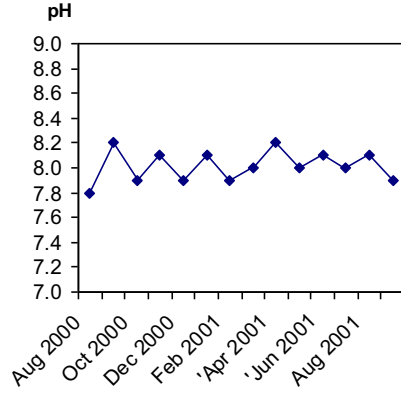
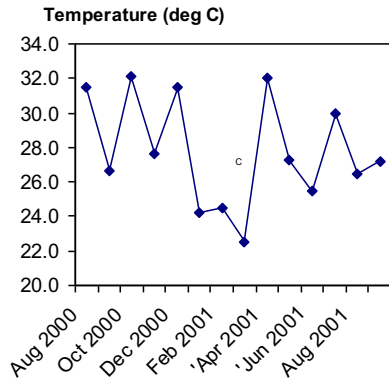


Figure 5.1.2: Water quality at Versova Creek during 2000-2001 at Ebb.

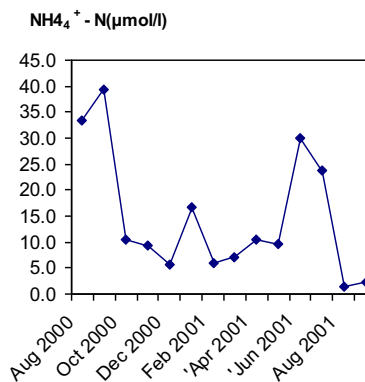
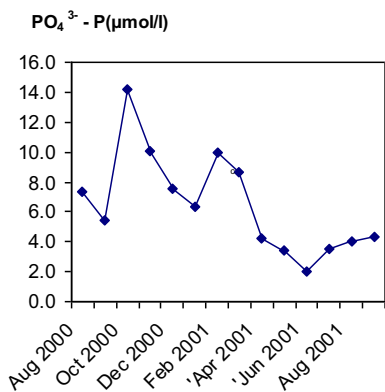
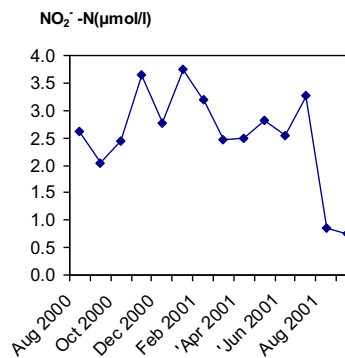
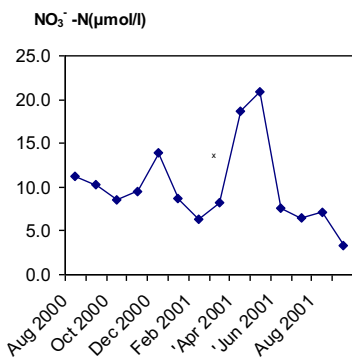
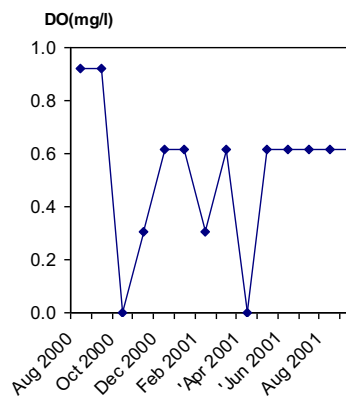
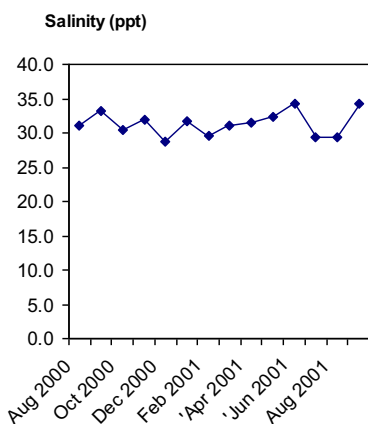
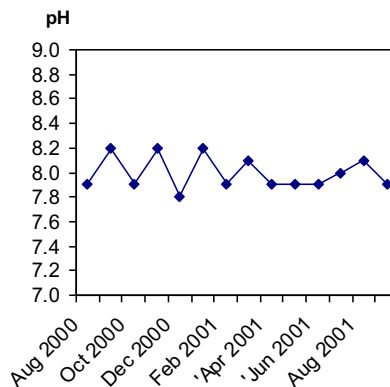
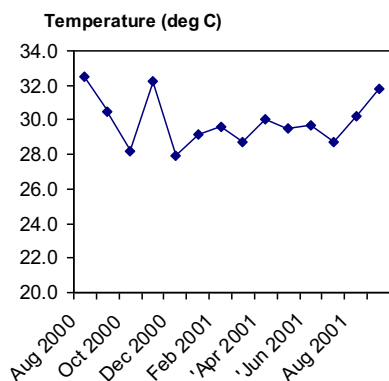


Figure 5.2.1: Water quality at Gorai during 2000-2001 at Flood.

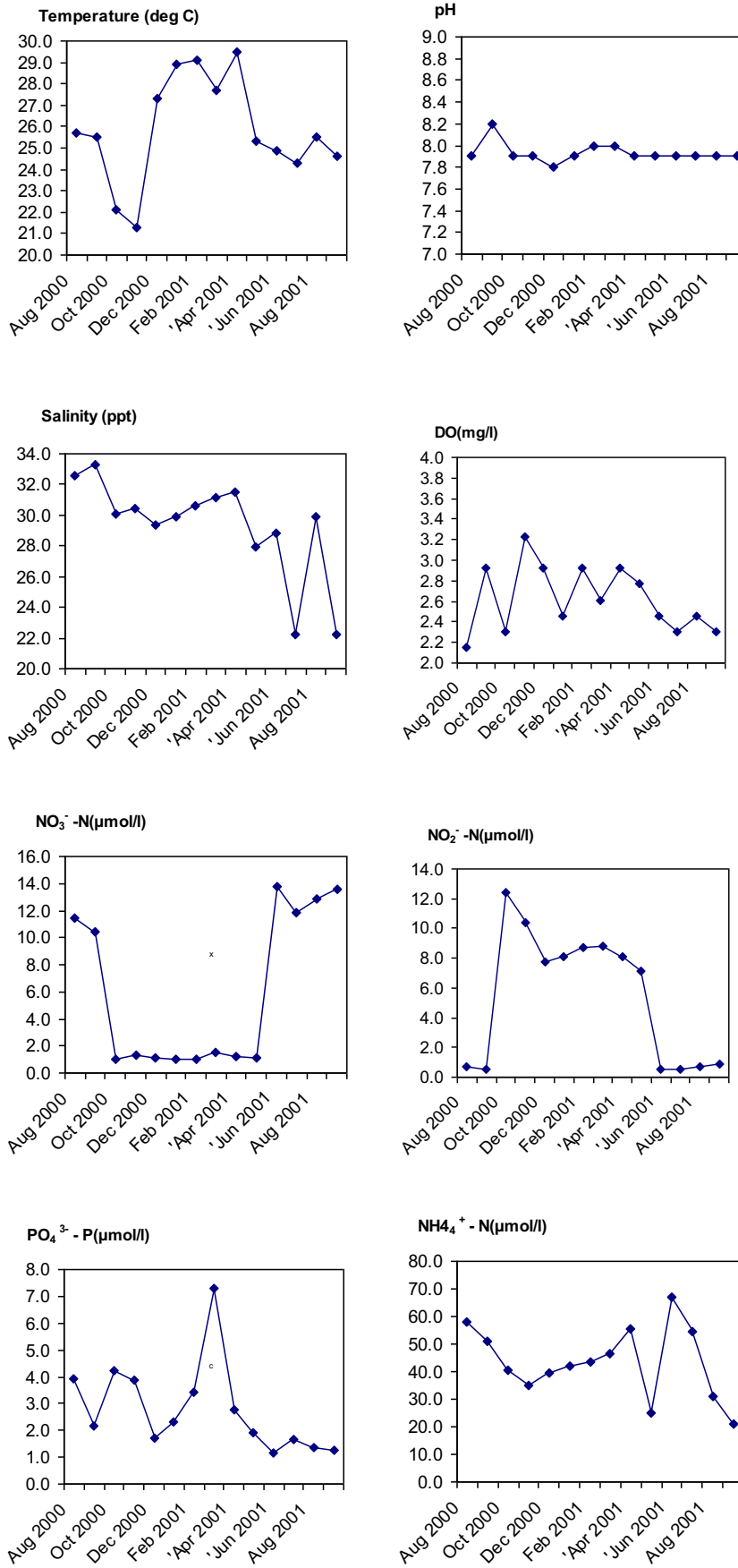


Figure 5.2.2: Water quality at Gorai during 2000-2001 at Ebb.

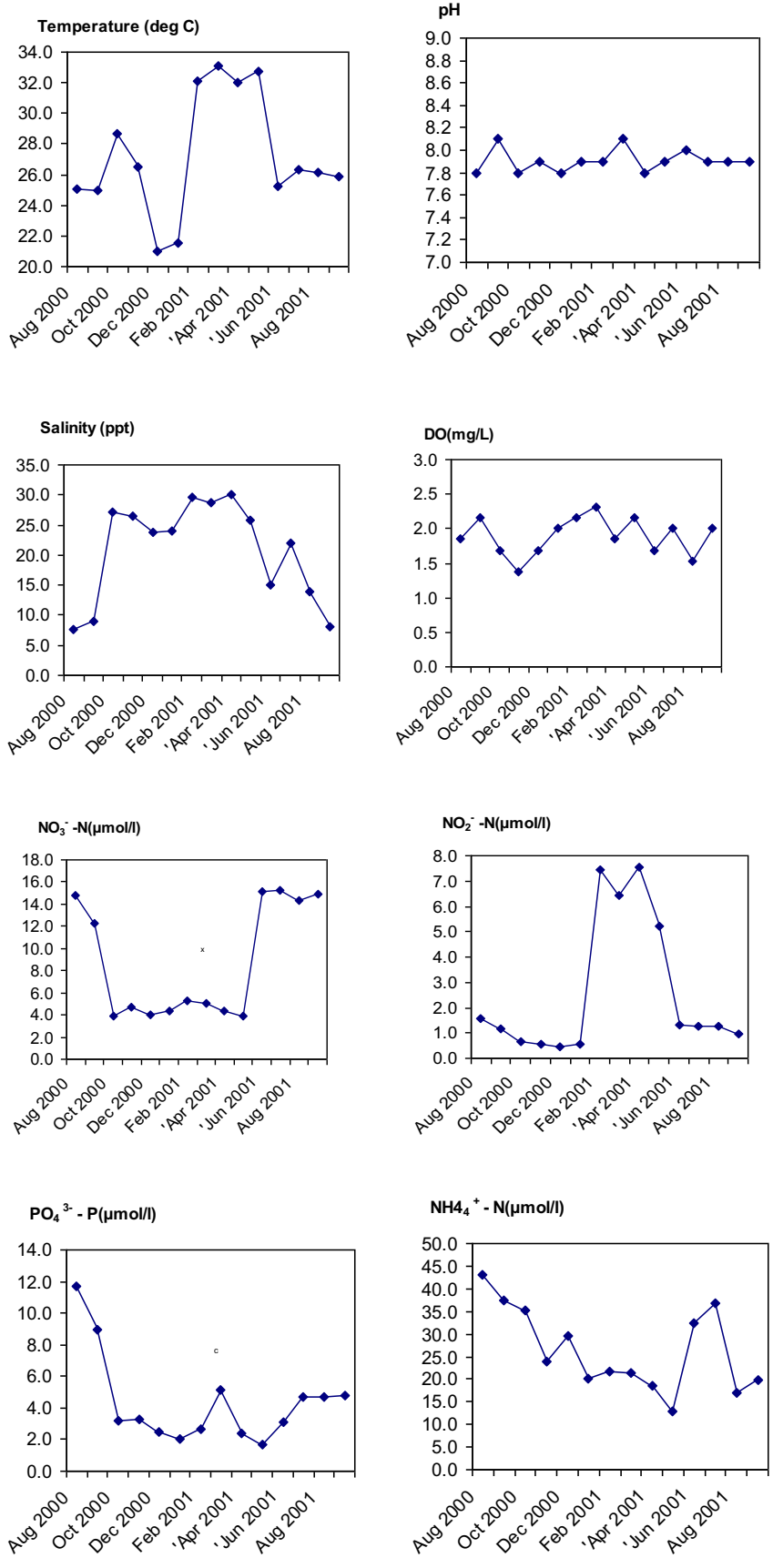


Figure 5.1.3: Depthwise variation in microphytobenthos species at Versova-HWL during study period.

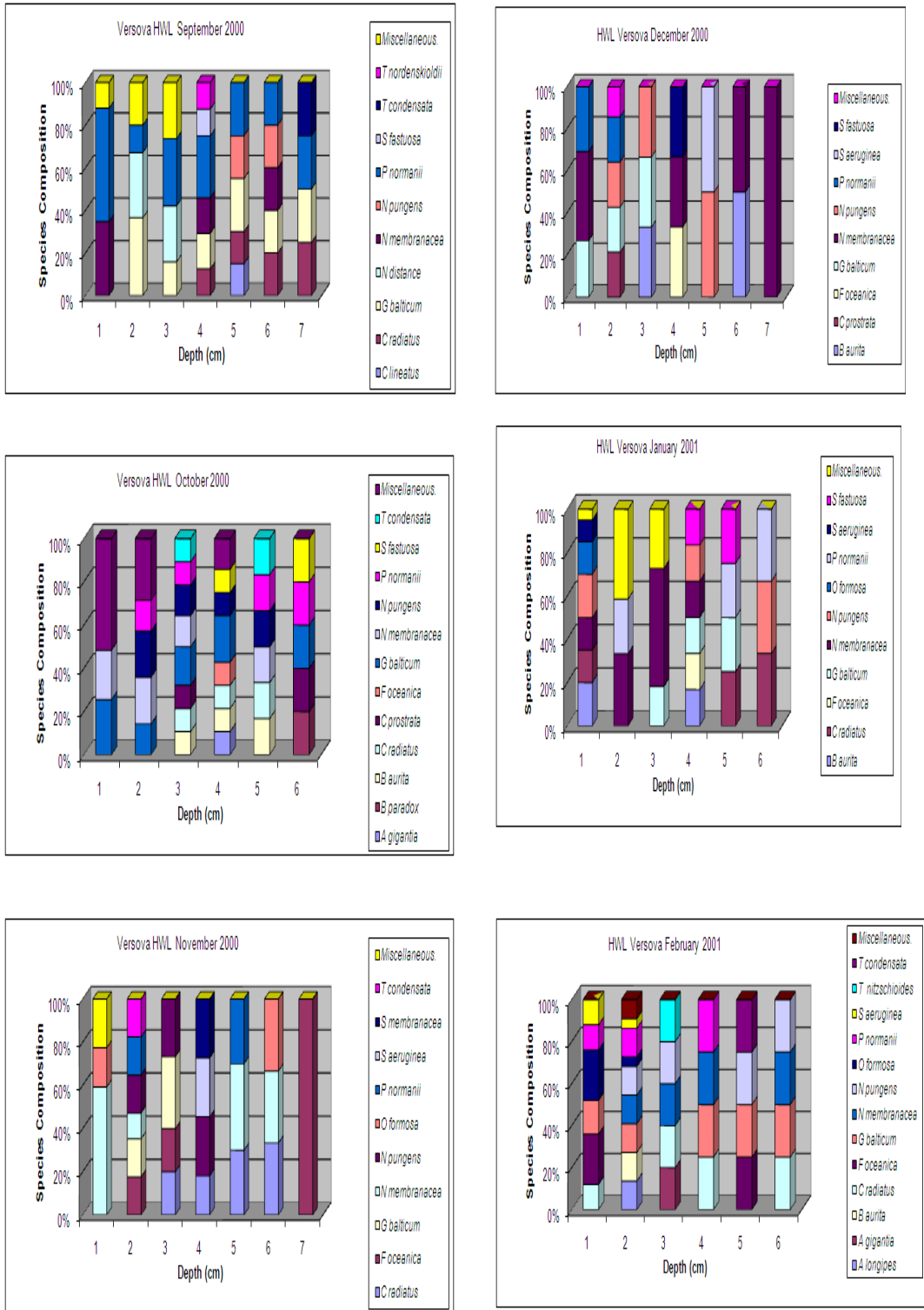


Figure 5.1.4: Depthwise variation in microphytobenthos species at Versova-HWL during study period.

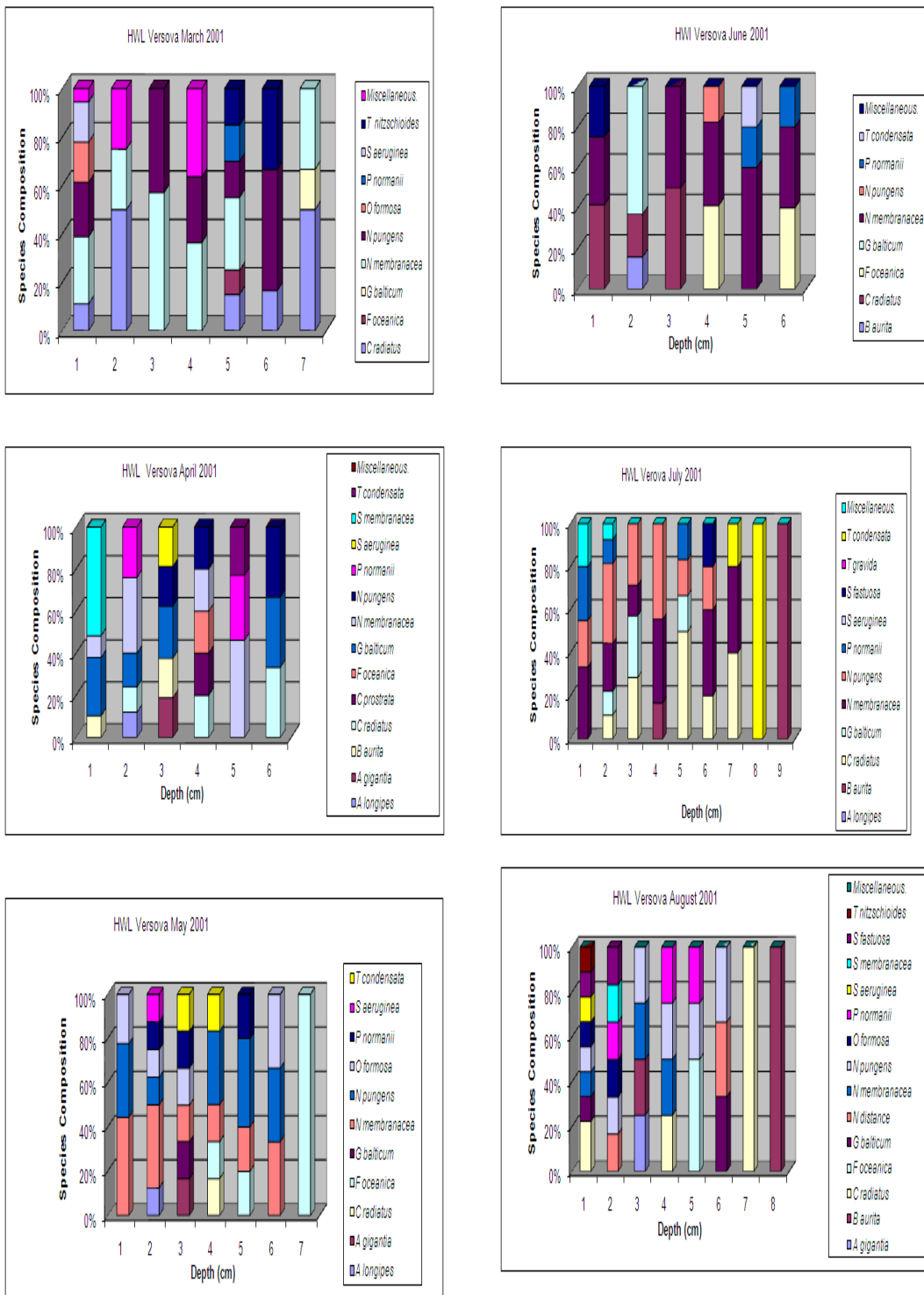


Figure 5.1.5: Depthwise variation in microphytobenthos species at Versova-LWL during study period.

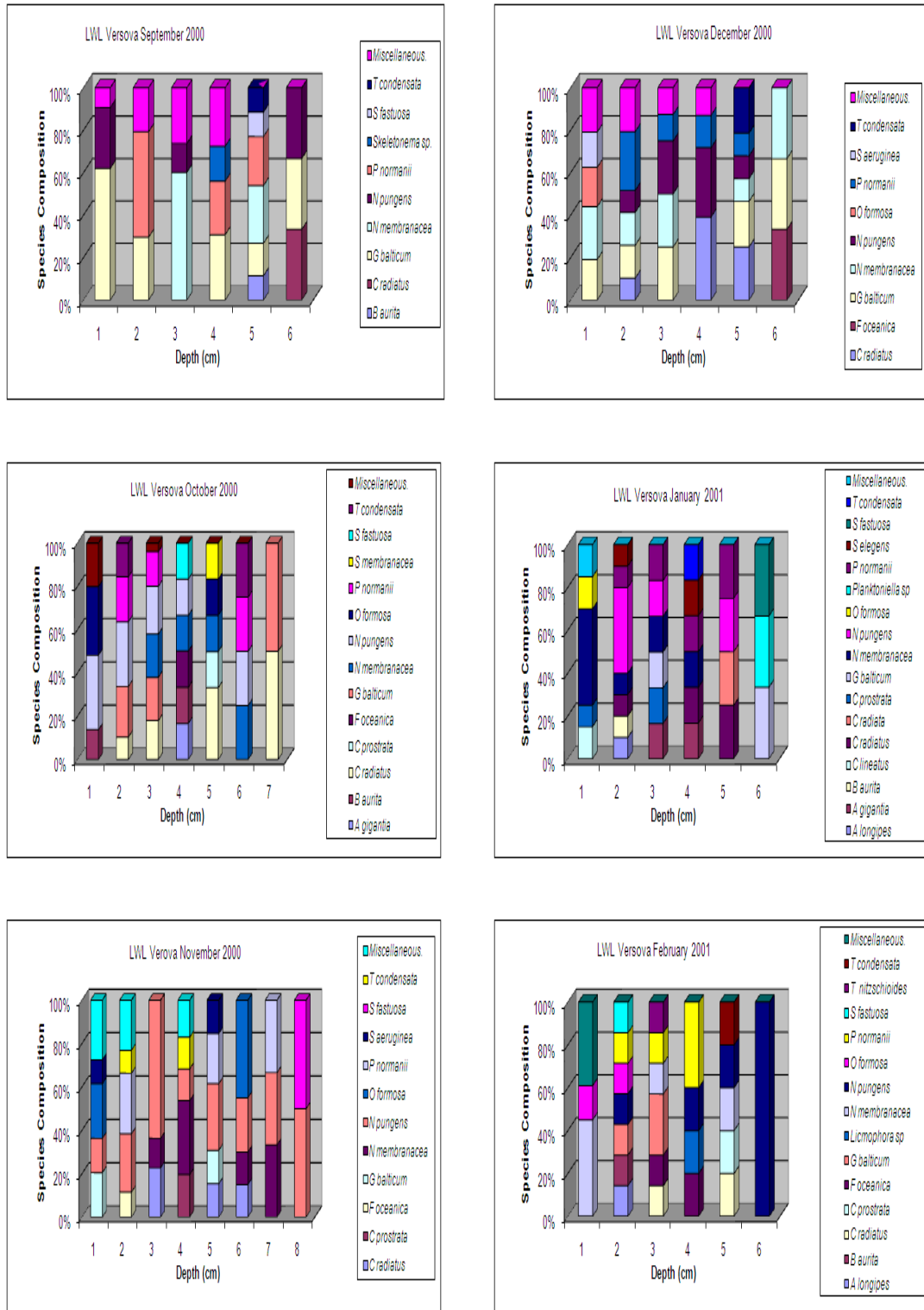


Figure 5.1.6: Depthwise variation in microphytobenthos species at Versova-LWL during study period.

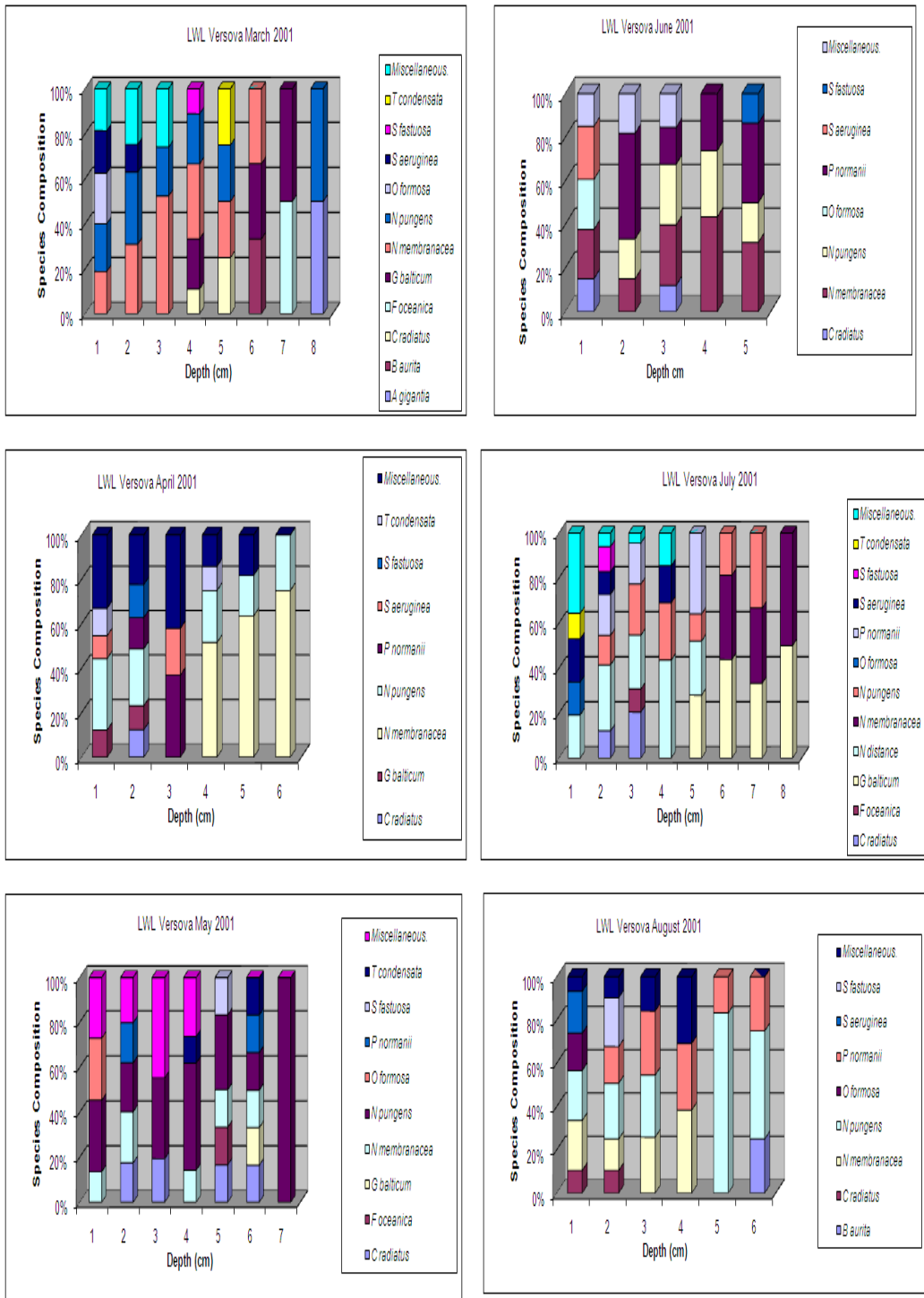


Figure 5.2.3: Depthwise variation in microphytobenthos species at Gorai-HWL during study period.

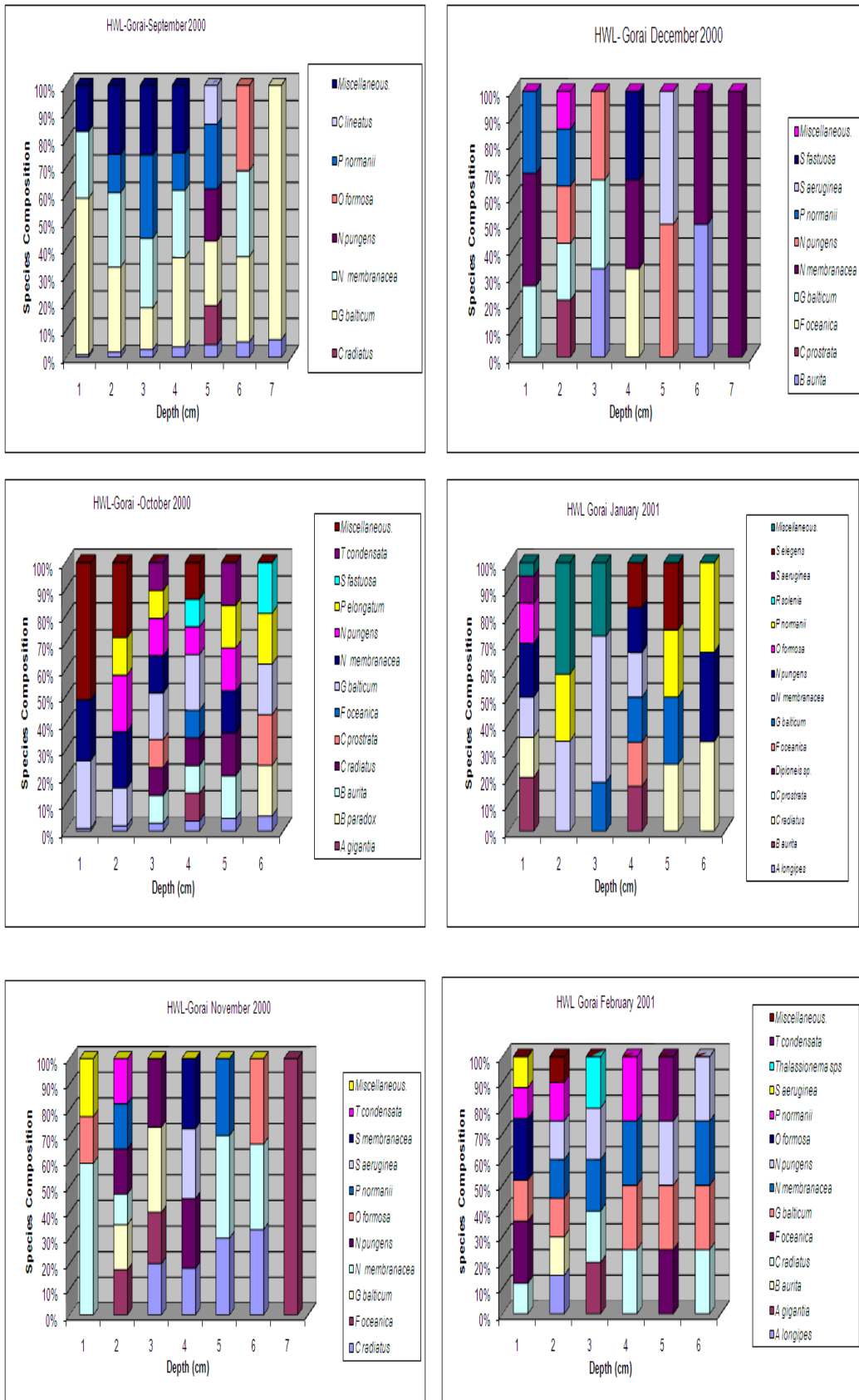


Figure 5.2.4 : Depthwise variation in microphytobenthos species at Gorai-HWL during study period.

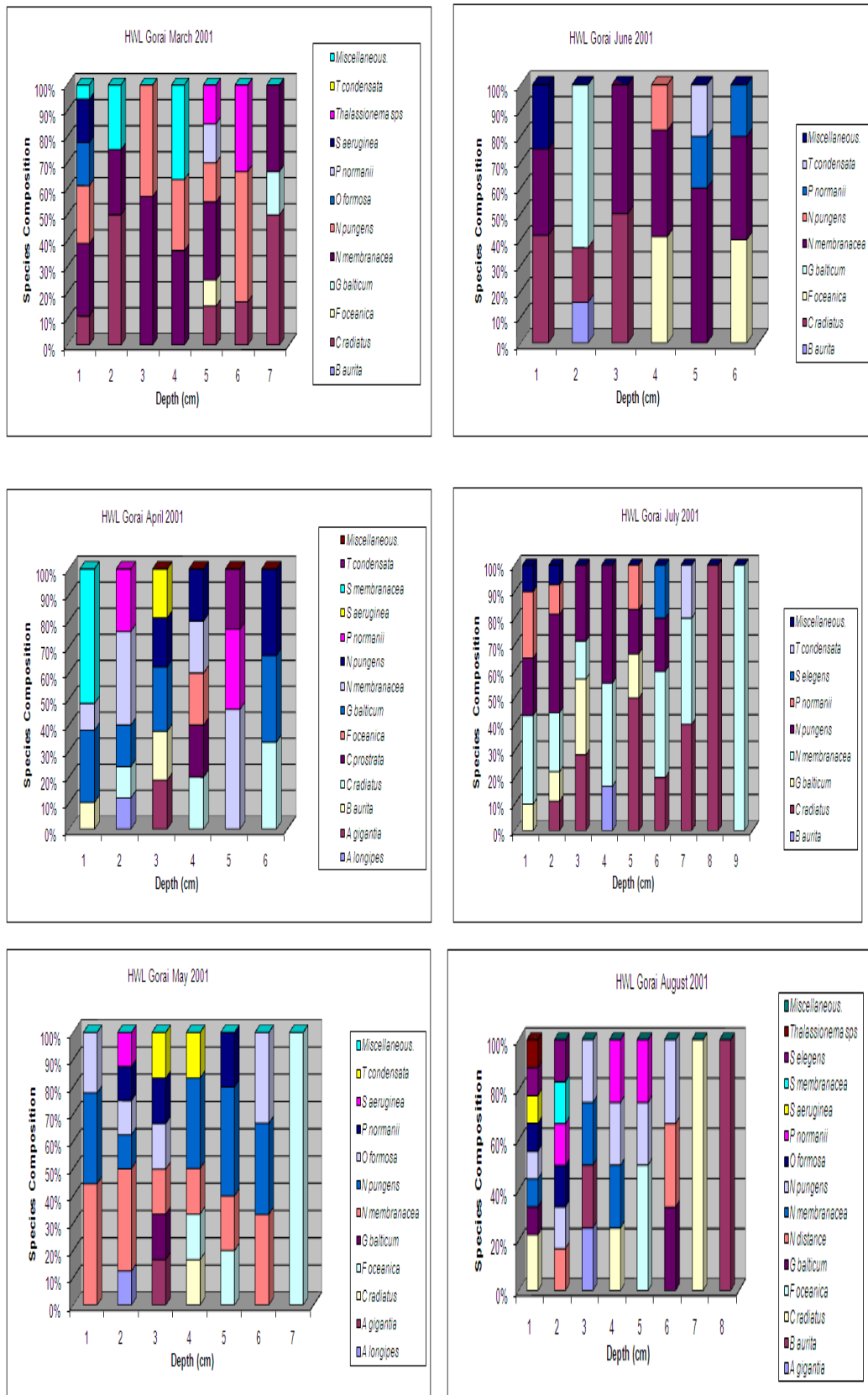


Figure 5.2.5: Depthwise variation in microphytobenthos species at Gorai-LWL during study period.

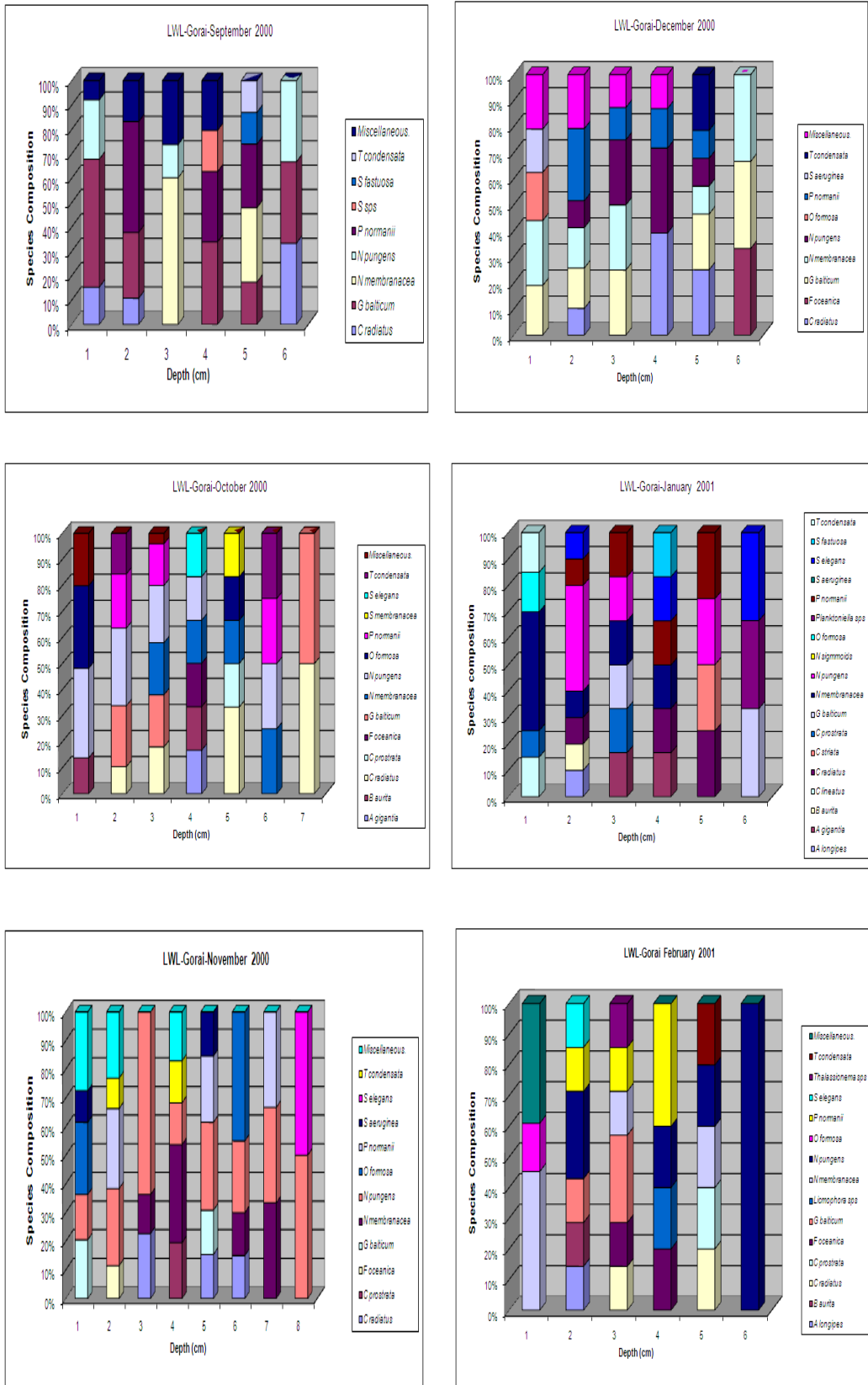
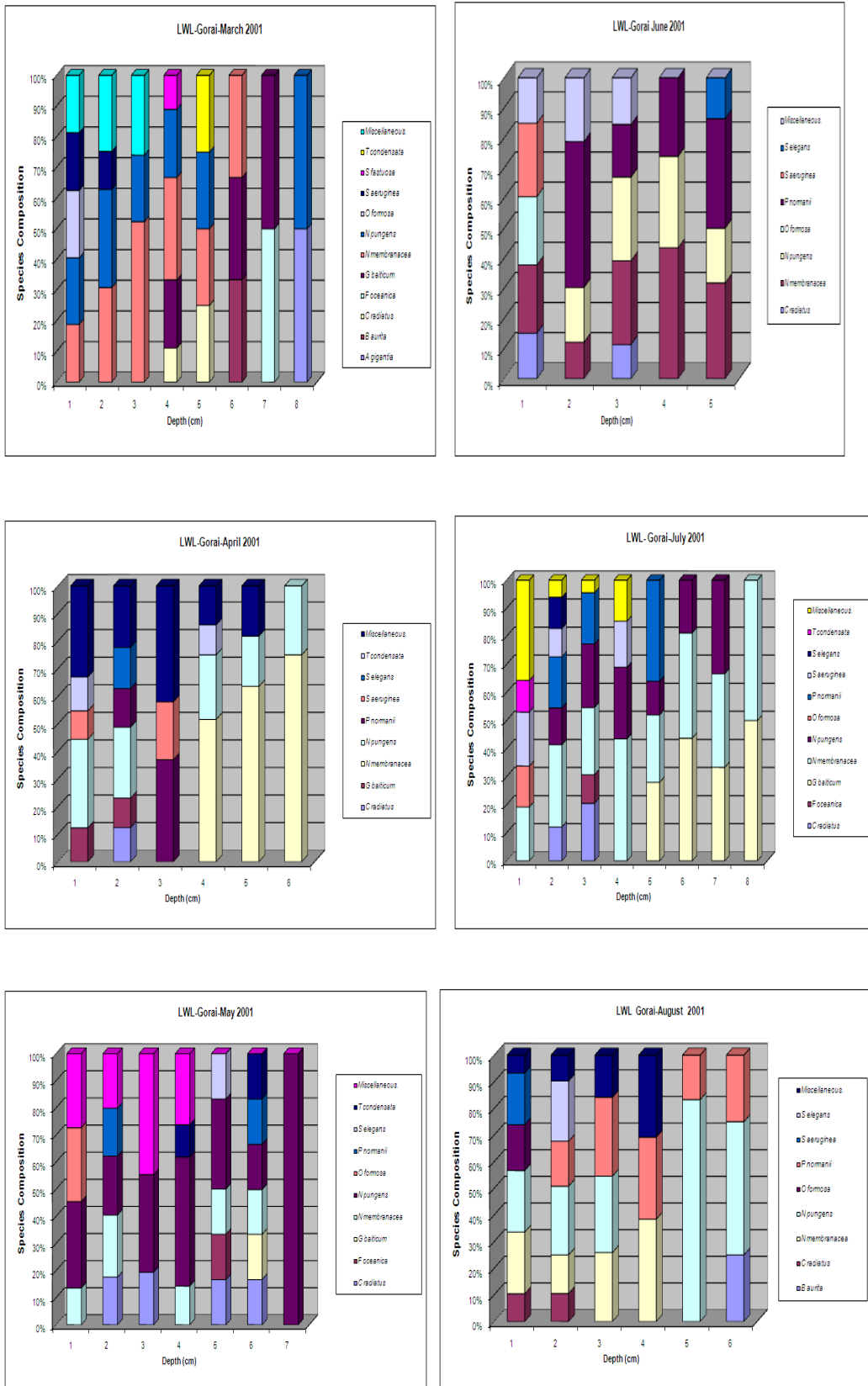


Figure 5.2.6: Depthwise variation in microphytobenthos species at Gorai-LWL during study period.



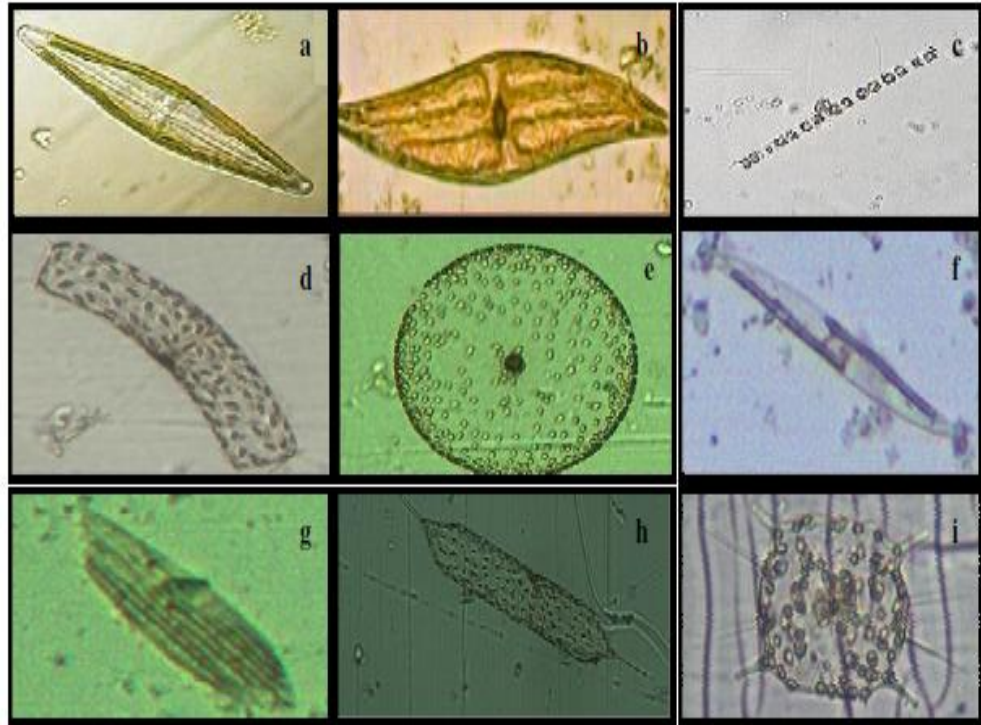


Plate 1:Phytoplanktons observed in overlying water during study.

- a: *Navicula radiosa* ; b: *Pleurosigma normanii* ; c: *Skeletonema costatum* ;
d: *Rhizosolenia stolterforthii* ; e: *Coscinodiscus granii* ; f : *Gyrosigma balticum* ;
g: *Bacillaria paradoxa* ; h: *Rhizosolenia setigera* ; i: *Biddulphia mobiliensis*.

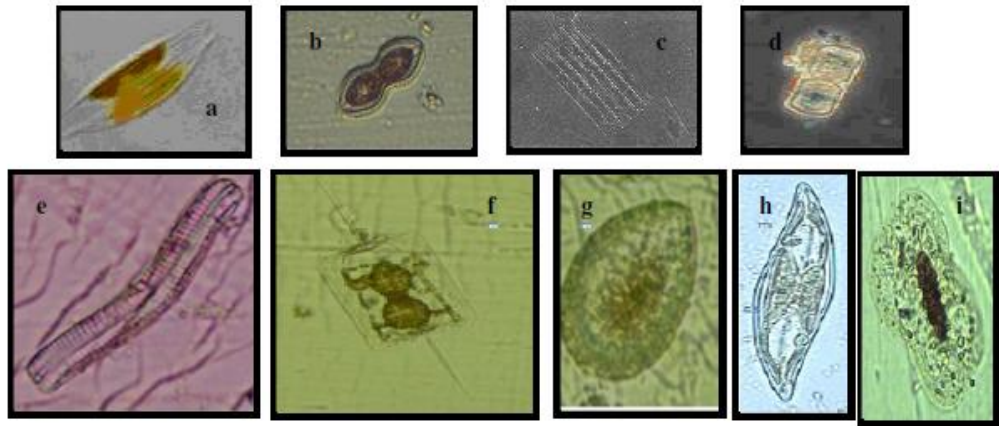


Plate 2: Phytoplankton observed in overlying water during study.

a: *Cymbella prostrata* ; b: *Diploneis weissflogii* ;

c: *Flagilaria oceanica* ; d: *Melosira borrei* ;

e: *Achnanthes longipes* ; f: *Ditylum brightwellii* ;

g: *Surirella fastuosa* ; h: *Pleurosigma normanii* ; i: *Amphiprora gigantea*.

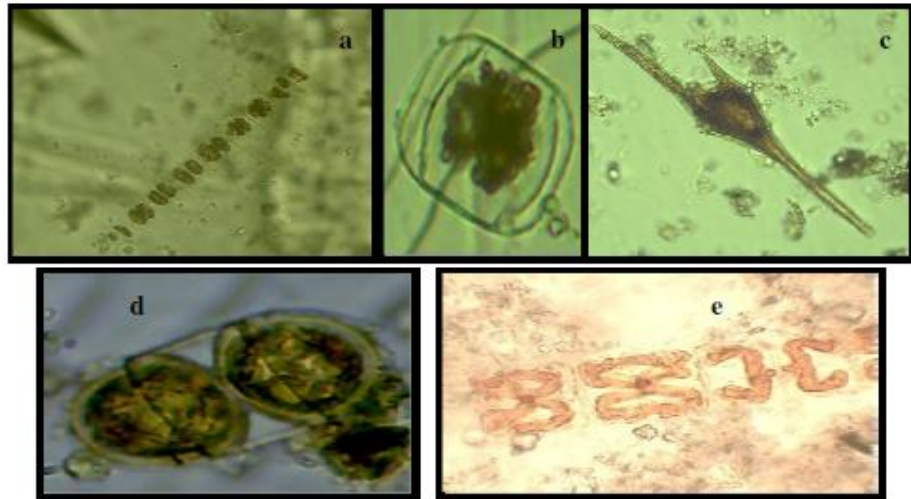


Plate 3: Phytoplankton observed in overlying water during study.

a: *Chaetoceros decipens* ; b : *Hyalodiscus subtilis*;

c: *Ceratium furca* ; d: *Melosira borrei* ;

e: *Navicula membranace* .

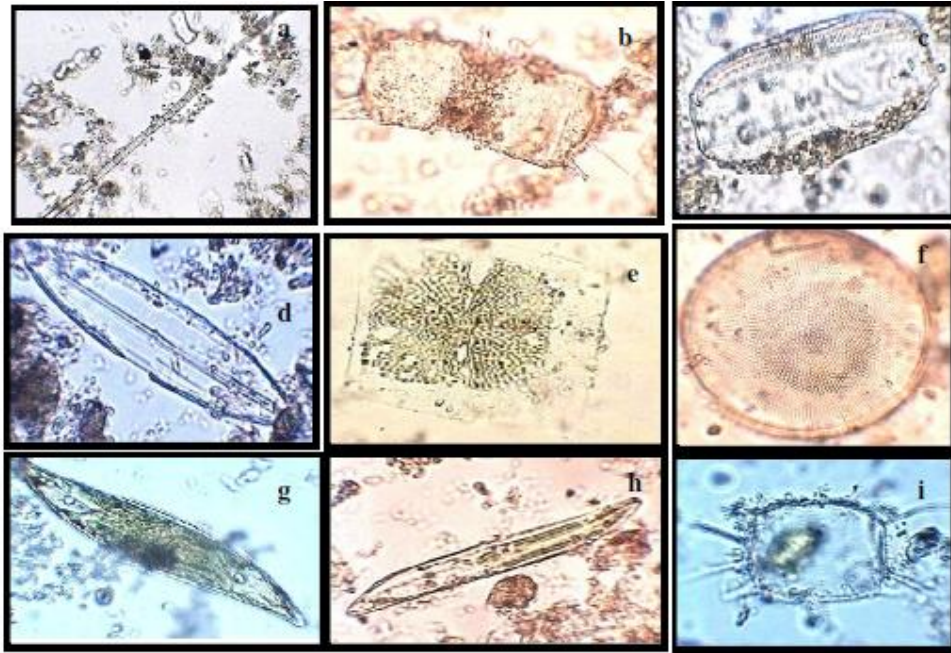


Plate 4: Microphytobenthos observed in sediment during study.

a: *Oscillatoria formosa* ; b: *Biddulphia mobilensis* ;

c: *Thalassiosira gravida* ; d: *Navicula distans* ;

e: *Streptotheca thamensis* ; f : *Coscinodiscus granii* ;

g: *Pleurosigma normanii* ; h: *Gyrosigma balticum* ;i: *Biddulphia mobilensis*

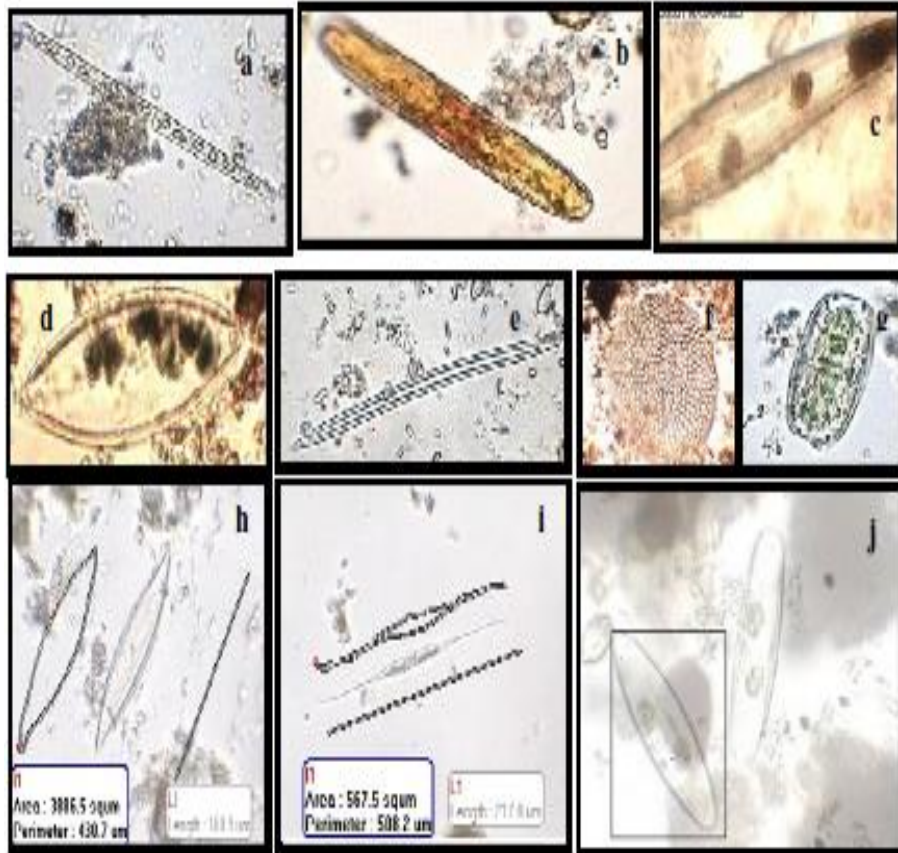


Plate 5: Microphytobenthos observed in sediment during study.

- a: *Synedra ulna*; b: *Navicula closterium* ;
 c: *Stauroneis membranacea* ; d: *Navicula lyra*;
 e: *Nitzschia closterium* ; f: *Coscinodiscus granii* ;
 g: *Navicula distans* ; h : *Navicula lanceolata* ;
 i: *Nitzschia pungens* ; j : *Navicula closterium* .

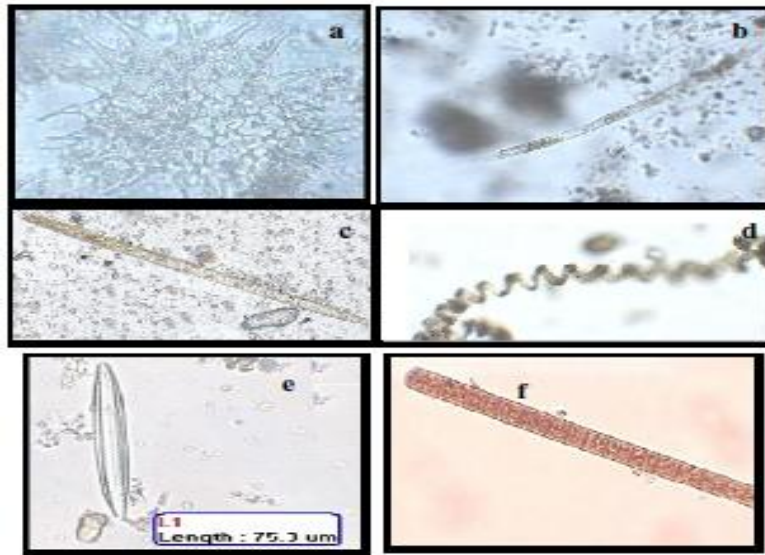


Plate 6 : Microphytobenthos observed in sediment during study.

a: *Pediastrum boryanum* ; b: *Nitzschia seriata*;

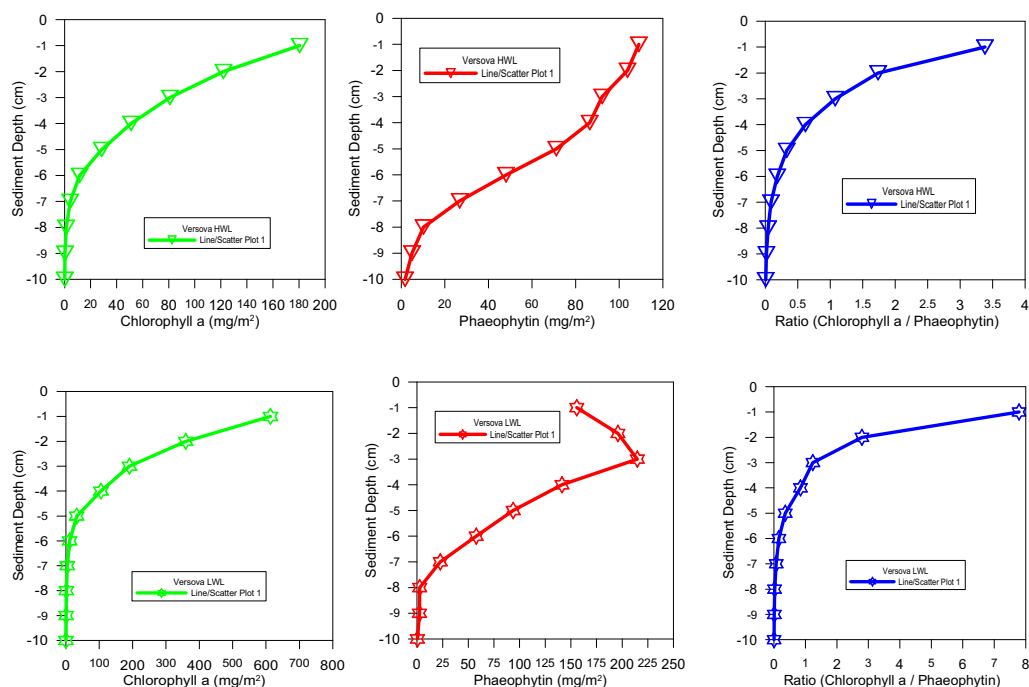
c: *Synedra ulna* ; d: *Spirulina aeruginea* ;

e: *Gyrosigma balticum*, ; f: *Oscillatoria limosa*.

6 Main Findings

6.1 Phaeophytin as a dead pigment

This study is an attempt to integrate the physico-chemical processes with the dynamics of microphytobenthos to understand the status of pigments structure corresponding to the depth of sediments. The results revealed a definite trend of variation of chlorophyll *a* and phaeophytin with respect to sediment depth. The results are recorded at both HWL and LWL are shown in following Figure:

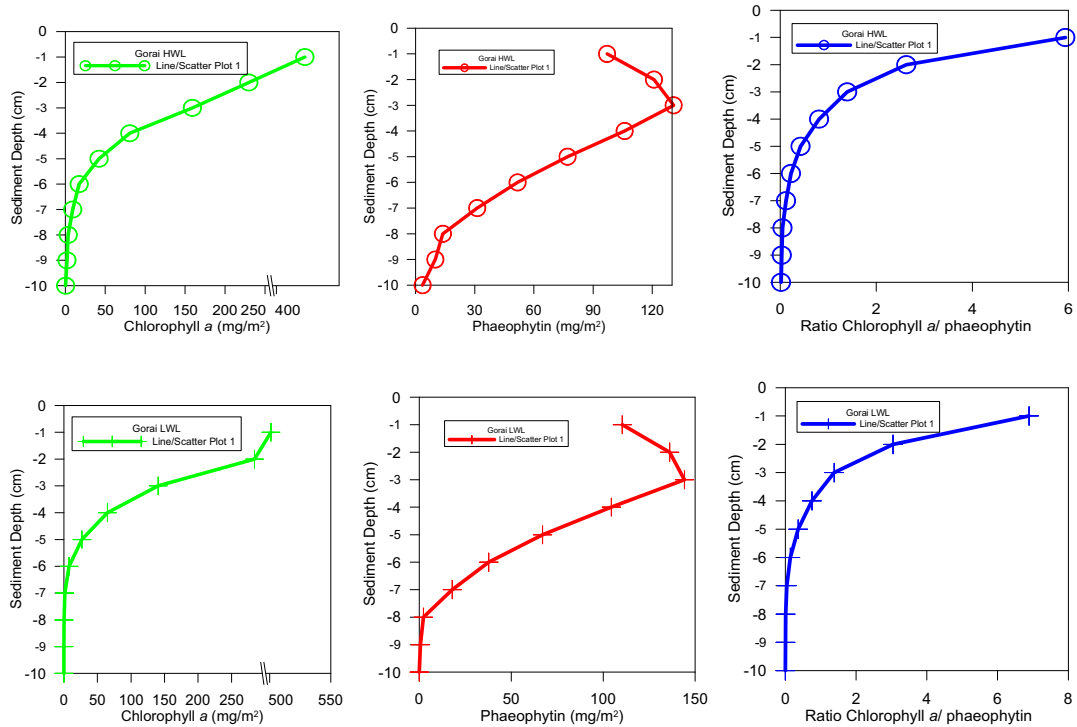


The highest concentration of chlorophyll *a* at superficial layer and gradual decrease following the depth of sediment at Versova revealed a definite trend of variation as evident in the above Figure. It is also evident from the above Figure that the concentration of phaeophytin is highest at superficial layer (1 cm) and maintains the level upto the certain depth (3 cm). Although, the phaeophytin gradually decreases with increasing depth of sediment following the similar pattern as chlorophyll *a*, the ratios (chl *a* /

phae) goes down significantly (<1.0) below the depth of 4 cm which could be due to lower irradiance and an anoxic condition available there.

The superficial layer of sediment exhibits high ratio (av 5.5) of microphytobenthic chlorophyll *a*/ phaeophytin and decreases miserably (av. 0.4) at deeper layer (5 cm) and still lower (av. 0.09) at deepest (10 cm) sediment studied at Versova. This trend clearly suggests that the reduction in pigments following depth of sediment may due to anoxic condition and lack of irradiance at deeper sediments. The reduction in microphytobenthic population with increasing depth similar to pigments may be due to either grazing effect by burrowing organisms or degradation of cells by bacterial activities or miserably poor synthesis of pigments caused by absence of irradiance. However, a hypothesis that the phaeophytin is a degraded product of pigments, can be proved by the present results with higher concentration of chlorophyll *a* than phaeophytin resulting higher (>1.0) ratios at superficial layer whereas, the scenario of pigment's structure at deeper layer is reverse with miserably declined chlorophyll *a* and comparatively increased phaeophytin resulting significantly poor ratios (0.01-0.1) corresponding to the depth of sediment which may be due to grazing effect by burrowing organisms or degradation of cells by bacterial activities or miserably poor synthesis of chlorophyll *a* caused by absence of irradiance.

An attempt in this thesis is also made to ascertain the above hypothesis by the results recorded at Gorai. The results of microphytobenthos chlorophyll *a* and phaeophytin observed at Gorai are illustrated in the following Figure:

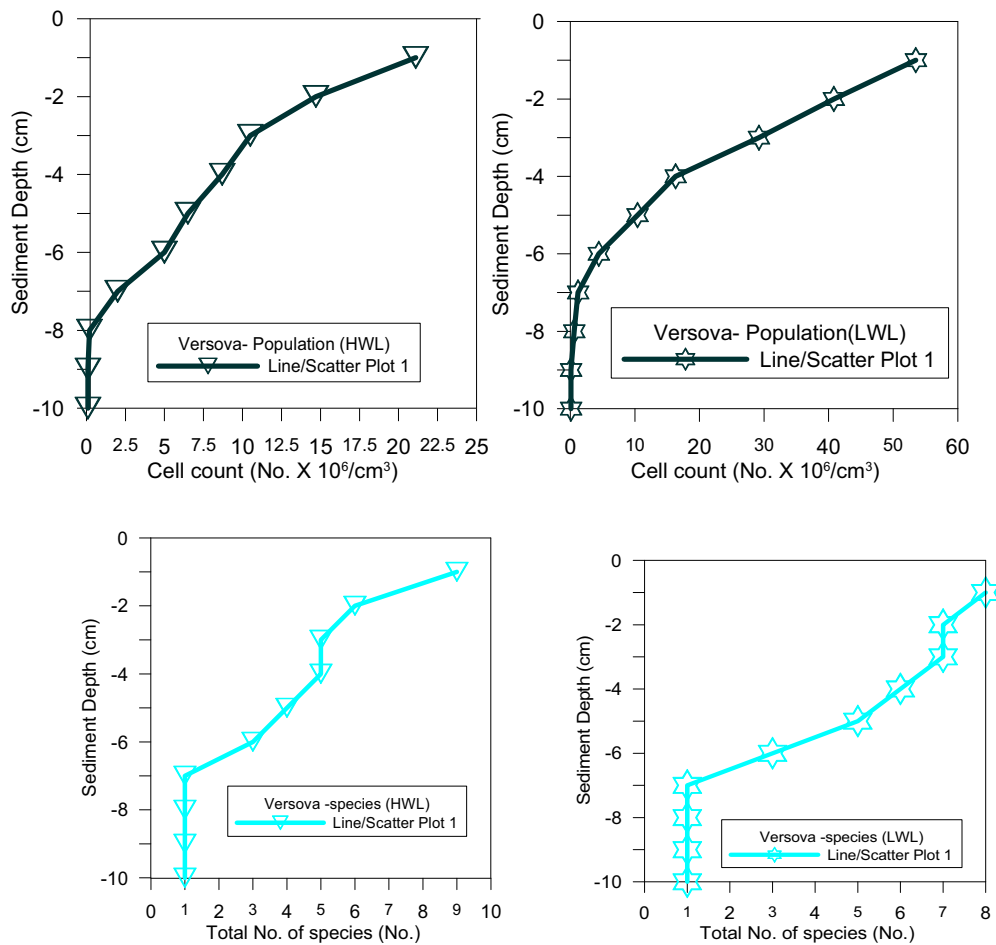


The above Figure again gives a clear idea of degradation of microphytobenthic pigments with increasing depth of sediments. It is evident in the above Figure that there is a sharp decrease in the concentration of chlorophyll *a* from superficial layer to the deeper layer of sediments. The scenario of phaeophytin is slightly different showing an increase in the concentration upto the depth of 3 cm and abrupt decline following the depth of sediment. The above Figure is also indicative of a definite structure of ratios of microphytobenthic chlorophyll *a* / phaeophytin showing miserably poor condition at deepest layer. Thus the decreasing concentration of microphytobenthic chlorophyll *a* as compared to phaeophytin corresponding to depth of sediment resulting significantly poor ratio can be referred as degradation of chlorophyll *a* to phaeophytin which may be the consequences of grazing by benthic organisms or diagenesis of cells by bacterial activities or lack of irradiance. Hence, significantly lower concentration of microphytobenthic chlorophyll *a* than phaeophytin resulting miserably poor ratios of these pigments at deeper layer of sediment is an

indicative of physiologically an unhealthy condition of microphytobenthic cells and also suggests phaeophytin as a degraded or dead pigment.

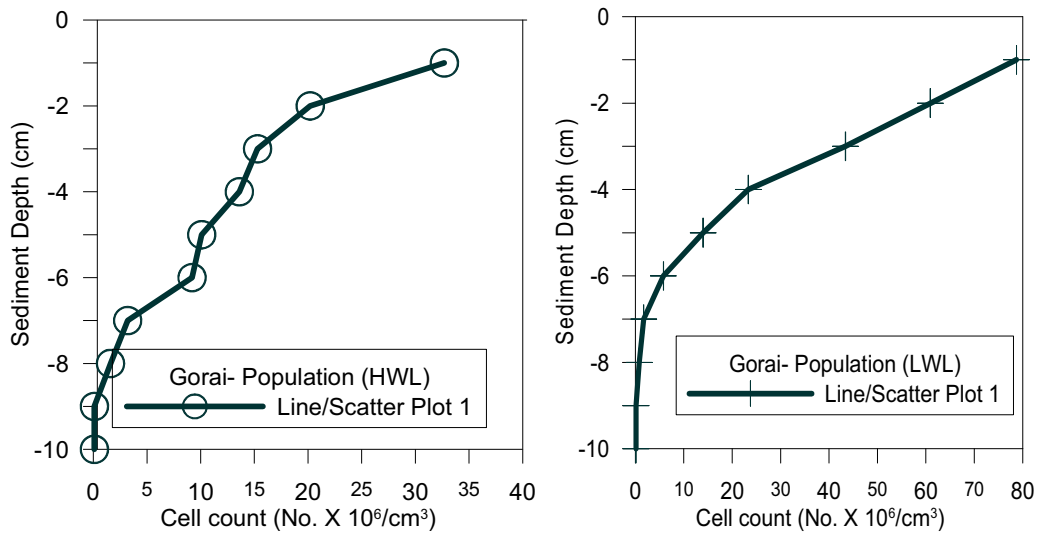
6.2 Pigments associated with population corresponding to sediment depth.

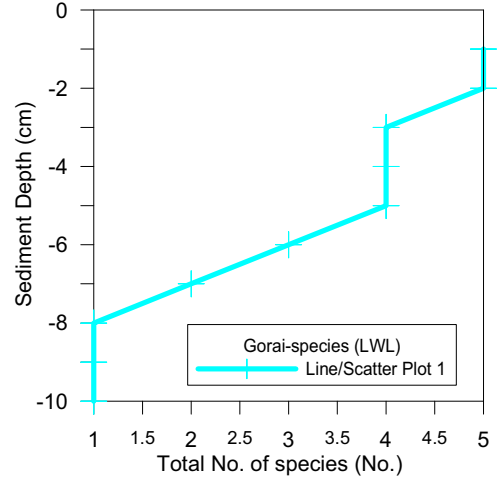
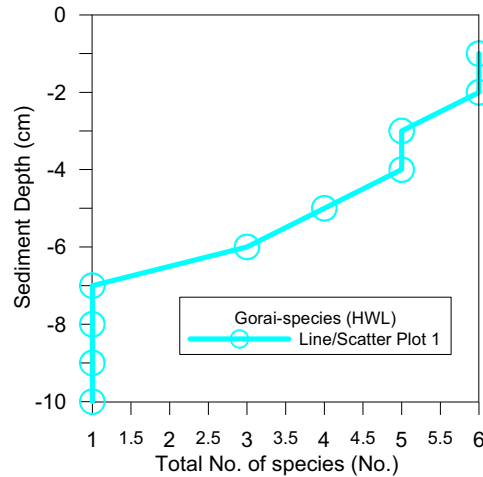
The gradual decrease in microphytobenthic pigments corresponding to depth of sediment is seen to be associated with declining population of microphytobenthos following the depth of sediment. The overall structure of microphytobenthic population at different depth of sediment at both HWL and LWL are shown in the following Figure:



Following the similar trend of variation as pigments, the cell count of microphytobenthos is also seen in highest number at superficial layer and gradual decrease with the increasing depth of sediment at both HWL and LWL of Versova. It is also discernible from the above Figure, that there is a sharp decrease in the microphytobenthic population below 6 cm of depth following the similar trend of variation as pigments. Thus, the present results confirm that the gradual decline of pigments is due to microphytobenthic population decreasing gradually with increasing depth of sediment.

The same pattern of vertical distribution of microphytobenthic population can also be seen at Gorai in the following Figure:



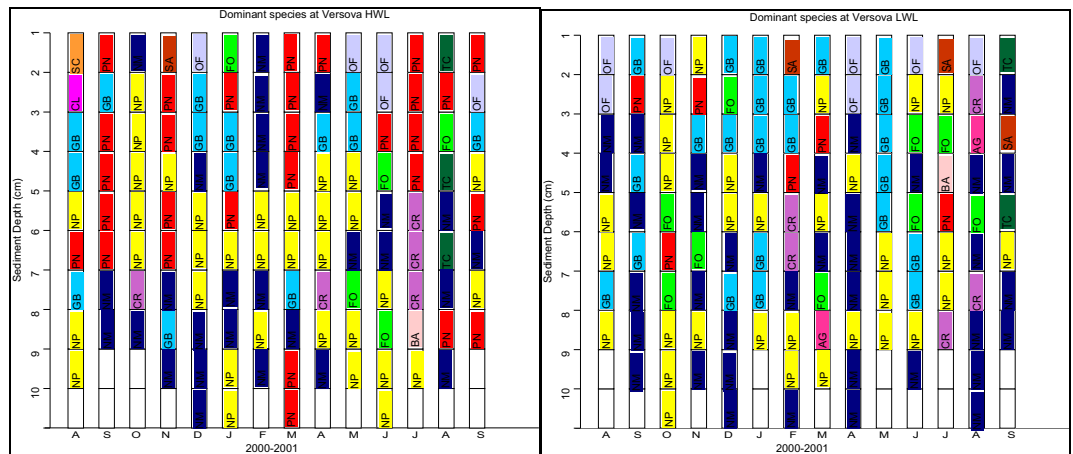


The above Figures clearly shows that the decreasing trend of microphytobenthic population corresponding to depth of sediments follows the similar pattern as pigments which is already explained in the Section 6.1.

Hence, the present investigation confirms that the gradual reduction in the pigments with increasing depth of sediment is due to decreasing trend of microphytobenthic population. This may be due to the fact that there are only certain microphytobenthic species which are getting burrowed by the burrowing organisms. The other species existing at superficial layer at sediment may not be able to survive in the condition of lack of irradiance and poor oxygen level and high grazing pressure.

6.3 Hardy species of microphytobenthos

The present result gives an idea of a definite community structure of microphytobenthos. The percentage composition studied continuously for 14 months are worked out separately to assess the microphytobenthic community structure corresponding to different depths of sediment and presented below:

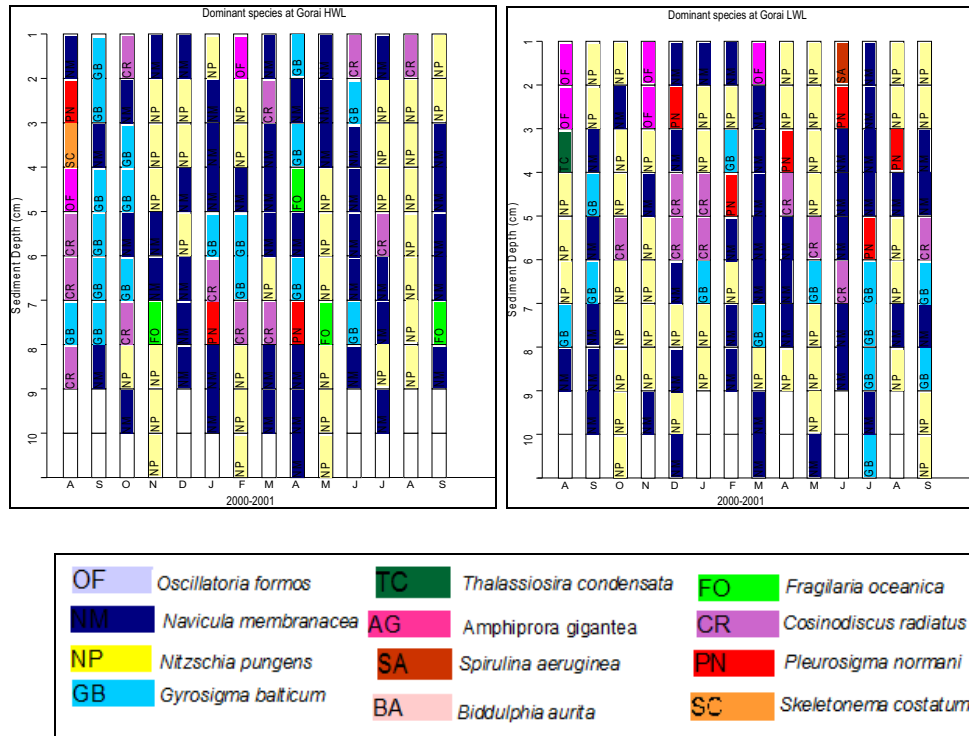


The above Figure clearly suggests a definite community structure of microphytobenthos corresponding to the depth of sediments. It is conspicuously discernible in the above Figure that superficial layer of sediment exhibits the dominance of *Skeletonema costatum*; *Pleurosigma normanii*; *Oscillatoria formosa*; *Fragilaria oceanica*; *Spirulina aeruginosa*; *Thalassiosira condensata*; and *Navicula membranacea* during different month at HWL. Scenario at deeper layer below 4 cm does not remain same. The microphytobenthic community structure at 5 cm depth of sediment reveals that there are only a few species viz., *Nitzschia pungens*; *Pleurosigma normanii*; *Navicula membranacea*; and *Coscinodiscus radiatus* which are burrowed by the benthic organisms. Microphytobenthic community structure at 9 cm depth of sediment is again quite different with the dominance of *Navicula membranacea*; *Nitzschia pungens* and *Pleurosigma normanii* in the order of dominance. However, the results of community structure at 10 cm depth of sediment reveals the presence of only *Nitzschia pungens* and *Navicula membranacea* which indicates that the burrowing organisms could bring only a few species to the deeper layer

of sediment. Thus, indicates that *Nitzschia pungens*; *Navicula membranacea* may be the hardiest species of microphytobenthos which could survive at the depth where grazing pressure is high with anoxic condition and unavailability of irradiance. The depth, to which these microphytobenthic species burrow, depends upon the status of texture of sediment. If the sediment is clayey the microphytobenthic species are burrowed to deeper layer than the one with the sandy sediment.

The overall vertical distribution of microphytobenthic species is also studied at LWL of Versova and the similar scenario is discernible in the above Figure. The Figure of community structure at LWL clearly shows that there are only certain species like *Navicula membranacea* and *Nitzschia pungens* which are burrowed at the deeper layer (below 8 cm) of sediment. Thus the results of present thesis establish a fact that the filamentous microphytobenthic species such as *Oscillatoria formosa* and *Spirulina aeruginosa* and the chain forming microphytobenthic species viz., *Skeletonema costatum*, *Fragilaria oceanica* and *Thalassiosira condensata* cannot be burrowed very deep in the sediment by the burrowing organisms. The existence of *Navicula membranacea* and *Nitzschia pungens* at the depth of 10 cm of sediment during LWL of Versova could be due to secretion of mucilage facilitating them to move towards deeper sediment with action of burrowing organism. This indicates the hardy nature of these microphytobenthic species.

The results of community structure of microphytobenthos recorded during present study at Gorai also ascertain the hardy nature of certain species of microphytobenthos which are shown in the following Figure:



The community structure of microphytobenthos at Gorai is exhibiting the similar pattern of vertical distribution as Versova. Thus this thesis confirms the fact that there are number of species such as *Oscillatoria formosa*, *Gyrosigma balticum*, *Nitzschia pungens*, *Navicula membranacea*, *Spirulina aeruginosa*, and *Coscinodiscus radiatus* thriving in superficial layer of sediment at both HWL and LWL. But this scenario of microphytobenthic community structure changes at deeper layer (5 cm) of sediment exhibiting only a few species viz., *Nitzschia pungens*; *Pleurosigma normanii*, *Gyrosigma balticum*, *Navicula membranacea*, and *Coscinodiscus radiates*. The community structure of microphytobenthos at 9-10 cm depth of sediment at Gorai is similar to that of Versova and again is very specific which has come out with the fact that there are only a few species like *Nitzschia pungens* and *Navicula membranacea* which secrete mucilageous substances to facilitate them to move at deeper layer of sediment by the action of burrowing organisms. Thus the present results confirms that *Nitzschia pungens* and *Navicula membranacea* may be the hardiest species of microphytobenthos and survives at the deeper layer of

sediment inspite of high grazing pressure, unavailability of irradiance and anoxic condition.

6.4 Carbon Sinking

Organic carbon produced during the process of microphytobenthic primary production is the driver for maintenance of metabolism and production of new algal cells, but nutrient depletion in dense diatom biofilms may cause unbalanced growth and result in over-production and excretion of carbohydrates (de Winder *et al.*, 1999). If 30–60% of the total microphytobenthic carbon fixation is excreted as Extracellular Polymeric Substances (EPS) near the sediment–water interface (Taylor and Paterson, 1998; Goto *et al.*, 2001; Smith and Underwood, 2000), the heterotrophic microbial community will be fuelled by a progressively larger pool of very labile substrates with time under light exposure. Such light stimulating respiration must be considered in estimation of gross primary production (Fenchel and Glud, 2000). The carbon uptake by microphytobenthos, which acts as a tool in carbon cycle can be considered an important component to evaluate the atmospheric carbon budget.

Phytoplankton play an important role in regulating atmospheric carbon cycle by uptake of carbon dioxide from atmosphere through water atmosphere interference and transporting the carbon to the sea bottom through sinking process after the death of cells and thus are importantly known for controlling global warming. Similarly the role of microphytobenthos is well described (de Jonge V N (1980); Grant J (1984); Cibic T, 2007) for transporting the carbon, from sediment-atmosphere interference, to the bottom sediment and playing an important role in balancing the atmospheric carbon cycle related to global warming. The present study is also aimed to assess the total carbon transport from superficial layer to the bottom sediments in unit area which would give an

idea of the role of microphytobenthos in carbon sinking at Versova. For this purpose, microphytobenthic carbon was estimated using a C: Chlorophyll *a* ratio of 40:1, described by de Jonge, 1980.

Considering average biomass from Versova (Chl *a* 396.8 mg/m²) and Gorai (Chl *a* 456.2 mg/m²), the overall average microphytobenthic chlorophyll *a* of 426.5 mg/m² in sediment of the intertidal area is estimated. By using the above ratio the total microphytobenthic carbon (C) was estimated for intertidal area of Mumbai. In the total intertidal area of Mumbai of 165 Km in length and 0.150 Km width, the total carbon (c) transport is estimated to be 41×10^5 tons in sediment. Hence, microphytobenthos can be considered playing a significant role in Carbon cycle.

Some authors have calculated cell carbon in microphytobenthic algae by using cell counts (Strathmann 1967, Cibic T, 2007). Cibic T, (2007). Strathmann, (1967) has calculated the carbon content ($\mu\text{g C}$) of microalgae by the transformation of cell volume to plasma volume, including an estimate of the vacuole volume, and the calculation of cell carbon was estimated based on the plasma volume multiplied by a factor of 0.11 for diatom cells and phytoflagellates.

Based on factors of cell volume and the average microphytobenthic cell count at Versova and Gorai the total carbon sink was estimated. Considering average cell count at Versova (av 38.0 No. $\times 10^6$ cells / cm³) and Gorai (av 55.7 No. $\times 10^6$ cells / cm³), the average would be 46.9 No. $\times 10^6$ cells / cm³ of microphytobenthos in sediment of the intertidal area. Accordingly, considering the total length of intertidal zone of Mumbai of 165 Km with the width of 0.150 Km, the total carbon transport due to sinking of microphytobenthic algae, would arrive to the value of 128×10^5 t C into sediment of the intertidal area.

Similarly the carbon sinking or carbon transport from atmosphere to the bottom sediment of any sea area through microphytobenthic algae can be worked out. Accordingly, taking the total area of the ocean into consideration the total carbon sink can also be worked out based on the average population of microphytobenthic algae of superficial layer of bed sediment prevailing in the ocean.

Thus the carbon sink of through microphytobenthos from superficial layer of sediment to bottom sediment would be expressively high in the ocean which is of a great interest to understand the role of microphytobenthos in regulating atmospheric carbon-cycle and consequently playing a significant role to control "Global Warming".

6.5 Impact of Pollution

i.) Phytoplankton

Overall comparison of selected water quality parameters and phytoplankton in overlying water of Versova and Gorai are described in brief in the Table shown below:

Parameter	Location	
Ebb		
	Versova	Gorai
DO(mg/l)	0	2.7
(PO ₄ ⁻ P) (μmol/l)	6.5	5.1
(NO ₃ ⁻ -N) (μmol/l)	10.3	9.3
(NO ₂ ⁻ -N)(μmol/l)	2.3	4.7
(NH ₄ ⁺ -N)(μmol/l)	44.9	28.6
Phytoplankton		
Chlorophyll a (mg/m ²)	3.6	2.9
Phaeophytin(mg/m ²)	1.3	1.2
Cell Count(No)	432.5 x 10 ³ cells/l	298 x 10 ³ cells/l
Total Species(No)	10	14
Study duration	38	43
Total species (No)		
Major Species	<i>Navicula membranacea</i> <i>Nitzschia seriata</i> <i>Oscillatoria limosa</i> <i>Skeletonema costatum</i>	<i>Navicula membranacea</i> <i>Chaetoceros decipens</i> <i>Oscillatoria formosa</i> <i>Pleurosigma elongatum</i>
Flood		
DO(mg/l)	0.9	3.7
(PO ₄ -P) (μmol/l)	4.5	2.8
(NO ₃ --N)(μmol/l)	3.3	6.5
(NO ₂ --N)(μmol/l)	1.7	2.3
(NH ₄ +--N)(μmol/l)	36.4	13.2
Phytoplankton		
Chlorophyll a (mg/m ²)	2.1	1.8
Phaeophytin(mg/m ²)	1.3	1.2
Cell Count(No)	256.1 x 10 ³ cells/l	128.9 x 10 ³ cells/l
Total Species(No)	12	14
Major Species	<i>Rhizosolenia styliformis</i> <i>Stauroneis membranacea</i> <i>Nitzschia seriata</i> <i>Chaetoceros pendulus</i> <i>Oscillatoria formosa</i> <i>Navicula membranacea</i>	<i>Chaetoceros decipiens</i> <i>Pleurosigma elongatum</i> <i>Thalassiosira subtilis</i> <i>Navicula membranacea</i> <i>Nitzschia seriata</i>

The above Table indicates a clear depletion at DO to the level as low as 0 mg/l during ebb and and improvement during flood at versova which suggests impact of anthropogenic pollution in the region of Versova. However, the phyto population reveals reverse trend with significantly higher

values during ebb than flood indicating the influence of higher concentration of nutrients. The higher values of phytoplankton pigments and cell counts at Versova than that of Gorai may be the consequence of nutrients stimulating the growth of phytoplankton. However, the depletion of DO did not show any significant impact on phytoplankton community structure at Versova in the comparison of Gorai.

ii.) Microphytobenthos

Microphytobenthos		
	Versova	Gorai
Chlorophyll <i>a</i> (mg/m ²)	598.8	503.1
Phaeophytin (mg/m ²)	157.8	111.9
Cell count (No)	133.5 x 10 ⁶ cells /cm ³	93.8 x 10 ⁶ cells /cm ³
Total species (No)	7	11
Study duration Total species (No)	55	57
Major Species	<i>Navicula membranacea</i> <i>Nitzschia pungens</i> <i>Spirulina aeruginosa</i> <i>Oscillatoria formosa</i>	<i>Navicula distans</i> <i>Fragilaria oceanica</i> <i>Oscillatoria formosa</i> <i>Gyrosigma balticum</i>

It is conspicuous from the above Table that the values of microphytobenthic pigments and population are significantly higher at superficial layer of sediment at Versova than that of Gorai. This trend of variation suggests an influence of higher concentration of the nutrients accelerating the growth of microphytobenthos at Versova in the comparison of Gorai. The significant depletion of DO in overlying water of Versova did not hinder the growth of these microphytobenthic algae because they produce oxygen during photosynthesis in the presence of incidence light at superficial layer of sediment. Thus present results conclude that the anthropogenic discharges at Versova, adds the nutrients level and supports the growth of microphytobenthic algae.

7 Summary and Conclusion

Microphytobenthos includes the diverse assemblage of photosynthetic diatoms, cyanobacteria, flagellates and other micro algae that inhabit the intertidal sediments of marine system.

Microphytobenthos are known to produce mucus which influences sediment properties and sedimentation. Organic particles and skeleton of microphytobenthos may form an important compartment of the sediment. The sediment properties including grain size particles, texture, water content, and related mechanical properties also influence the biota and provide the ability of organisms to burrow in the sediments.

The dynamics of microphytobenthos may be influenced by water pollution which can be through anthropogenic discharges including domestic waste water and industrial effluents. The pollutants in overlying water settle at the intertidal area during ebb periods and affect the microphytobenthos. Thus, the comprehensive study on microphytobenthos in polluted environment like Versova is thought to give an idea of the pollutants affecting the dynamics of microphytobenthic flora. Microphytobenthos communities act as traps for contaminants or as bio indicator species in these polluted areas. The changes in microphytobenthic community structure, alteration in pigments corresponding to the increasing depth of the sediments, are the major theme of present study to answer many problems related microphytobenthic dynamics which are not well understood.

In addition to water quality, geological background and human interference may also cause variation in community structure and alteration in pigments of microphytobenthos. Keeping this in view, the present investigation is conducted at two different locations viz, Versova and Gorai and the results are described in brief.

7.1 Versova

The results, of water quality in the overlying water at Versova Creek, reveals that the concentration of DO falls down significantly and attains the level as low as zero during low tide. The improvement of DO during high tide clearly suggested that the anthropogenic pressure remains only for few hours during low tide. Relatively higher level of $\text{PO}_4^{3-}\text{-P}$ & $\text{NH}_4^+\text{-N}$, and $\text{NO}_3^-\text{-N}$ during ebb than that of flood was associated with depleted DO levels in the area which could give a clear idea of anthropogenic releases altering the water quality of Versova.

The overlying water exhibited a high concentration of chlorophyll a (av $4.2 \pm 3.6 \text{ mg/m}^3$) suggesting an enhanced phytoplankton biomass. Similarly phytoplankton population (av $344.2 \times 10^3 /\text{l}$) with abundance of species ranging from 7 to 17; av 14 indicated an excess growth of phytoplankton stimulated by high concentration of nutrients. The phytoplankton biomass and population were also significantly higher during ebb than that of flood indicating the support of nutrients for the growth of phytoplankton. Thus a total 55 species recorded in Versova Creek during the whole study period suggested a good species diversity in the region. Community structure indicated that *Navicula membranacea* was predominant followed by *Nitzschia closterium* and *Oscillatoria formosa* in Versova Creek during ebb period which was associated with markedly depleted DO (0 mg/l) and high concentration of Reactive Phosphate (PO_4^-P), Nitrate - Nitrogen ($\text{NO}_3^-\text{.N}$), Nitrite – Nitrogen ($\text{NO}_2^-\text{-N}$), Ammonium – Nitrogen ($\text{NH}_4^+\text{-N}$).

The results of phytoplankton of present study conspicuously showed that *Oscillatoria formosa* existing in high number particularly during ebb period was associated with very low salinity, nil DO and significantly high concentration of nutrients suggesting the hardy nature of this alga in Versova creek. The presence of *Stauronies membranacea*, *Thalassiosira*

subtilis and sometimes *T. gravida* in slightly enhanced number at Versova creek gave an idea of these algae adapting the creek environment under the influence of organic pollution.

The microphytobenthos were studied in the sediments at HWL and LWL of intertidal area at Versova Creek. The Sediment texture showed the dominance of sand with low silt concentration. The overall average of C_{org} was 686.9 %.

The vertical distribution of microphytobenthic pigment revealed a clear trend of variation with significantly enhanced values of microphytobenthic chlorophyll *a* at LWL (av $613.2 \pm 278.1 \text{ mg/m}^2$) whereas at HWL it was recorded to be av $180.6 \pm 155.4 \text{ mg/m}^2$) in superficial layer of sediments. Phaeophytin was recorded with av $118.7 \pm 132.6 \text{ mg/m}^2$ at HWL whereas at LWL the values were recorded with av $221.2 \pm 133.2 \text{ mg/m}^2$ in superficial layer of sediment. Significance level of $p < 0.05$ was recorded between microphytobenthic chlorophyll *a* and Nitrate – Nitrogen.

The average concentration of microphytobenthic chlorophyll *a* av $31.05 \pm 24.2 \text{ mg/m}^2$ was 2.4 times lower than the values of phaeophytin (av $75.3 \pm 47.5 \text{ mg/m}^2$) resulting poor ratio (0.41) at 5 cm layer of sediment at HWL. The results recorded during LWL indicated still lower values (av $32.3 \pm 17.5 \text{ mg/m}^2$) of Chlorophyll *a* and higher values of microphytobenthic phaeophytin (av $94.4 \pm 37.1 \text{ mg/m}^2$) at 5 cm depth of sediment.

A hypothesis that the phaeophytin is a degraded product of pigments is proved by the present results. The findings clearly indicate that higher concentration of chlorophyll *a* than phaeophytin resulting higher (>1.0) ratios are at superficial layer whereas, the scenario of pigment's structure at deeper layer is reverse with miserably declined ratio corresponding to the depth of sediment. This may be due to the fact that the grazing effect by burrowing organisms or degradation of cells by bacterial activities or miserably poor synthesis of chlorophyll *a* caused by absence of irradiance

could be degrading the chlorophyll *a* and enhancing phaeophytin. This is the reason that the concentration of chlorophyll *a* is seen to decrease in comparison of phaeophytin with the deeper layer of sediment which results poor ratios of these pigments. Hence the present results confirm the hypothesis that phaeophytin is a degrading product of chlorophyll *a*.

Microphytobenthic biomass in sediment was consistently of higher magnitude in multiple orders than phytoplankton biomass existing in overlying water. Similarly the significantly higher microphytobenthic population in sediment than that of phytoplankton population in water clearly suggested a marked existence of flora in the sediment.

Vertical distribution of microphytobenthic population was clear with significantly higher cell count at superficial layer and gradual decrease with the increasing depth at Versova. A sharp decrease in the microphytobenthic population below 6 cm of sediment depth is associated with declining trend of pigments and confirms that the gradual decline of pigments with deeper layer of sediment is due to microphytobenthic population decreasing gradually with increasing depth.

Microphytobenthic community reveals that *Skeletonema costatum*; *Pleurosigma normanii*; *Oscillatoria formosa*; *Fragilaria oceanica*; *Spirulina aeruginosa*; *Thalassiosira condensata*; and *Navicula membranaceae* are major species in order of dominance during different month at 1 cm. Scenario changes at deeper layers of 5 cm depth of sediment which suggests that there are only a few species viz., *Nitzschia pungens*; *Pleurosigma normanii*; *Navicula membranacea*; and *Coscinodiscus radiatus* which are burrowed by the benthic organisms. The community structure at the depth of 9 cm of sediment is again different with the dominance of *Navicula membranacea*; *Nitzschia pungens* and *Pleurosigma normanii*. The species composition at 10 cm depth of sediment reveal the presence of only *Nitzschia pungens* and *Navicula membranacea* which indicates that the burrowing organisms may be able to bring only a few hardy species in

the deepest layer of sediment. Other sensitive species degraded and did not reach at the deepest layer of the sediment. This trend of variation also indicates that *Nitzschia pungens* and *Navicula membranacea* may be the hardest species of microphytobenthos which could survive at the depth where grazing pressure is high with anoxic conditions and absence of irradiance. The depth, to which these microphytobenthic species burrow, depends upon the status of texture of sediment. If the sediment is clayey the microphytobenthic species are burrowed deeper than the one with the sandy sediment.

The results of present thesis establish a fact that the filamentous microphytobenthic species such as *Oscillatoria formosa* and *Spirulina aeruginosa* and the chain forming microphytobenthic species viz., *Skeletonema costatum*, *Fragilaria oceanica* and *Thalassiosira condensata* cannot be burrowed by the burrowing organisms to the deep layer of sediment (below 8.0 cm).

Considering microphytobenthos to be source for transporting the carbon from sediment-atmosphere interference to the deeper layer of sediment and playing an important role in balancing the atmospheric carbon cycle related to global warming, carbon sink was estimated at Versova.

7.2 Gorai

Gorai Creek also receives domestic waste water resulting considerable environmental stress with low DO & high nutrients. Phytoplankton results indicated an enhanced primary production which probably may be due to enrichment of water by nutrients.

Concentration of chlorophyll *a* (av 4.1 ± 4.3 mg/m³) suggests an enhanced phytoplankton biomass which could be due to an excess growth of phytoplankton in Gorai Creek.

Augmented level of microphytobenthic chlorophyll *a* (av 411.3 ± 336.0 mg/m²) associated with an enhanced in phytoplankton population (av $335.2.1 \pm 391.0 \times 10^3 / l$) in 1cm layer of sediment at Gorai Creek could be attributed with high concentration of nutrients prevailing in the creek

The comparison of showed consistently multiple orders of magnitude higher microphytobenthic chlorophyll *a* than phytoplankton chlorophyll *a* in overlying water. The values of microphytobenthic chlorophyll *a* were always higher than phaeophytin at superficial layer of sediment suggesting a good ratio of pigments sustained by healthy cells.

Microphytobenthic chlorophyll *a* declined considerably (av 39.3 ± 34.0 mg/m²) whereas the values of phaeophytin increased (av 80.9 ± 41.4 mg/m²) at 5 cm layer of sediment. This trend of variation of pigment corresponding to depth of sediment clearly indicated the degradation of chlorophyll *a* due to unhealthy conditions of cells.

The sediment at LWL sustains higher population (av: $78.7 \pm 25.0 \times 10^6$ cells / cm³) than that of the values (av: $32.7 \pm 28.0 \times 10^6$ cells /cm³) recorded at HWL. The microphytobenthic population decreased significantly at 5 cm depth of sediment which varied in the range of $3.8 \times 10^6 - 26.9 \times 10^6$ cells / cm³ av: 10.1×10^6 cells /cm³ .

The pre dominance of *Navicula distans* (22.9%), *Fragilaria oceanica* (12.8 %), *Navicula membranacea* (12.5%) and *Nitzschia seriata* (12.3%) at HWL and *Oscillatoria formosa* (19.5%), *Nitzschia pungens* (17.6 %), *Navicula membranacea* (17.2%), *Spirulina aeruginea* (12.7%) and *Gyrosigma balticum* (11.1%) at LWL recorded at superficial layer of sediment clearly suggested the influence of domestic waste water during ebb period.

The structure of phaeophytin is slightly different showing an increase in the concentration upto the depth of 3 cm and abrupt decline following the depth of sediment. It is also an indicative of definite structure of the

microphytobenthic chlorophyll *a*/ phaeophytin ratios showing miserably poor condition at deepest layer. Thus the decreasing concentration of microphytobenthic chlorophyll *a* than phaeophytin corresponding to depth of sediment resulting significantly poor ratios could be the reason of degradation of chlorophyll *a* to phaeophytin which may be the consequences of combined effect of absence of sunlight, grazing by benthic organisms and diagenesis of cells by bacterial activities.

Decreasing trend of microphytobenthic population corresponding to depth of sediments follows the similar pattern as pigments. Hence, the present investigation confirms that the gradual reduction in the pigments with increasing depth of sediment is due to decreasing trend of microphytobenthic population. This may be due to the fact that there are only certain microphytobenthic species which are getting burrowed by the burrowing organisms.

The results at Gorai also reveals the similar pattern of vertical distribution as recorded at Versova. These results confirms the fact that there are number of species such as *Oscillatoria formosa*, *Gyrosigma balticum*, *Nitzschia pungens*, *Navicula membranacea*, *Spirulina aeruginosa*, and *Coscinodiscus radiatus* thriving in superficial layer of sediment. But this scenario of microphytobenthic community structure changes at deeper layer (5 cm) of sediment showing only a few species viz., *Nitzschia pungens*; *Pleurosigma normanii*, *Gyrosigma balticum*, *Navicula membranacea*, and *Coscinodiscus radiates*.

The pigment structure in 10 cm depth of intertidal sediment showed a significantly decrease in microphytobenthic chlorophyll *a* (0.6 mg/m²) and markedly increase in phaeophytin (8.2 mg/m²) resulting an expressively poor ratio (0.01) of these pigments at deeper layer of sediment.

The community structure of microphytobenthos at 10 cm depth of sediment is very specific which has come out with the fact that there are

only a few species like *Nitzschia pungens* and *Navicula membranacea* which secrete mucilaginous substances that facilitate them to get burrowed by burrowing organisms at deeper layer of sediment. This confirms that *Nitzschia pungens*; *Navicula membranacea* may be the hardiest species of microphytobenthos and could survive at such a deeper layer of sediment associated with high grazing pressure and unavailable irradiance.

Impact of anthropogenic pollution on microphytobenthos at Versova was similar to that of phytoplankton in overlying water. Similar to phytoplankton, the population of microphytobenthic algae was influenced by high concentration of nutrients prevailing in overlying water. As a result of which, the significantly higher microphytobenthic biomass and population at Versova than that of Gorai was recorded. The lack of DO in overlying water during ebb at Versova in the comparison of Gorai could not hamper the growth of microphytobenthic algae. There was a slight alteration in community structure of microphytobenthos at Versova when compared with the results of Gorai.

We have already seen in section 7.1 that microphytobenthos are major tools for Carbon (C) sinking process and thus play a role in balancing the carbon cycle and controlling global warming. Now, using the results of microphytobenthic biomass recorded at Versova and Gorai during present study, the total carbon sink of 41×10^5 tons was estimated for the intertidal area of Mumbai measuring 165 Km length and 0.15 Km width. Similarly the total carbon sink for the intertidal area of the whole world ocean can be worked out by using the overall average of microphytobenthic biomass.

8 References

- Abidi, S. A. H., JiyalalRam, Desai, B. N. and Gajbhiye, S. N. 1982. Distribution of chlorophyll pigments in polluted water of Thana Creek (Bombay) National Institute of Oceanography, Seminar on Estuaries- Their Physics. Chemistry, Biology, Geology and Engineering
- Ackerman, S., Bunick, D., Zandomeni, R. and Weinmann, R., 1983. *Nucleic Acids Res.*, 11, 6041-6064.
- Adams, J.B. and Bate, G.C., 1999. Primary producers. Estuarine microalgae. In Allanson BR, and Balrd D (eds.), *Estuaries of South Africa*. Cambridge University Press, Cambridge.
- Admiraal, W. 1984. The ecology of estuarine sediment-inhabiting diatoms. *Prog Phycol Res.*, 3:269–322.
- Agatz, M., Asmus, R.M. and Deventer B 1999. Structural changes in the benthic diatom community along a eutrophication gradient on a tidal flat. *Helgoland Marine Research* 2, 92-101.
- Alkershi-Akram, Menon, N.R. and Joseph, K.J. 2003. Contribution of size fractions of planktonic algae to primary organic productivity in the coastal waters of Cochin. *J.Mar.Biol.Ass.India*, 45:1-8.
- Alongi D M 1987. Intertidal zonation and seasonality of meiobenthos in tropical mangrove estuaries. *Mar Biol*, 95; 447
- Amspoker, M.C., and McIntyre, C. D., 1986. effects of sedimentary processes and salinity on the diatom flora of the Columbia river estuary. *Bot Mar* 29 : 391-399
- Anderson, J. G., Boonruang, P. and Meadows, P. S., 1981. Interrelationships Between Chlorophylls, Carbon, Nitrogen and Heterotrophic Bacteria in Intertidal Sediment Transect. *Mar. Ecol. Prog. Ser. Vol. 6: 277-283*.
- Anil, A. C., Mitbavkar, S., D'Silva, M. S., Hegde, S., D'Costa, P. M., Meher, S. S. and Banerjee, D., 2007. Effect of ageing on survival of benthic diatom propagules *Journal of Experimental Marine Biology and Ecology* 343, 37–43
- Ansari, Z. A., Sreepada, R. A ., Matondakar, S. G. P. and Parulekar A H, 1993. Meiofaunal stratification in relation to microbial food in a tropical mangrove mud flat. *Mar Bio*, 115 279
- Ansari, Z. A. and Parulekar, A. H., 1993. Distribution, abundance and ecology of the meiofauna in a tropical estuary along the west coast of india. *Hydrobiologia*, 262 115

APHA, 1998. standard methods for the examination of water and waste water. 20th edn. Clesceri, L. S., Greenberg, A. E. & Eaton, A. D. (eds.).

Azovsky, I. A., Chetropod, M. V., Kucheruk, N. V., Rybnikov, P.V. and Sapozhnikov, F. V., 2000. Fractal properties of spatial distribution of intertidal benthic communities. *Marine Biology* 136: 581-590.

Ballie, P.W. and Welsh, B.L. 1980. The effect of tidal resuspension on the distribution of intertidal epipelagic algae in an estuary. *Estuar. Coast. Mar. Sci.*, 10:165-180.

Barlow, R.G., Mantoura, R.F.C., Gough, M.A. and Fileman, T.W., 1993. Phaeopigment distribution during the 1990 spring bloom in the northeastern Atlantic. *Deep-Sea Res.* 40, 2229-2242.

Barranguet, C., 1997. The role of Microphytobenthic Primary Production in Mediterranean Mussel Culture Area. *Estuarine, Coastal and Shelf Science*, 44: 753-765

Barranguet, C., Kromkamp, J. and Peene, J., 1998. Factor controlling primary production and photosynthetic characteristics of intertidal microphytobenthos. *Mar Ecol Prog Ser* 173: 117–126.

Bennett, A., Bianchi, T. S., Means, J. C. and Carman, K. R., 1999. The effects of polycyclic aromatic hydrocarbon contamination and grazing on the abundance and composition of microphytobenthos in salt marsh sediments (Pass Fourchon, LA) I. A microcosm experiment, *Journal of Experimental Marine Biology and Ecology* 242 : 1–20

Bianchi, T.S., Findlay, S. and Dawson, R., 1993. Organic matter sources in the water column and sediments of the Hudson river estuary: the use of plant pigments as tracers. *Estuar. Coast. Shelf Sci.* 36, 360-376.

Blanchard, G. F., 1990. Overlapping microscale dispersion patterns of meiofauna and microphytobenthos. *Marine Ecology Progress Series* 68, 101-111.

Blanchard, G. F., 1991. Measurement of meiofauna grazing rates on microphytobenthos is primary production a limiting factor. *Journal of Experimental Marine Biology and Ecology* **147**, 37-46

Blanchard, G. F. and P.A. Montagna, 1992. Photosynthetic response of natural assemblages of marine benthic microalgae to short- and long-term variations of incident irradiance in Ballin Bay, Texas. *J. PhycoZ.*, Vol. 28, pp. 7-14.

Blanchard, G. F. and Gall, C V., 1994. Photosynthetic characteristics of microphytobenthos in Marennes-Olron Bay, France: Preliminary results., *Journal of Experimental Marine Biology and Ecology* 182 : 1-14

Blanchard, G. F., Paterson, D.M., Stal, L.J., Richard, P., Galios, R., Heut, V., Kelly, J.A., Honeywill, C., de Brouwer, J., Dyer, K. and Seguignes, M., 2000. The effect of geomorphological structures on potential biostabilisation by microphytobenthos on intertidal mudflats. *Continental Shelf Research* 20, 1243–1256.

Blanchard, G. F., Guarini, J. M., Orvaln, F. and Sauriau, P-G., 2001, Dynamic behaviour of benthic microalgal biomass in intertidal mudflats, *Journal of Experimental Marine Biology and Ecology*, 264: 85-100.

Blomqvist, P., 1996. Late summer phytoplankton responses to experimental manipulations of nutrients and grazing in an unlimed and limed lake, Njupftatet, Central Sweden. *Archiv fuer Hydrobiologie* 137. 425-455

Brito, A., Newton, A., Tett, P. and Fernandes, T. F., 2009. Temporal and spatial variability of microphytobenthos in a shallow lagoon: Ria Formosa (Portugal) *Estuarine, Coastal and Shelf Science* 83: 67–76.

Brotas, V. and Plante-Cuny, M.R., 1998. Spatial and Temporal patterns of microphytobenthic taxa of estuarine tidal flats in the Tagus estuary (Portugal) using pigment analysis by HPLC, *Marine Ecology Progress Series*, 171: 43-57.

Brotas, V. and Sero^odio, J., 1995. A mathematical model for the vertical distribution of chlorophyll *a* in estuarine intertidal sediments. *Netherlands Journal of Aquatic Ecology* 29, 315–321.

Burkholder, P.R., Repark A. and Sibert, J., 1965. Studies on some Long Island South littoral communities of microorganisms and their primary productivity. *Bull. Torrey Bot. Club*, Vol. 92, pp. 378-402.

Cadee, G.C. and Hegeman, J., 1974. Primary production of the benthic microflora living on tidal flats in the Dutch Wadden Sea. *Neth. J. Sea Res.* 8, 260-291.

Cailame, B. and Debyser, I., 1954. Observations sur les mouvements des diatomandes a la surface des sediments marins de la zone intercotidale. *Vie Milieu*, Vol. V, pp. 243-249.

Cardinale, B.J., Nelson, K. and Palmer, M.A., 2000. Linking species diversity to the functioning of ecosystems: On the importance of environmental context. *O/kos* vol.91, pp 175-183.

Cariou-LeGall, V. and Blanchard, G.F., 1995. Monthly HPLC measurements of pigment concentration from an intertidal muddy sediment of Marennes-Oltron Bay, France. *Mar. Ecol. Prog. Ser.* 121, 171-179.

Cartaxana, P., Jesus, B. and Brotas, V., 2003. Phaeophorbide and phaeophytin *a* like pigments as useful markers for intertidal

Microphytobenthos grazing by *Hydrobia ulvae*, Estuarine, Coastal and Shelf Science, 58: 293-297.

Charpy-Roubaud, C. J., 1988. Production primaire des fonds meubles du lagon de Tikehau. *Oceanologica Acta* 11, 241-248.

Chevalier, E.M., Gévaert, F. and Créach, A., 2010. In situ photosynthetic activity and xanthophylls cycle development of undisturbed microphytobenthos in an intertidal mudflat. *Journal of Experimental Marine Biology and Ecology* 385: 44–49.

Chong, V. C. and A. Sasekumar. 1981. Food and feeding habits of the white prawn *Penaeus merguensis*. *Mar. Ecol. Prog. Ser.* 5: 185–191.

Choy, E. J., An, S. and Kang, C.-K., 2008. Pathways of organic matter through food webs of diverse habitats in the regulated Nakdong River estuary (Korea) *Estuarine, Coastal and Shelf Science* 78: 215-226

Cibic, T., Blasutto, O., Falconi, C. and Umani, S. F., 2007a. Microphytobenthic biomass, species composition and nutrient availability in sublittoral sediments of the Gulf of Trieste (northern Adriatic Sea) *Estuarine, Coastal and Shelf Science* 75 : 50-62

Cibic, T., Blasutto, O., Hancke, K. and Johnsen, G., 2007b. Microphytobenthic Species Composition, Pigment Concentration, And Primary Production In Sublittoral Sediments Of The Trondheimsfjord (Norway) *J. Phycol.* 43: 1126–1137.

Colijn, F. and de Jonge V N., 1984. Primary production of microphytobenthos in the Ems-Dollard Estuary *Mar. Ecol. Prog. Ser.* Vol. 14: 185-196.

Colijn, F. and Van Buurt, G., 1975. Influence of light and temperature on the photosynthetic rate of marine benthic diatoms. *Mar. Biol.*, Vol. 31, pp. 209-214.

Colijn, F. and Dijkema, K.S., 1981. Species distribution of benthic diatoms and distribution of chlorophyll-*a* on an intertidal flat in the Dutch Wadden Sea. *Mar. Ecol. Prog. Ser.* 4, 9-21.

Colijn, F. 1982. Light absorption in the waters of the Ems- Dollard Estuary and its consequences for the growth of phytoplankton and microphytobenthos. *Neth. J. Sea Res.* 15 (2): 196-216

Colletti P.J., Blinn D.W., Pickart A. and Wagner V.T., 1987. Influence of different densities of the mayfly grazer *Heptagenia criddlei* on lotic diatom communities. *J. N. Am. Benthol. Soc.* 6:270-280.

- Dade, W. B., Davis, J.D., Nichols, P.D., Nowell, A.R.M., Thistle, D., Trexler, M.B. and White, D.C. 1990. Effects of exopolymer adhesion on the entrainment of sand. *Geomicrobiol. J.* 8: 1-16.
- Daehnick, A. E., Sullivan, M. J. and Moncreiff, C. A., 1992. Primary production of the sand microflora in seagrass beds of Mississippi sound. *Botanica Marina* 35, 131-139.
- Daily, G. C., Soderquist, T., Aniyar, S., Arrow, K. and Crawford, P., 2000: The value of nature and the nature of value. *Science Magazine* vol.288: pp 395-396.
- Daniel, G. F., Chamberlain A. H. L. and Jones, E. B. G. 1987. Cytochemical and electron microscopical observations on the adhesive materials of marine fouling diatoms. *British Phycological Journal*, 22- 2, pp. 101–118.
- Davis, M.W. and McIntyre, C.D., 1983. Effects of physical gradients on the production dynamics of sediment-associated algae, *Mar. Ecol. Prog. Ser.* 13 103–104.
- Dawes, C.J., 1998. *Marine Botany*. 2nd ed. Willey, New York 479 p.
- Decho, A.W. 1990. Microbial exopolymer secretions in Ocean environments: Their role(s) in food webs and marine processes. *Oceanogr.Mar.Biol: an ann.Rev.*,28:73-153.
- Decho, A. W. and Fleeger, J. W. 1988. Microscale dispersion of meiobenthic copepods in response to food-resource patchiness. *J Exp Mar Biol Ecol* 118 : 229-243.
- Delgado, M., 1989. Abundance and Distribution of Microphytobenthos in the Bays of Ebro Delta (Spain) Estuarine, Coastal and Shelf Science, 29: 183-194
- Desai, B. N., Jiyalal Ram, M., Abidi, S. A. H. and Nair. V. R. 1984. Distribution of Phytoplankton pigments in Auranga, Ambika and Purna and Mindola Estuaries of Gujarat. *Mahasagar Bulletin of the N I of* 17(2), 79-87.
- Desikachary, T.V. and Renjitha Devi, K. A. 1986. Marine fossil diatoms from India and Indian Ocean. *Fasc.I, Madras Science Foundation, Madras.*
- Desikachary, T.V. and Prema, 1987a. Diatoms from the Bay of Bengal. *Fasc. III, Madras Science Foundation, Madras.*
- Desikachary, T.V., Gowthaman, S. and Latha, Y. 1987b. Diatom flora of some sediments from the Indian Ocean region *Fasc. II, Madras Science Foundation, Madras.*

Desikachary, T.V., Prema, Prsaad, A.K.S.K., Sreelatha, P. M., Sreedharan, V.T. and Subrahmanyam, R. 1987c. Marine diatoms from the Arabian Sea and Indian Ocean. Fasc. IV, Madras Science Foundation, Madras.

Desikachary, T.V. 1988. Marine diatoms of the Indian Ocean region Atlas of Diatoms. Fasc. V, Madras Science Foundation, Madras.

Desikachary, T.V. and Sreelatha, P.M. 1989. Oamaru Diatoms, J. Cramer, Berlin, pp. 330. D. Dietrich á., H. Arndt, 2000. Biomass partitioning of benthic microbes in a Baltic inlet: relationships between bacteria, algae, heterotrophic flagellates and ciliates Marine Biology 136: 309±322.

De Boer, P., 1981. Mechanical effects of micro-organisms on intertidal bedform migration. Sedimentology 28, 129– 132.

de Jonge, D. J. and de Jonge, V. N. 1995. Dynamics and distribution of microphytobenthos chlorophyll *a* in the western Scheldt Estuary (SW Netherlands) Hydrobiologia 311: 21-30

de Jonge, V. N., 1980. Fluctuations in the Organic Carbon to Chlorophyll *a* ratios for Estuarine Benthic Diatom Populations. Mar. Ecol. Prog. Ser. Vol 2: 345-353.

de Jonge, V.N., 1985. The occurrence of Episammic Diatom populations : A result of interaction between physical sorting of sediment and certain properties of Diatom species, Estuarine, Coastal and Shelf Science, 21: 607-622.

de Jonge, V. N. and Van Beusekom, J. E. E. 1992. Contribution of resuspended microphytobenthos to total phytoplankton in the Ems estuary and its possible role for grazers. Netherlands Journal of Sea Research 30, 91–105.

de Jonge, V N. and Colijn, F., 1994. Dynamics of microphytobenthos biomass in the Ems estuary Mar. Ecol. Prog. Ser. Vol. 104: 185-196.

de Jonge, V. N. and van Beusekom, J. E. E. 1995. Wind and tide induced resuspension of sediment and microphytobenthos from tidal flats in Ems estuary. Limnology Oceanography 40, 766–778.

Drebes, G., 1974: Marine Phytoplankton. 186pp.

Du, G. Y., Son, M., An, S. and Chung, I. K., 2010. Temporal variation in the vertical distribution of microphytobenthos in intertidal flats of the Nakdong River estuary, Korea Estuarine, Coastal and Shelf Science 86: 62–70

Dwivedi, S.N. and K.G. Padmakumar, 1980. Ecology of mangrove swamp near Juhu Beach, Bombay, with special reference to sewage pollution. 2nd International Symposium on Biology and Management of Mangroves. Port Morseby, 24 (Abstract).

Edgar, L. A. and Pickett-Heaps, J. D. 1983. Diatom locomotion. *Prog Phycol Res* 3:47–88.

Facca, C., Sfriso, A. and Socal, G., 2002. Changes in Abundance and Composition of Phytoplankton and Microphytobenthos due to Increased Sediment Fluxes in the Venice Lagoon, Italy *Estuarine, Coastal and Shelf Science* (2002) 54: 773–792

Fenchel, T., 1968. The ecology of marine microbenthos. II. The food of marine benthic ciliates. *Ophelia* 5, 73-121.

Fenchel, T., 1975a. Character displacement and coexistence in mud snails Hydrobiidae. *Oecologia* 20, 19-32.

Fenchel, T. and Glud, R.N., 2000. Benthic primary production and O₂/ CO₂ dynamics in a shallow-water sediment: spatial and temporal heterogeneity. *Ophelia* 53, 159–171.

Flemming, B. W. and Delafontaine, M. T., 2000. Mass physical properties of muddy intertidal sediment: some applications, misapplications and non-application. *Cont. Shelf Res.* 20: 1179-1197.

Fogg, G. E., Steward, W. D. P. P. Fay and Walsby, A. E., 1973. *The Blue-green Algae*, Academic Press, London, 459 pp

Forster, R. M., Kromkamp, J. C., 2004. Modelling the effects of Chlorophyll fluorescence from subsurface layers on photosynthetic efficiency measurements in microphytobenthic algae. *Marine Ecology Progress Series.* 284, 9-22.

Fourqurean, J. W., Muth, M. F. and Boyer, J.N., 2010. Epiphyte loads on seagrasses and microphytobenthos abundance are not reliable indicators of nutrient availability in oligotrophic coastal ecosystems *Marine Pollution Bulletin* 60: 971–983.

Fry, B. and Sherr, E., 1984. Delta 13C measurements as indicators of carbon flow in marine and freshwater ecosystems. *Contributions in Marine Science* 27, 13-47.

Gaetje, C., 1992. Biomass and primary production of microphytobenthos of Elba stuars. Dissertation. University of Hamburg. 221 p.

Gajbhiye, S. N., Stephen, R., Nair, V R., and Desai, B. N., 1991. Copepods of the nearshore waters of Bombay *Indian Journal of Marine sciences* vol.20: 187-194

Gajbhiye, S. N. and Abidi, S. A. H., 1993. Zooplankton distribution in the polluted environment around Bombay. *Environmental Impact on Aquatic and Terrestrial Habitats* 127-142

- Gargas, E., 1971. "Sun-shade" adaptation in microbenthic algae from the Oresund. *Ophelia*, Vol. 9, pp. 107-112.
- Geetha Madhav, V. & Kondalarao, B.K. 2004. Distribution of phytoplankton in the coastal waters of east coast of India. *Indian J. Mar. Sci.*, 33: 269-275.
- Golubic, S., Sreong-Joo, L. and Brown, K.M., 2000. Cyanobacteria: architects of sedimentary structures. In: Riding, R., Awramik S. (Eds.), *Microbial Sediments*. Springer, Berlin, pp. 57–67.
- Gopinathan, C.P., 1972. Seasonal abundance of phytoplankton in the Cochin Backwaters. *J.Mar.biol.Ass.India*, 14: 568-577
- Gopinathan, C.P., 1975a. Studies on the estuarine diatoms of India. *Bull. Dept. Mar. Sci.Univ. Cochin*, 7: 995-1004.
- Gopinathan, C.P., 1975b. On new distributional records of plankton diatoms from the Indian Seas. *J. Mar. Biol. Ass. India*, 17:223-240.
- Gopinathan, C.P., 1984. A systematic account of the littoral diatoms of the southwest coast of India. *J. Mar. biol. Ass. India*, 26:1-31.
- Gopinathan, C.P., Rodigro, J.X., Qasim, M.H. & Rajagopalan, M.S. 1994. Phytoplankton pigments in relation to primary production and nutrients in the inshore waters of Tuticorin, South West coast of India. *Indian J. Mar. Sci.*, 23:204-212.
- Goto, N., Mitamura, O., and Teral, H., 2001. Biodegradation of photosynthetically produced extracellular organic carbon from intertidal benthic algae. *J. Exp. Mar. Biol. Ecol.* 257, 73–86.
- Gowda, G., Gupta, T.R.C., Rajesh, K.M., Gowda, H., Lingadhal, C. and Ramesh, A.M. 2001. Seasonal distribution of phytoplankton in Nethravathi estuary. *J.Mar.Biol.Ass.India*, 43: 31-40.
- Graham, L. E. and Wilcox, L. W., 2000. *Algae*. Prentice-Hall, NY, 700 p
- Grall, J., Loc'h, Le F., Guyonnet, B. and Riera, P., 2006. Community structure and food web based on stable isotopes ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) analysis of a North Eastern Atlantic maerl bed *Journal of Experimental Marine Biology and Ecology* 338, 1–15
- Grant J. and Gust, G. 1987. Prediction of coastal sediment stability from photopigment content from mats of purple sulphur bacteria. *Nature*, 330 pp. 244–246.
- Grasshoff, K., Ehrhardt, M., Kremling, K. and Almgren, T., 1983. 'Methods of seawater analysis.' (Weinheim Verlag Chemie, pp. 419)

Guarini, J.-M., Blanchard, G.F., Bacher, C., Gros, P., Riera, P., Richard, P., Gouleau, D., Galois, R., Prou, J. and Sauriau, P.-G., 1998. Dynamics of spatial patterns of microphytobenthic biomass: inferences from geostatistical analysis of two comprehensive surveys in Marennes-Ole'ron bay (France). *Marine Ecology Progress Series* 166, 131-141

Gupta, I., Dhage, S. and Kumar, R., .2009. Study of Variations in water quality of Mumbai coast through multivariate analysis techniques *Indian Journal of Marine Sciences* Vol. 38 : 170-177

Happey-Wood, C. M. and Jones, P., 1988. Rhythms of vertical migration and motility in intertidal benthic diatoms with particular reference to *Pleurosigma angulatum*. *Diatom Res* 3: 83–93

Harper, M. A., 1969. Movement and migration of diatoms on sand grains. *British Phycological Journal* 4, 97–103.

Hawkins, C. M. and Lewis, J. B., 1982. Benthic primary production on a fringing coral reef in Barbados, West Indies *Aquatic Botany* 12;355-363.

Hecky, R. E. and Hesslein, R. H., 1995. Contributions of benthic algae to lake food webs as revealed by stable isotope analysis. *Journal of North American Benthological Society* 14: 631-653

Heip, C. H. R., Goosen N. K., Herman, P. M. J., Kromkamp J., Middleburg, J. J. and Soetaert, K., 1995. Production and Consumption of biological particles in temperate tidal estuaries. *Oceanography Marine Annual Reviews* 33:1-150

Hendey, N. I., 1964. An introductory account of the smaller algae of the coastal waters. Part V. Bacillariophyceae (Diatoms). Ottokoeltz Science Publishers, Koenigstein, Germany, pp. 317.

Herman, P. M. J., Middelburg, J. J., Widdows, J., Lucas, C.H., and Heip, C. H. R., 2000. Stables isotopes as trophic tracers: Combining field sampling and manipulative labelling of food resources for macrobenthos. *Mar. Ecol. Prog. Ser.* 204, 79–92.

Hillebrand, H., and Kahlert, M., 2001. Effects of grazing and nutrient supply on periphyton biomass and nutrient stoichiometry in habitats of different productivity. *Limnology and Oceanography* vol 46 No. 8: pp 1881-1898

Hillebrand, H., Kahlert, M., Haglund, A., Beringer, U., Nagel, S., and Wickham, S., 2002. Control of microphytobenthic communities by grazing and nutrient supply. *Ecology* 83. 2205-2219.

Holmes, N. A. and McIntyre, A. D., 1984. *Methods for the study of marine benthos*, Second Edition., Blackwell Scientific Publications, Galliard (Printers) Ltd., Great Yarmouth, Norfolk, 387 pp.

Hopkins, J., 1963. A study of diatoms of the Ouse Estuary, Sussex. The movement of the mudflat diatoms in response to some chemical and physical changes. *Journal of the Marine Biological Association of the United Kingdom* 43: pp653-663.

Ingole, B. S. and Parulekar, A. H. 1998. Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach : Field evidence *Indian Journal of Marine Sciences* Vol.27, 356-361

James, M. R., Hawes, I., Weatherhead, M., Stanger, C, and Gibbs, M., 2000. Carbon flow in the littoral food web of an oligotrophy lake. *Hydrobiologia* 441:93-106.

Jiyalal Ram, M. J. 1985. Studies on phytoplankton in polluted and unpolluted aquatic environments of the north West coast of India Ph. D Thesis Bombay University 519 pp

Jaiswar, J. M. , Desai, B. N. and Abidi, S. A. H., 1984. Diurnal variations of phytoplankton pigments and populations in the nearshore waters off Thal (Maharashtra). *Mahasagar Bull. Nat. Inst. Oceanography* 17 (1) ; 41- 47.

Jiyalal Ram, M. J and Goswami, S.C. 1993. Observations on phytoplankton pigments, zooplankton and physico-chemical parameters in surface waters from Southern Indian Ocean and Antartic region. *Mahasagar*. 26:123-131

Jiyalal Ram M. Jaiswar, Mandalia A. V., Narvekar S. M. and Karangutkar S. H. 2011. Nutrient fluxes and adaptation to environmental dynamics by phytoplankton in the Gulf of Khambhat. *Int. J. Curr. Res.*, vol.3; 5-13.

Jaiswar, A. R M. and Zingde, M. D., 2000. Interstitial Water chemistry and nutrients fluxes from tropical intertidal sediment, *Indian Journal of Marine Sciences.*, Vol. 29, Dec., pp 310-318.

Jayalakshmy, K.V., Kumaran, S. and Vijayan, M., 1986. Phytoplankton distribution in Cochin Backwaters-a seasonal study. *Mahasagar*. 19:29-37.

Jemakoff, P., Breartey, A. and Nielsen, J., 1996. Factors affecting grazer epiphyte interactions in temperate seagrass meadows. *Oceanography and Marine Biology. An Annual Review* 34:109-162

Jesus, B., Mendes, C. R., Brotas, V., Paterson, D. M., 2006, Effect of sediment type on microphytobenthos vertical distribution: Modelling the productive biomass and improving ground truth measurements. *Journal of Experimental Marine Biology and Ecology* 332 : 60– 74

Jesus, B., Brotas, V., Ribeiro, L., Mendes, C. R., Cartaxana, P., and Paterson, D. M., 2009. Adaptations of microphytobenthos assemblages to sediment type and tidal position, *Continental Shelf Research* 29: 1624–1634

Johnstone, R. N', Koop, K. and Larkum, A. W. D., 1990. Physical aspects of coral reef lagoon sediments in relation to detritus processing and primary production. *Mar Ecol Prog se*; 66: 273-283

Kelly, M. G., Cazanbon, A., Coring, E. and Goldsmith, B., 1998. Recommendations for the Routine Sampling of diatoms for water quality assessments in Europe. *Journal of Applied Phycology*W: 215-224.

Kelly, J., Honeywill, C., and Paterson, D. M., 2001. Microscale analysis of chlorophyll *a* in cohesive, intertidal sediments: the implications of microphytobenthos distribution. *Journal of the Marine Biological Association of the United Kingdom* 81, 161–162.

Kitting, C. L., Fry, B. and Morgan, M.D., 1984. Detection of inconspicuous epiphytic algae supporting food webs in seagrass meadows. *Oecologia* 62: 145-149.

Klamer, H. J. C. and Laane, R. W. P. M., 1990. "The behaviour of dissolved and particulate polychlorinated biphenyls (PCB's) and polycyclic aromatic hydrocarbons (PAH's) in the Rhine estuary, 1988/1989". Paper presented at the 4th International Conference on Environmental Contamination, Barcelona, pp. 98-100.

Knoben, R.A.E., Roos, C. and van Oirschot, M.C.M., 1995. Biological assessment methods for water courses vol. 3: pp86.

Knox, G.A., 1986. Estuarine ecosystems: a systems approach, Vol. I. CRC Press, Boca Raton, 289 pp.

Koh, C.-H., Khim, J.S., Araki, H., Yamanishi, H. and Koga, K., 2007. Within-day and seasonal patterns of microphytobenthos biomass determined by co-measurement of sediment and water column chlorophylls in the intertidal mudflat of Nanaura, Saga, Ariake Sea, Japan Estuarine, Coastal and Shelf Science 72: 42-52

Krumbein, W. E., Cohen, Y. and Shilo M., 1977. Stromatolitic cyanobacterial mats. *Limnology and Oceanography*, 22 , pp. 635–656

Krumme, U., Keuthen, H., Barletta, M., Ulrich Salnt, P. and Villwock W., 2008. Resuspended intertidal microphytobenthos as major diet component of planktivorous Atlantic anchoveta *Cetengraulis edentulus* (Engraulidae) from equatorial mangrove creeks *Ecotropica* 14: 121–128.

Kumaran, S. and Rao, T. S. S. 1975. Phytoplankton distribution and abundance in the Cochin Backwaters during 1971-72. *Bull.Dept.Mar.Sci.Univ.Cochin*, 7: 791-799.

Kwandrans, J., Elorant, A.P., and Kaweck, A.B., 1998: Use of benthic diatom communities to evaluate water quality in rivers of Southern Poland. *Journal of Applied Phycology* 10:193-210.

Lebour, M. V. 1930. The Planktonic diatoms of Northern Seas. Roy.Soc. Publ., London,116:. 244.

Lebretona, B., Richarda, P., Galoisa, R., Radenaca, G., Pflégera, C., Guilloua, G., Mornetb, F., and Blancharda, G. F., 2011. Trophic importance of diatoms in an intertidal *Zostera noltii* seagrass bed: Evidence from stable isotope and fatty acid analyses *Estuarine, Coastal and Shelf Science* Volume 92, Issue 1: 140-153

Leh, M. U. C. and A. Sasekumar. 1984. Feeding ecology of prawns in shallow waters adjoining mangrove shores. Pages 331–353 in E. Soepadmo, A. N. Rao, and D. J. Macintosh, eds. *Proc. Asian Symp. on Mangrove Environment: Research and Management*, University of Malaya and UNESCO, Ardyas Publication, Kuala Lumpur.

Longphuir, S. Ni´., Clavier, J., Grall, J., Chauvaud, L., François Le Loc’h c, Iwan Le Berre., Flye-S-M, J., Richard, J. and Leynaert, A., 2007. Primary production and spatial distribution of subtidal microphytobenthos in a temperate coastal system, the Bay of Brest, France *Estuarine, Coastal and Shelf Science* 74: 367-380

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J.P. and Hector, A., 2000. Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges. *Science Magazine* vol. 294: 804-808pp.

Loreau, M., 2001. Microbial diversity producer, decompose interactions and ecosystem processes: a theoretical model. *Proceedings of Royal Society Biological Series* vol. 268: 303-309.

Lorenzen J. C., 1967. Notes and comments, Determination of Chlorophyll and Phaeo-pigments: Spectrometric Equations. *Limnology Oceanography*, 12: 343-346

Lucas, C. H., Widdows, J., Brinsley, M.D., Salkeld, P.N. and Herman, P. M. J., 2000. Benthic-pelagic exchange of microalgae at a tidal flat. 1. Pigment analysis. *Marine Ecology Progress Series* 196, 59-73.

MacIntyre, H. L., Geider, R.J. and Miller, D.C., 1996. Microphytobenthos: the ecological role of the “secret garden” of un-investigated shallow water marine habitats. I. Distribution, abundance and primary production. *Estuaries* 19:186-201.

Madhu, N. V., Jyothibabu, R., Maheswaran, P. A., Gerson, V. J., Gopalakrishnan, T.C. and Nair, K. K. C. 2006. Lack of seasonality in

phytoplankton standing stock (chl.a) and production in the western Bay of Bengal. *Cont. Shelf Res.*, 26:1868-1883.

Marks, J. C. and Lowe, R. L. 1989. The independent and interactive effects of snail grazing and nutrient enrichment on structuring periphyton communities. – *Hydrobiologia* 185: 9–17.

Mc Cormick, P. V. and Stevenson, R. J., 1991: Grazer control of nutrient availability in the periphyton. *Oecologia* 86: 287-291.

McLusky, D. S., 1989. *The estuarine ecosystem*. Blackie, Glasgow, second edition, 215 pp.

Meurer, A. Z. and Netto, S. A. 2007 Seasonal dynamics of benthic communities in a shallow Sublittoral site of laguna estuarine system Braz. *J. Aquat. Sci. Technol.*, 11(2):53-62.

Middelburg, J. J., Barranguet, C., Boschker, H.T.S., Herman, P.M.J., Moens, T. and Heip, C.H.R., 2000. The fate of intertidal microphytobenthos carbon: an in situ ¹³C-labelling study. *Limnology and Oceanography* 45, 1224-1234

Miller, D. C., Geider, R. J. and MacIntyre, H. L., 1996. Microphytobenthos: The ecological role of the “ Secret Garden’ of unvegetated, shallow-water marine habitats. II. Role in sediment stability and shallow- water food webs. *Estuaries* 19: 202-212.

Mitbavkar, S. and Anil, A. C., 2002. Diatoms of the microphytobenthic community: population structure in a tropical intertidal sand flat. *Marine Biology* 140: 41-57.

Mitbavkar, S. and Anil, A. C., 2004. Vertical migration rhythms of benthic diatoms in a tropical intertidal sand flat: influence of irradiance and tides. *Marine Biology* 145: 9-20.

Mitbavkar, S. and Anil, A. C., 2006. Diatoms of the microphytobenthic community in a tropical intertidal sand flat influenced by monsoons: Spatial and temporal variations. *Mar. Biol.* 148: 693-709.

Mitbavkar S. and Anil, A. C., 2008 Seasonal variations in the fouling diatom community structure from a monsoon influenced tropical estuary *Biofouling*, vol. 24(6): 415-426

Moncreiff, C. A., Sullivan, M. J. and Daehnick, A. E., 1992. Primary production dynamics in seagrass beds of Mississippi Sound: the contributions of seagrass, epiphytic algae, sand microflora, and phytoplankton. *Marine Ecology Progress Series* 87, 161-171.

- Moncreiff, C. A. and Sullivan, M. J., 2001. Trophic importance of epiphytic algae in subtropical seagrass beds: evidence from multiple stable isotope analyses. *Marine Ecology Progress Series* 215, 93-106.
- Montagana, P. A. and Blanchard G F., 1995. Effect of production and biomass of intertidal microphytobenthos on meiofaunal grazing rates., *Journal of Exp Marine Biology and Ecology*, 185: 149-165.
- Montani, S., Magni, P. and Abe, N., 2003. Seasonal and interannual patterns of intertidal microphytobenthos in combination with laboratory and areal production estimates. *Mar Ecol Prog Ser Vol.* 249: 79–91
- Mortazavi, Y., Iverson, R.L, Landing, W.M., Lewis, F.G., and Huang, W., 2000: Control of diatom production and biomass in a river dominated estuary. *Marine Ecology Progress Series* vol.198, pp 19-31
- Mukherji, D. (2002). Degradation of creeks and mangroves and its impact on urban environment: A case study of Mumbai. In *Proceedings of the national seminar on creeks, estuaries and mangroves: Pollution and conservation* (pp. 331–333).
- Naeem, S., Thompson, L., Lawler, S.P., Lawton, H. and Woodfin, R.M., 1994. Declining biodiversity can alter the performance of ecosystems. *Nature* vol.368, no. 6473, pp. 734-737.
- Nair, P.V.R., Samuel, S., Joseph, K.J. and Balachandran, V.K., 1968. Primary production and potential fishery resources in the seas around India. *Pocceed.Symp.Living. Res.Seas around India.*, CMFRI spl. publication, 184-198.
- Nair, P.V.R., Joseph, K.J., Balachandran, V.K. and Pillal, V.K. 1975. A Study of the primary production in the Vembanad Lake. *Bull. Dept. Mar. Sci., Univ. Cochin.*,7:161-170.
- Nair Sreekumaran, S. R., C. T. Achutankutty, V. R. Nair and V. P. Devassy 1980 Plankton composition in the coastal waters between Jaigargh and Rajapur along west coast of India.
- Nair, P.V.R. and Gopinathan, C.P. 1981. Productivity of the Exclusive Economic Zone of India. *J. Mar. biol. Ass. India.*, 23: 48-54.
- Nair, V. R., Gajbhiye, S. N. and Desai, B. N., 1991. Effect of pollution on the distribution of chaetognaths in the nearshore waters of Bombay Indian *Journal of Marine Sciences* Vol. 20, 43-48
- Narveker, P. V. and Zingde, M. D., 1992. Influence of pollution on Boron Chlorinity ratio *Environment and Biodegradation* 55-68

Nozais, C., Perissinotto, R., Mundree, S., 2001. Annual cycle of microalgal biomass in a South African temporarily-open estuary: nutrient versus light limitation. *Marine Ecology Progress Series* 223, 39–48.

Nozais, C., Perissinotto, R. and Tita, G., 2005. Seasonal dynamics of meiofauna in a South African temporarily open/closed estuary (Mdloti Estuary, Indian Ocean) *Estuarine, Coastal and Shelf Science* 62: 325–338.

Nozaki, K., Khadbaatar, D., Tetsuji, A., Naoshige, G., and Osamu, M., 2003: Development of filaments green algae in a benthic algal community in a littoral sand beach zone of Lake Birva. *Limnology* 4, 161-165.

Paerl, H.W. and Pinckney, J. L., 1996. A mini-review of microbial consortia: their roles in aquatic production and biogeochemical cycling. *Microb Ecol* 31:225–247

Palmer, J. D. and Round, F. E., 1965. Persistent, vertical-migration rhythms in benthic microflora. I. The effect of light and temperature on the rhythmic behaviour of *Euglena obtusa*. *J. Mar. Biol. Assoc. UK*, Vol.45, pp. 567-582.

Paropkari, A. L., Iyer, S. D., Chauhan, O. S. and PrakashBabu, C. 1991. Depositional environments inferred from variations of calcium carbonate, organic carbon, and sulfide sulfur: a core from southeastern Arabian Sea *Geo-Marine Letters*, Vol.11; 96-102p.

Paropkari, A. L., PrakashBabu, C., Mascarenhas, 1992. A critical evaluation of depositional parameters controlling the variability of organic carbon in Arabian Sea sediments *A. Marine Geology*, Vol.107; 213-226p.

Pascal, P., Y, Dupuy, C., Richard, P., Mallet, C., du Chaîtelet, E. A. and Niquilb N., 2009. Seasonal variation in consumption of benthic bacteria by meio- and macrofauna in an intertidal mudflat *Limnol. Oceanogr.*, 54(4): 1048–1059

Paterson, D. M., 1989. Short term changes in the erodability of intertidal cohesive sediments related to the migratory behaviour of epipellic diatoms. *Limnol. Ocean.* 34: 223-234.

Paterson, D. M. and Daborn, G. R., 1991. Sediment stabilisation by biological action: significance for coastal engineering, D.H. Peregrine, J.H. Loveless, Editors , *Developments in Coastal Engineering*, University of Bristol Press, Bristol pp. 111–119.

Paterson, D. M., 1995. Biogenic structure of early sediment fabric visualized by low temperature scanning electron microscopy. *J. Geol. Soc. London* 152, 131–140

Paterson, D. M., Tolhurst, T. J., Kelly, J. A., Honeywell, C., de Deckere, E. M. G. T., Huet, V., Shayler, S.A., Black, K.S., de Brouwer, J. and Davidson,

I., 2000. Variations in sediment properties, Skeffling mudflat, Humber Estuary, UK. *Cont.Shelf Res.* 20: 1373-1396.

Paterson, D. M. and Hagerthey, S. E., 2001. Microphytobenthos in contrasting coastal ecosystems: biology and dynamics. In: Reise, K. (Ed.), *Ecological Comparisons of Sedimentary Shores*. Springer, Berlin, Heidelberg, NY, pp. 105–125.

Patil, J. S. and Arga, C. A., 2008. Temporal variation of diatom benthic propagules in a monsoon-influenced tropical estuary *Continental Shelf Research* 28: 2404– 2416

Peletier, H., 1996. Long-term changes in intertidal estuarine diatom assemblages related to reduced input of organic waste. *Mar Ecol Prog Ser* 137:265–271

Perissinotto, R., Nozais, C. and Kibirige, I. 2002. Spatio-temporal dynamics of phytoplankton and microphytobenthos in a South African temporarily open estuary. *Estuar. Coast. Shelf Sci.* 55:47– 58.

Petchey, O.L, Downing, A.L., Mittelbach, G.G., Persson, L, Steiner, C.F., Warren, P.H. and Woodward, G., 2004. Species loss and the structure and functioning of multitrophic aquatic systems vol. 104: pp. 467-468.

Peterson, B. J., R. W. Howarth, and R. H. Garritt., 1985. Multiple stable isotopes used to trace the flow of organic matter flow in estuarine food webs. *Science* 227:1361–1363.

Pillai, V. K., Joseph, K. J. and Nair, A. K. K. 1975. The plankton production in the Vembanad lake and adjacent waters in relation to the environmental parameters. *Bull. Dept. Mar. Sci. Univ. Cochin.*, 1:137-150.

Pinckney, J. and Zingmark, R. G. 1991. Effect of tidal stage and sun angles on intertidal benthic microalgal productivity. *Mar Ecol Prog Ser* 76:81–89.

Plante-Cuny, M. R. Bodoy, A., 1987. Biomass and primary production of phytoplankton and microphytobenthos in a sheltered and an exposed beach (Gulf of Fos, France). *Oceanologica acta* 10: 223-237

Plante- Cuny, M.R. and Plante, R., 1984. Benthic diatoms as a food source for benthic animals. In *8th Diatom Symposium*,525-531

Pomeroy, L. R., Darley, W.M., Dunn, E.L., Gallagher, J.L., Hames, E.B and Whrtney, D.M., 1981. Primary production. In, *Tzdemarsh ecology*, edited by P.G. Pomeroy and R.G. Wiegert. Springer-Verlag. New York, pp. 39-67.

Potter, I. C., Cannon, D. and Moore, J.W., 1975. The ecology of algae in the Moruya River, Australia. *Hydrobiologia* 47: 415-430

Qasim, S. Z., Wafar, M. V. M., Vijayaraghavan, S., Royan, J.P and Krishnakumari, N., 1978. Biological productivity of coastal waters of India from Dabhol to Tuticorin. *Indal J. Mar. Sci.*, 7:84-93.

Rasmussen, M. B., K. Henriksen and A. Jensen, 1983. Possible causes of temporal fluctuations in primary production of the microphytobenthos in the Danish Wadden Sea. *Mar. Biol.*, Vol. 73, pp. 109-114.

Raymont, J. E. G., 1980. Plankton and productivity in the oceans, 2nd Ed., 1101. 1. Phytoplankton, 489 pp. Pergamon: Oxford

Reay, W. G., Gallagher, D. H. and Simmons, G. M., 1995. Sediment water column oxygen and nutrient fluxes in nearshore environments of the lower Delmarva Peninsula. *Marine Ecology Progress Series* 118:215-227

Renjith, K. R., Varma, K. K., Haridevi, C. K., Houlath, K. H. Vijayakumar, C. T. and Joseph, P., 2004. Primary production and fishery potential of the Panangad region in the Cochin estuarine system. *J.Mar.Biol.Ass.India.*, 46:126-132.

Riaux-Gobin, C. and Bourgoin, P., 2002. Microphytobenthos biomass at Kerguelen's Land (Subantarctic Indian Ocean): repartition and variability during austral summers *Journal of Marine Systems* 32: 295– 306

Rizzo, W. M., Lackey, G. J., and Christan, R. R., 1992. significance of euphotic, subtidal sediments to oxygen and nutrient cycling in a temperate estuary. *Marine Ecological Progress Series* 86:51-61

Round, F.E. and Palmer, J. D., 1966. Persistent, vertical-migration rhythms in benthic microflora. II. Field and laboratory studies on diatoms from the banks of the river Avon. *Journal of the Marine Association of the United Kingdom* 46, 191–241.

Round, F. E., 1971. Benthic marine diatoms. *Oceanography and Marine Biology. An Annual Review* 9, 83e139.

Roy, P. S., Thom, B. G. and Wright, L D., 1980. Holocene sequences on an embayed high-energy coast: an evolutionary model: *Sed. Geology*, v. 26, p. 1-19.

Roy, R., Pratihary, A., Gauns, M. and Naqvi, S. W. A. 2006. Spatial variation of phytoplankton pigments along the southwest coast of India. *Estuar. Coast Shelf Sci.*, 69:189-195.

Sanilkumar M.G., Padmakumar K.B., Menon, N.R., Joseph, K.J., Sanjeevan, V.N. and Saramma, A.V. 2009a. Algal blooms along the coastal waters of southwest India during 2005-08. In 'MECOS', International Symposium on Marine Ecosystems: Opportunities and Challenges., Cochin, 222-224.

- Sanilkumar, M., Saramma, A. V. and Joseph, K. J., 2009b. Vertical distribution of microphytobenthos in Cochin estuary J. Mar.Biol. Ass. India, 51 (1) : 61-68
- Sankaranarayanan, V. N. and Qasim, S.Z. 1969. Nutrients in the Cochin Backwaters in relation to environmental characteristics. Mar.Biol., 2:236-247.
- Santra, S.C., Das, U.C., Sima Sen, T.M., Rita Saha, Dutta, S. and Gosh Dastida, P., 1989. Phytoplankton of Bhagirathi-Hooghly estuary: An illustrative account. Ind. Biol.,21:1-27
- Sarupria, J.S. and Bhargava, R.M.S. 1993. Seasonal primary production in different sectors of the EEZ of India. Mahasagar., 26:139:147.
- Sasekumar, A. and V. C. Chong. 1987. Mangroves and prawns: Further perspectives. Pages 10–22 in A. Sasekumar, S. M. Phang, and E. L. Chong, eds. Towards conserving Malaysia's heritage. Proc. 10th Annual Seminar of the Malaysian Society of Marine Sciences, Kuala Lumpur, Malaysia.
- Selvaraj, G. S. D., Thomas, V. J. and Khambadkar, L. R. 2003. Seasonal variation of phyto plankton and productivity in the surf zone and Backwaters at Cochin. J.Mar.biol.Ass.India., 45: 9-19.
- Serôdio, J., 2004. Analysis of variable chlorophyll fluorescence in microphytobenthos assemblages: implications of the use of depth-integrated measurements. Aquat. Microb. Ecol. 36, 137–152.
- Serôdio, J., Coelho, H., Vieira, S. and Cruz, S., 2006. Microphytobenthos vertical migratory photoresponse as characterised by light-response curves of surface biomass. Estuarine, Coastal and Shelf Science 68: 547-556
- Seuront, L. and Spilmont, N., 2002. Self-organized critically in intertidal microphytobenthos patch patterns. Physica A 313, 513–539.
- Shaffer, M. G. and Sullivan, M.J., 1987. Water column productivity attributable to displaced benthic diatoms in well-mixed shallow estuaries. J. Phycol , Vol. 24, pp. 132-140.
- Shang, X., Zhang, G. S. and Zhang, J., 2008. Relative importance of vascular plants and algal production in the food web of a Spartina-invaded salt marsh in the Yangtze River estuary Mar Ecol Prog Ser Vol. 367: 93–107
- Sheeba, S. and Ramanujan, N. 2003. Seasonal variation in the density and composition of the phytoplankton population in the estuarine environment of Ithikkara River, Kerala. Seaweed Res.Utiln., 25:175-180.

- Sivadasan, K. K. and Joseph K. J. 1995. Photosynthetic pigments of benthic microalgae in Cochin estuary. *Indian J. Mar. Sci.*,24:231-232.
- Sivadasan, K. K. and Joseph K. J., 1997. Distribution and role of benthic microalgae in Cochin estuary. *J. Mar. Biol. Assn. India.*, 39:27-32.
- Sivadasan, K. K. and Joseph K. J., 1998a. Potential productivity of microbenthic algae in Cochin estuary. *J. Mar. Biol. Assn. India.*, 40.
- Sivadasan, K. K. and Joseph, K. J., 1998b. Community structure of micro algal benthos in the Cochin Backwaters. *Indian J.Mar.Sci.*, 27:323-327.
- Smith, D.J., Underwood, G.J.C., 1998. Exopolymer production by intertidal epipellic diatoms. *Limnol. Oceanogr.* 43 (7), 1578–1591.
- Smith, D.J., Underwood, G.J.C., 2000. The production of extracellular carbohydrates by estuarine benthic diatoms: the effects of growth phase and light and dark treatment. *J. Phycol.* 36, 321–333.
- Sreekumar, R. and Joseph, K. J., 1995a. Periphytic flora of Cochin estuary. *Phycos.*34:83-89.
- Sreekumar, R. and Joseph, K.J., 1995b. Periphyton colonization in Cochin estuary. *Indian.J. Mar. Sci.*, 24:94-96.
- Sreekumar, R., 1996. Studies on the eco-physiology of periphytic algae in Cochin estuary. Ph.D Thesis, Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, Kochi, India.
- Sreekumar, R. and Joseph K.J., 1996. Seasonal and spatial distribution of chlorophyll *a* and phaeophytin *a* of periphytic algae in Cochin back waters. *Phycos.*35:31-38.
- Sreekumar, R. and Joseph K.J., 1997. Contribution of periphytic algae towards the bioproductivity of Cochin estuary. *J.Mar.Biol.Assn.India.*, 39:13-19.
- Stevenson, R.J., Pan, Y., Hill, B.H. and Herlihy, A T , 1996. Using diatoms as indicators of ecological conditions, a regional assessment in lotic systems. *Journal of the North American Benthological Society* 15 (4): 481-495
- Strathmann, R.R., 1967. Estimating the organic carbon content of phytoplankton from cell volume or plasma volume. *Limnology and Oceanography* 12,411-418.
- Strickland, J.D.H. and Parsons, T.R., 1972. A practical handbook of seawater analysis. Fisheries Research Board, Canada, 311.

Subrahmayan, R., 1946. A systematic account of the Madras coast. Proc.Indian Acad.Sci., 24:85-197.

Sullivan, M. and Moncreiff, C., 1990. Edaphic algae are an important component of salt marsh food-webs: Evidence from multiple stable isotope analyses. Mar. Ecol. Progr. Ser. 62: 149-159.

Sumner, W.T. and McIntyre, C D., 1982. Grazer peri-phyton interactions in laboratory streams. Archiv fuer Hydrobiologie 93:135-157.

Sunderman, K. and Thistle, d., 2004. The relative impacts of spills of two alternative fuels on the microalgae of a sandy site : a microcosm study, Marine Pollution Bulletin,49:473-478.

Sundbäck, K. and Jönsson, B., 1988. Microphytobenthic productivity and biomass in sublittoral sediments of a stratified bay, southeastern Kattegat. J Exp Mar Biol Ecol 122:63–81.

Tang, M. and Kristensen, E., 2007. Impact of microphytobenthos and macroinfauna on temporal variation of benthic metabolism in shallow coastal sediments Journal of Experimental Marine Biology and Ecology 349: 99–112

Taylor, A. H., Geider, R J. and Gilbert, F J. H. 1997. Seasonal and latitudinal dependencies of phytoplankton carbon-to-chlorophyll *a* ratios: results of a modelling study Mar Ecol Prog Ser Vol. 152: 51-66.

Taylor, I.R. and Paterson, D. M., 1998. Microspatial variation in carbohydrate concentrations with depth in the upper millimetres of intertidal cohesive sediments. Estuarine, Coastal and Shelf Sciences vol46, pp. 359-370.

Thong, K L. Sasekumar, A. and Marshall, N., 1993. Nitrogen concentration in a mangrove creek with a large tidal range, Peninsular Malaysia. Hydrobiologia, 254: 124—132

Tomas, C.R., (Ed.) 1997. Identifying Marine Phytoplankton. Academic Press, California, pp.858.

Totti, C., 2003. Influence of the Plume of the River Po on the Distribution of Subtidal Microphytobenthos in the Northern Adriatic Sea Botanica Marina Vol. 46: 161–178

Underwood, G.J.C. and Paterson, D.M., 1993. Seasonal changes in diatom biomass, sediment stability and biogenic stabilization in the Severn estuary. J. Mar. Biol. Ass. UK 73, 871-887.

Underwood, G.J.C., Parterson, D.M. and Parkes, R.J., 1995. The measurement of microbial carbohydrate exopolymers from intertidal sediments. Limnol. Oceanogr. 40, 1243–1253.

Underwood, J. C. G., Phillips, J. and Saunders, K., 1998. Distribution of estuarine benthic diatom species along salinity and nutrient gradients. *Eur. J. Phycol.*, 33: 173-183.

Underwood, G. J. C. and Kromkamp J., 1999. Primary production by phytoplankton and microphytobenthos in estuaries. *Advances in Ecological Research*, 29: 93-153.

Underwood, G.J.C., 2010. Microphytobenthos and phytoplankton in the Severn estuary, UK: Present situation and possible consequences of a tidal energy barrage. *Marine Pollution Bulletin* 61 ; 83-91

Van Dam, H., Mertens, A. and Sinkeldam, J., 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Netherlands Journal of Aquatic Ecology* 28:133-177

Varela, M. and Penas, E., 1985. Primary production of benthic microalgae in an intertidal sand flat of the Ria de Arosa, NW Spain. *Marine Ecology Progress Series* 25, 111-119.

Venkataraman, G. 1939. A systematic account of some south Indian diatoms. *Proc. Indian Acad. Sci.*, 10:293-368.

Vijay, R., Sardar, V. K., Dhage, S. S., Kelkar, P. S. and Gupta, A., 2010. Hydrodynamic assessment of sewage impact on water quality of Malad Creek, Mumbai, India *Environ Monit Assess* 165:559-571

Vijayalakshmi, G. S. and Venugopalan, V. K. 1975. Studies on diversity of phytoplankton species, pigments and succession with a note on primary production at a tidal zone in the Vellar estuary. *Recent Res. Estu. Biol.*, 237-246.

Vitousek, P. M., Mooney, H. A., Lubchenco, J. and Melillo, J. M., 1997. Human domination on earth's ecosystem. *Science Magazine* vol. 277. no.5325, pp. 494-499.

Wallkey, A. and Black, I. A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37:28-30

Watt, D. A., 1998. Estuaries of contrasting trophic status in Kwa Zulu-Natal, South Africa. *Estuarine, Coastal and Shelf Science* 47:209-216

Welker, C., Sdrigotti, E., Covelli, S. and Faganeli, J., 2002. Microphytobenthos in the Gulf of Trieste (Northern Adriatic Sea): Relationship with Labile Sedimentary Organic Matter and Nutrients, *Estuarine, Coastal and Shelf Science*, 55, No. 2: 259-273,

Williams, C. J., Boyer, J. N. and Jochem, F. J., 2009. Microbial activity and carbon, nitrogen, and phosphorus content in a subtropical seagrass estuary

(Florida Bay): evidence for limited bacterial use of seagrass production Mar Biol 156:341–353

Wilson, C. J. and Holmes, R. W., 1981 The ecological importance of distinguishing between living and dead diatoms in estuarine sediments British Phycological Journal Volume 16, Issue 4,

Wolff, W.J., 1979: Flora and vegetation of the Wadden Sea Report 3: pp206.

Woodroffe, C. 1992. Mangrove sediments and geomorphology. In A. I. Robertson and D.M. Alongi (eds.). Tropical mangrove ecosystem, American Geophysical Union, Washington D.C. pp. 7-41.

Yallop, M. L., De Winder, B., Paterson, M.D. and Stal, L.J., 1994. Comparative Structure, Primary Production and Biogenic Stabilization of Cohesive and Non-Cohesive Marine sediments inhabited by Microphytobenthos, Estuarine, Coastal and Shelf Science, 39: 565-582.

Zingde, M D. and Desai, B N., 1980. Waste water discharge and its effect on the quality of water of Mahim Creek and Bay. Mahasagar 13 (3): 205-213.

SYNOPSIS

Distribution of intertidal phytobenthos of polluted and comparatively unpolluted regions along Mumbai.

Microphytobenthos is a descriptive term for the diverse assemblage of benthic algae belonging to mainly class bacillariophyceae, cyanophyceae and dinoflagellates that inhabit the surface layers of sediments in marine ecosystem. Microphytobenthos occur wherever light penetrates to the sediment's surface of intertidal mud and sandflats and subtidal regions. They also play a major role in nutrients input to the sediments. The abundance of benthic diatoms provide stability in sediments and thus prevents the sediment movement. The stabilizing effect of biofilms is probably more conspicuous in non-cohesive sands than in cohesive muds (Grant J., 1988)

Granulometry, submersion frequency and current microphytobenthic velocity are the responsible factors for regulating the growth rate of microalgae. The sediments are substrate for the proliferation of benthic microalgal communities. Their distribution and abundance are controlled by many factors such as salinity, temperature, organic load, grazing pressure and sediment texture (Colijn & Dijkema, 1981; Amspoker & McIntire, 1986). Microphytobenthos consisting of unicellular algae inhabiting upper few millimeters of the sediments play a vital role in primary production, intermingling with benthos and pelagic food chain and it constitutes the primary food for a wide variety of meiofaunal organisms. Gall & Blanchard, 1995, has reported highest production of benthic microalgae at the intertidal area of Marennes-Oleron Bay, during March and June along with high phaeopigments.

The lacking of detail information on marine microphytobenthos is the problem to answer many question related to this aspect. A detailed study on seasonal, spatial and vertical distribution of microphytobenthos would be useful in the assessment of benthic renewable bioresources. This study was aimed to

understand the vertical distribution of microphytobenthos by determining biomass in terms of chlorophyll *a*, phaeophytin and population in terms of cell count at different depths of sediments. Enrichment of the coastal water of Mumbai, through anthropogenic sources resulting an enhanced phytopopulation, intend an idea of determining their movements in different depth of sediments and evaluate the health of cells by means of chlorophyll *a* and phaeophytin ratios. Though there are the few informations on microphytobenthos such as Ansari et al., Ansari & Parulekar, (1993); Colijn & Dijkema, (1981); Amspoker & Mcintire, (1986) Alongi, (1987); Delgado, (1989) Sivadasan & Joseph, (1995 & 1998) Gall & Blanchard, (1995); and Peletier, (1996) Ingole & Parulekar, (1998) Brotas & Plante-Cunha (1998), the detail study is lacking.

Due to absence of information on microphytobenthos in the intertidal regions of Mumbai coast, it is difficult to know the source of food for burrowing organisms. Pollution may play a role on the microphytobenthos and consequently on the pelagic organisms of sediments. The intertidal region of Mumbai coast being highly contaminated by the industrial pollutants in general and domestic pollutants in particular, it is of interest to understand the dynamics of microphytobenthos including the pigments and their ratios, population density, species diversity and their correlation with the physicochemical parameters. The present study is the first record in detail on the vertical distribution of microphytobenthos at locations under anthropogenic pressure. Thus this investigation will be useful to justify the hypothesis of phaeophytin known as dead pigment and assessment of hardy species of microphytobenthos. The present study will also enable to understand the carbon sinking process related to maintain the balance of atmospheric –sediment carbon interference.

The result of study revealed a definite trend of vertical distribution of pigments with significantly enhanced values of microphytobenthic chlorophyll *a* (52.9 - 648.4 mg/m² ; av 195.6 mg/m²) in superficial layer and showed decreasing order with the increasing depth of the sediment at Versova. Phaeophytin (16.3 - 199.2 mg/m²; av 74.8 mg/m²) was seen to follow a opposite pattern to chlorophyll *a* with minimum concentration at superficial layer and increasing order with

deeper layer of the sediment. Microphytobenthic population ($10.4 - 35.3 \times 10^6/l$; av $18.5 \times 10^6/l$) followed a similar trend of distribution as chlorophyll *a*, with enhanced counts at superficial layer and decreasing trend with the increasing depth of the sediment. The observation at Gorai revealed a similar pattern of variation of microphytobenthic structure.

The thesis is presented in 8 chapters:**Chapter 1** is the Introduction to the Thesis and includes the need and philosophy of selecting the topic of investigation. **Chapter 2** includes Literature information pertaining to the topic and aim of the Thesis required to interpret the results emerging from the study in proper perspective. Methods of collection, analyses for physicochemical parameters, sediment texture, phytoplankton and microphytobenthos are described in **Chapter 3**. The study locations viz i) Versova and ii) Gorai are briefly described in **Chapter 4**. The results of present study with respect to physicochemical parameters, sediment texture, phytoplankton and microphytobenthos and interpretation are presented in **Chapter 5**. The **Chapter 6** contains the main findings of the present study. The results and findings are summarized in **Chapter 7**. The references cited in the Thesis are listed in **Chapter 8**.